CONTROL DE LA CONTAMINACION ATMOSFERICA

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HORARIO PRIMERA SEMANA

HORA	LUNES	MARTES	MIERCOLES	JUEVES	VIERNES	SABADO
9:00 a 10:00	Inscripciones e inauguración	Emisiones visibles. Evaluación	Unidades de medida y conversión de unidades	Programas de control	Meteorología y sus relaciones con la contaminación atmosférica	Torres de adsorción
10:00 a 11:00	Aspectos sanitarios económicos y sociales	Monitoreo manual para gases y partículas	Criterios de calidad del aire y estándares			
11:00 a 12:00	Contaminantes origen y características		Elementos de evaluación estadística	Legislación		
12:00 a 13:00	Partículas, gases y olores	Métodos y equipos portátiles de monitoreo				
15:00 a 16:00	Partículas, gases y olores	Métodos, equipos instrumental para muestreo automático	Elementos de evaluación estadística	Preparación de personal	Difusión Atmosférica	
16:00 a 17:00	Aspectos de los contaminantes: en la salud humana, vegetal y animal. Efectos en los materiales	Equipo de telemetría	Redes y estaciones de muestreo	El problema de la ciudad de México		
17:00 a 18:00		Discusión o consultas	Discusión o consultas			

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HORARIO SEGUNDA SEMANA

HORA	LUNES	MARTES	MIERCOLES	JUEVES	VIERNES
9:00 a 10:00	Funcionamiento y actividades de un organismo local para el control de la contaminación atmosférica (Ciudad de Chicago)	Dinámica de gases y partículas	Principios de la combustión e incineradores. Hornos, calderas e incineradores	Técnicas específicas de control para los procesos industriales y de incineración	nl combustión interna
10:00 a 11:00				Ciclones, tanques de lavado, precipitadores electrostáticos	
11:00 a 12:00					Emisiones de la combustión interna
12:00 a 13:00					
15:00 a 16:00	Funcionamiento de actividades de un organismo local para el control de la contaminación atmosférica (Ciudad de Chicago)	Muestreo en chimeneas	Principios de la combustión e incineradores. Hornos, calderas e incineradores	Ciclones, tanques de lavado, precipitadores electrostáticos	Control de la combustión interna
16:00 a 17:00				Selección de equipos y discusión	Mesa redonda
17:00 a 18:00	Red panamericana de muestreo normalizado	Discusión	Discusión		

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CONTAMINACION DEL AIRE

Ing. Ricardo Haddad *

Las Ciudades y el Hombre

Las investigaciones más recientes parecen coincidir en que el hombre apareció sobre la tierra hace aproximadamente 1 millón de años. Pronto aprendió a fabricar armas y herramientas y estuvo así en situación de destruir el equilibrio ecológico, normal entre las diversas especies vivas, multiplicándose más allá de lo que los recursos naturales y sus enemigos potenciales de toda clase se lo hubiesen permitido. Al aumentar en número, y posiblemente como un mecanismo instintivo de defensa, se hizo gregario y social, agrupándose las familias en clanes, tribus y pueblos, y convirtiéndose de nómadas cazadores y pescadores en agricultores y ganaderos sedentarios. Esto liberó, a su vez, a parte de la población de la búsqueda permanente de los alimentos y permitió la formación de las clases dirigentes e intelectuales, iniciándose una organización social primaria, pero estable. Surgieron así las primeras ciudades y se iniciaron los procesos de crecimiento demográfico y de urbanización, lentos al comienzo, pero adquiriendo un ritmo cada vez más acelerado, hasta culminar en la época presente en una verdadera explosión urbana y demográfica.

Es probable que las primeras ciudades hayan surgido en la Mesopotamia, hace aproximadamente unos 5500 años, y entre las más antiguas se pueden mencionar las de Eridu, Ur y Babilonia seguidas, o precedidas, por las de Memfis y Tebas en Egipto. Las de China y la India parecen ser algo posteriores. Todas eran pequeñas de acuerdo a las normas actuales y es dudoso que hayan sobrepasado de los 5 ó 10 mil habitantes, aunque se estima que ya en el año 2000 A.C. la población de Ur alcanzaba a 34 000 personas.

En América las primeras ciudades pertenecieron a la cultura Maya, con las más importantes ubicadas probablemente en Tikal (Guatemala) y en

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Dzibilchaltún (Yucatán), y a los diversos pueblos que formaron la nación mexicana. Teotihuacán, la actual Ciudad de México, ya a fines del Siglo X de nuestra era alcanzaba a más de 100 000 habitantes.

Este proceso ininterrumpido de urbanización fue lento mientras el hombre fue agricultor y artesano. El descubrimiento de nuevas fuentes de energía permitió, con la invención de la máquina de vapor a fines del Siglo XVIII, la instalación de las primeras fábricas. Estas significaron de inmediato un importante mercado de trabajo y requirieron a su vez de grandes mercados de consumo y mano de obra, comenzando a formarse las primeras metrópolis.

Antes de 1850, poco más de un siglo atrás, la población rural predominaba en todos los países del mundo y ninguno podía ser considerado altamente urbanizado. En 1900, 50 años después, existía uno sólo: Inglaterra. Sin embargo bastaron apenas otros 50 años para que todas las naciones industrializadas llegasen a tener una población principalmente urbana, y en 1960 en los EE.UU. 96 millones de personas (53% de la población total) estaban concentradas en 213 áreas urbanas que ocupaban sólo el 0.7% de la superficie del territorio. En ese mismo año el 33% de la población mundial vivía en conglomerados urbanos, y extrapolando las cifras disponibles se puede estimar que en 1990 más de la mitad del total de la población del mundo residirá en ciudades de 100 000 habitantes o más. Actualmente existen por lo menos 36 metrópolis con más de 2 000 000 de habitantes y 1374 ciudades con más de 100 000.

Las grandes aglomeraciones urbanas exigen disponer de servicios como viviendas, energía, transporte, agua potable, sistemas de alcantarillado y de disposición de excretas y residuos industriales. Lamentablemente, el crecimiento repentino y desmesurado de las ciudades las ha sorprendido sin servicios adecuados y el costo de proporcionarlos es tan elevado que difícilmente cualquier país, y mucho menos aquellos insuficientemente desarrollados, está en situación de afrontarlo en forma conveniente. Más aún, la

población crece generalmente más rápido que la capacidad de aumento de los servicios, por lo que el déficit es cada vez mayor.

El metabolismo de las ciudades exige que diariamente ingresen a éstas numerosas substancias que deben actuar como sus elementos nutritivos: Agua, aire, energía, alimentos, materias primas, etc. Por otra parte, este mismo proceso metabólico produce una gran cantidad de desechos, de los que es indispensable disponer adecuadamente si no queremos que la ciudad muera, aniquilada por sus propios subproductos. Esto lo comprendieron muy bien las culturas primitivas que edificaron sus ciudades a orillas de cursos o masas de agua que les servían simultáneamente como abasto de agua potable, medio de transporte, fuente de energía y como etapa final en la disposición de excretas humanas y otros residuos. El crecimiento de las ciudades, sin embargo, demostró que cuando éstas excedían de ciertos límites, y muy especialmente cuando con el avance de la industrialización comenzó a aumentar el volumen de residuos, la autopurificación del agua era insuficiente para la disposición adecuada de los desechos.

La urbanización e industrialización tuvo que avanzar mucho más antes de que se hiciese notorio que otro de los abastos indispensables para la vida humana tampoco era inagotable. El hombre, que demoró casi un millón de años para reconocer siquiera la existencia del aire, y algunos siglos en investigar su composición, en los últimos 30 años ha comenzado a darse cuenta en forma cada vez más clara de que no puede seguirlo utilizando como un gran resumidero para sus desechos gaseosos o en partículas finas, sin poner en peligro su bienestar y su propia vida.

Definición

Entendemos por contaminación atmosférica la presencia en el aire de substancias puestas allí por la actividad humana, en cantidades y concentraciones capaces de interferir con el bienestar y la salud de las personas, los animales y las plantas, o con el pleno uso y disfrute de la propiedad.

Como podrá observarse, en esta definición no se consideran los contaminantes atmosféricos naturales, que en algunos lugares forman una parte importante del total y constituyen el telón de fondo sobre el cual se agregan las substancias que el hombre vacía a la atmósfera.

La atmósfera

Nuestro planeta está rodeado de una capa gaseosa, que al parecer lo hace único dentro del sistema solar, compuesta principalmente de nitrógeno y oxígeno, que va disminuyendo en densidad a medida que aumenta la distancia a la superficie terrestre, hasta que a una altura sobre los 400 kilómetros comienza a confundirse con el vacío del espacio exterior. Se suele distinguir en ella 3 capas, la troposfera, entre la base y una altura de 12 kilómetros, la estratosfera, entre 12 y 90 kilómetros, y la ionosfera, por encima de los 90 kilómetros. La composición porcentual en volumen de la atmósfera seca es la siguiente:

Nitrógeno	78.09 %
Oxígeno	20.94 %
Argón	0.93 %
Anhídrido carbónico	0.03 %

Se encuentran además indicios de neón y otros gases nobles, de metano, hidrógeno y óxidos de nitrógeno.

Aparte de los componentes que se encuentran en una proporción fija existen otros, también de origen natural, para los cuales no es posible señalar un porcentaje dada la gran variabilidad en que se les halla. El más importante es el vapor de agua, que suele oscilar entre el 1 y el 3 %. Se pueden mencionar además substancias tales como el ozono, formado por acción fotoquímica y por las descargas eléctricas; materias de origen volcánico, como polvo y cenizas, anhídrido sulfuroso y ácidos clorhídrico, fluorhídrico y sulfhídrico, este último también producto de procesos bacterianos de putrefacción; polen y esporas de origen vegetal; polvo levantado del suelo y de origen meteórico; cloruro de sodio, de origen marino; etc.

La temperatura del aire puede ser muy variable, con diferencias horarias y estacionales. Una característica importante es que en condiciones normales disminuye con la altura, en la proporción de casi $1^{o}C$ por cada 100 m. Se pueden, sin embargo, producir condiciones inversas, durante las cuales la temperatura aumenta con la altura. Si esto se combina con ausencia de vientos se produce un estancamiento de las masas de aire y un aumento de las concentraciones de contaminantes, con las consiguientes consecuencias.

La densidad atmosférica, al nivel de la tierra, es de 1.293 gr/dm^3. En la literatura se encuentran cifras variables para su masa total, que van desde 4.5×10^{15} a 6×10^{15} toneladas. Esto significa que, en la actualidad, cada ser humano dispone de 1.2 a 1.6 millones de toneladas de aire.

Parece difícil que esta enorme cantidad pueda llegar a contaminarse. En forma similar, la inmensidad de los océanos, con una masa total 230 veces mayor que la de la atmósfera, parece imposible de contaminar. Sin embargo sabemos que esto ha ocurrido y sigue ocurriendo, y que son numerosos los casos de aguas costeras, que son las que realmente nos interesan, que llegan a estarlo en grado suficiente para poner en peligro la salud y el confort de las personas y la flora y fauna marinas.

En la misma forma, desde nuestro punto de vista, la masa de aire que importa es la que está sobre la superficie de las ciudades, es decir, bastante menos del 1% de la superficie terrestre, y hasta una altura de no más de un kilómetro. Es aquí donde vivimos, donde mantenemos nuestras industrias y nuestros vehículos motorizados, de donde sacamos el aire que respiramos y utilizamos en los procesos industriales, y donde vaciamos nuestros desechos gaseosos o en forma de partículas finas. Y aquí también tenemos cifras muy elevadas. Se estima, por ejemplo, que la industria consume anualmente 2×10^{11} toneladas de aire. Si bien esta cantidad sólo alcanza a un 0.004% de la masa total de la atmósfera, este porcentaje se aproxima al 1% si consideramos sólo el aire que cubre a las ciudades. Y es aquí mismo donde los aproximadamente 100 millones de automóviles que hay en el mundo, que consumen

alrededor de 2×10^9 toneladas de aire por año, vacían diariamente 500 000 toneladas de monóxido de carbono, 50 000 toneladas de hidrocarburos y 20 000 toneladas de óxidos de nitrógeno, mientras que el sólo consumo de carbón representa 500 000 toneladas de anhídrido sulfuroso, a las que deben agregarse las que provienen del petróleo, minerales sulfurados e industrias químicas. Si recordamos que el aire debemos respirarlo permanentemente, que no podemos prescindir de él por más de 4 minutos sin que comience a producirse la muerte de nuestras células más sensibles; que es el alimento que consumimos en mayor cantidad, con unos 15 a 20 kilogramos por día; y que debemos aceptarlo tal como está, sin poder purificarlo ni seleccionarlo, podemos formarnos una idea de lo que puede representar para nuestra salud y economía esta masa enorme de contaminantes.

Antecedentes Históricos

Una de las causas fundamentales de la contaminación del aire la constituyen las combustiones. Podemos suponer, por ello, que las primeras molestias se presentaron tan pronto como el hombre aprendió a utilizar el fuego. Sin embargo, mientras no se formaron agrupaciones humanas de cierta consideración, esto no representó un problema importante. Así, aunque ya los códigos romanos contienen algunas disposiciones destinadas a regular la incineración de cadáveres y la cantidad de basuras que los ciudadanos podían quemar dentro de sus predios, las primeras referencias históricas a un problema serio sólo se encuentran a fines del Siglo XIII, en Inglaterra, época de la cual datan también las primeras disposiciones legislativas al respecto, de carácter estrictamente prohibitivo y que no ofrecían soluciones adecuadas.

El uso del primer combustible fósil, el carbón de piedra, precisamente en Inglaterra, debido a la importante disminución que habían sufrido los bosques ante el avance cada vez mayor de los grupos humanos, significó un agravamiento considerable del problema. Fue en este país también donde apareció la primera literatura seria sobre la materia, en la forma de un opúsculo de unas pocas páginas, el ya clásico "FUMIFUGIUM", publicado por

John Evelyn en mayo de 1661, con todo el sabor del lenguaje de la época y lleno de citas latinas y griegas. Vale la pena tal vez destacar que el análisis hecho por Evelyn de las causas de la contaminación del aire en Londres es bastante bueno, y que propuso como solución el traslado de las industrias a lugares alejados de la ciudad, seleccionados considerando las características topográficas, lo que aún podría ser valedero actualmente, más de 300 años después.

La contaminación del aire, pese a esto, es fundamentalmente un problema del Siglo XX. En su forma actual su origen se remonta a 1930 cuando el Valle del Mosa, en Bélgica, se vio cubierto durante casi una semana por una niebla espesa a la que se atribuyó la muerte de 63 personas y de 3000 cabezas de ganado. Un fenómeno similar ocurrió en Donora, pequeña ciudad del Estado de Pennsylvania, EE.UU., donde en 1948, una niebla cargada de anhídridos sulfuroso y sulfúrico, que duró cinco días, obligó a huir a sus 14 000 habitantes que, presa del pánico, dejaron abandonada la ciudad después de que enfermaron 6000 personas (43% del total) y murieron 20. Con caracteres menos espectaculares se repitió en Londres en 1952, donde variaciones inesperadas en las curvas de mortalidad hacen que algunos autores atribuyan hasta 12 000 muertes no previstas a un período también de 5 días de una niebla espesa y cargada de hollín, recordada como la "Niebla Negra" por los londinenses. Estudios posteriores permiten afirmar que esto no constituyó un fenómeno aislado, sino que se ha repetido, aunque en forma aparentemente menos grave, por lo menos en 1956, 1960 y 1962, y además en Nueva York en 1963 y 1970, en Tokyo en 1970, y en otras ciudades.

Mientras tanto, y a partir de 1943, la ciudad de Los Angeles, EE.UU., comenzaba a padecer de un fenómeno cada vez más molesto y persistente. Su atmósfera pura, uno de los orgullos del Estado de California, comenzaba a dejar de serlo y la ciudad no sólo se veía durante más y más tiempo cubierta por una vaga nebulosidad de color azulado, sino que sus habitantes comenzaban a sentir molestias cada vez más pronunciadas, que se traducían en picazón a los ojos y ataques de asma e insuficiencia respiratoria. Para designar este tipo de contaminación se hizo popular la palabra "smog", acuñada

al parecer en 1905 como contracción de "smoke" y "fog", humo y niebla respectivamente. El término se ha hecho habitual y actualmente se le utiliza, aun en nuestros países y en los europeos que emplean idiomas distintos del inglés, como sinónimo de contaminación del aire. Se ha propuesto traducirlo al español como "brumo", contracción de "bruma" y "humo".

La situación en América Latina

Entre 1950 y 1960 algunos países latinoamericanos comenzaron a preocuparse de esta materia, realizaron mediciones esporádicas y trataron de controlar algunas fuentes de contaminantes. Este proceso se aceleró cuando muchas ciudades comenzaron a darse cuenta de la seriedad del problema y a analizar su futuro desarrollo mediante proyecciones del crecimiento demográfico, industrial, urbano y de los medios de transporte. El evidente, y en algunos casos muy rápido, deterioro de la calidad de la atmósfera, y el conocimiento de lo que estaba ocurriendo en los Estados Unidos y Europa, dio mayor urgencia a estas actividades.

Santiago y Sao Paulo fueron las ciudades donde la situación alcanzó probablemente mayor notoriedad y donde, como consecuencia, los esfuerzos fueron también mayores. Como era de esperar el interés fue creciendo en la medida en que el problema empeoraba, pasando de las autoridades sanitarias a las administrativas, la prensa y el público en general. En 1961 se fundó en Santiago el Instituto de Higiene del Trabajo y Contaminación Atmosférica, destinado a la docencia y la realización de investigaciones en estas disciplinas. En 1963 Sao Paulo expandió los programas de su Comisión Intermunicipal para el Control de la Contaminación del Agua y el Aire. Otras ciudades, como Lima y México, habían realizado estudios bastante extensos y la primera había promulgado la reglamentación destinada a controlar los olores de su importante y floreciente industria de harina de pescado. Buenos Aires, por su parte, había organizado en 1962 un Congreso Latinoamericano de Contaminación del Aire y en 1964 un Congreso Mundial sobre el mismo tema. El Instituto de Ingeniería Sanitaria del Estado de Guanabara, Brasil, contaba con una Sección Contaminación del Aire e inició un buen programa de medición y algunas actividades de control.

El problema más grave que afecta en forma general a todos los países latinoamericanos es la falta de personal y la ausencia de una estructura administrativa apropiada que permita realmente atacarlo y controlarlo. El personal que a la fecha trabaja a tiempo completo en todo el continente, con excepción de los Estados Unidos y el Canadá, probablemente no alcanza a 30 personas, con otras 70 a tiempo parcial, algunas de las cuales dedican sólo unos pocos minutos diarios a estas actividades. Estas cifras incluyen tanto a los profesionales como a sus colaboradores. El personal profesional con algún tipo de entrenamiento formal tampoco llega a más de 20 personas, y apenas la mitad se desempeña en organismos gubernamentales. Es probable que en toda la América Latina sea difícil seleccionar 50 personas con un conocimiento adecuado en esta materia, aun incluyendo aquellos que han aprendido esta disciplina a través de cursos cortos, lecturas personales, experiencia práctica y entrenamiento en terreno.

En ningún país de la América Latina existe todavía una organización de control realmente adecuada. Tampoco ninguno ha asignado a esta materia un presupuesto específico que pueda considerarse suficiente. Hay sólo tres ciudades con algún tipo de programa activo de control. Los programas de evaluación pueden considerarse semi-adecuados en otras tres ciudades.

Sin embargo, es posible notar algún progreso, especialmente en los años más recientes. Los países están haciendo esfuerzos cada vez mayores para el control de la contaminación. Los programas de evaluación son más amplios y continuados y, como consecuencia, existe actualmente algún conocimiento cuantitativo de la magnitud del problema. En marzo del presente año por lo menos dos países, Colombia y México, han promulgado legislación específica. Otros dos, Argentina y Venezuela, están preparando leyes sobre la materia.

Actividades de la Organización Panamericana de la Salud

La Organización Panamericana de la Salud está dando colaboración a los Países Miembros, en el campo de la contaminación del aire, desde hace ya más de diez años. En 1961 participó en la estructuración y puesta en marcha del

Instituto de Salud Ocupacional y Contaminación Atmosférica de Chile y posteriormente en la del Instituto de Ingeniería Sanitaria del Estado de Guanabara, Brasil. En 1963 asesoró en la preparación del programa de la Comisión Intermunicipal para la Contaminación del Agua y del Aire en Sao Paulo, Brasil, destinando a partir de 1965 a un asesor permanente para colaborar a su mejor desarrollo, a la extensión de los programas de contaminación del aire a todo el Estado de Sao Paulo y a la iniciación de actividades en otras tres ciudades de Brasil. A petición de diversos países, entre los que se puede mencionar Argentina, Brasil, Colombia, Costa Rica, Cuba, Chile, Honduras, Jamaica, México, Venezuela y otros, ha dado asesoría en la elaboración de programas generales o en la solución de problemas específicos.

En 1965 el Consejo Directivo de la Organización resolvió: "Encomendar al Director que conceda la debida atención a los crecientes problemas de la contaminación de la atmósfera y el agua en los programas de asistencia de la Organización...". De acuerdo a esta recomendación, en 1966 se acordó crear un cargo permanente de Asesor en Contaminación del Aire y patrocinar el establecimiento de la Red Panamericana de Muestreo Normalizado de la Contaminación del Aire, que comenzó a operar a mediados de 1967. La supervisión de este programa depende actualmente del Centro Panamericano de Ingeniería Sanitaria y Ciencias del Ambiente, con sede en Lima.

Se ha contribuido igualmente a la formación de personal especializado mediante cursos cortos intensivos, otorgando becas para estudios de postgrado y bolsas para viajes de observación a diversos países. En 1968 se desarrolló, en Río de Janeiro, un Seminario Latinoamericano de Contaminación del Aire. La publicación de los trabajos presentados ha contribuido de manera valiosa a difundir un mejor conocimiento sobre esta materia.

Causas de la Contaminación Atmosférica

Como ya se dijo, algunos de los contaminantes más importantes corresponden a los subproductos de todo tipo de combustiones, como las que se realizan en la industria, en los generadores de vapor o energía eléctrica, o como parte integrante de los diversos procesos industriales; en los sistemas domésticos

de agua caliente, calefacción e incineración; en los servicios públicos, como plantas termoeléctricas y sistemas de disposición de residuos y basuras; en el transporte motorizado, sea en motores a explosión o del tipo diesel, y en ferrocarriles y barcos. En algunas ciudades adquiere bastante importancia la disposición doméstica, mediante combustiones al aire libre, de basuras y hojas secas, la que suele agravarse en el otoño y comienzos del invierno.

Aparte de las combustiones constituyen fuentes importantes de contaminación los residuos industriales, especialmente los de la industria química, metalúrgica y petrolera, y los vapores orgánicos que salen al aire durante el almacenamiento y las operaciones de trasvasijado de solventes, gasolina y otros combustibles similares.

No basta, sin embargo, que se vacíen al aire algunos contaminantes para que exista un problema. Estos deben sobrepasar una concentración y tiempo de permanencia mínimos para llegar a representar un riesgo para la salud o la economía. La atmósfera, como los cursos y masas de agua, tiene un poder autopurificador importante cuya acción permite que, hasta ahora, pueda seguir funcionando nuestra presente civilización tecnológica. Sin embargo esta capacidad autopurificadora tiene un límite, que depende de las condiciones meteorológicas imperantes, las que a su vez están determinadas por las condiciones geográficas. Dependiendo de su meteorología característica una ciudad tendrá buena o mala ventilación, y los desechos que vaciemos en ella permanecerán en el aire durante un tiempo más o menos prolongado, lo que fijará a su vez la cantidad de substancias que podremos agregar por unidad de tiempo sin que ellas se transformen en un peligro potencial.

Las condiciones meteorológicas, por su parte, se ven influenciadas por la topografía, la existencia de ríos, masas de aguas, montañas, etc. Debido a esto es posible afirmar que, en referencia a la contaminación atmosférica, cada ciudad posee características naturales propias, que combinadas con su población, clima, concentración industrial, tipo y tamaño de las industrias,

combustibles utilizados, etc., dan a cada problema una fisonomía propia que debe ser estudiada en forma individual. Las soluciones válidas en determinada ciudad no pueden trasladarse directamente a otras, confiando en obtener los mismos resultados.

Principales Contaminantes

Estos pueden ser sólidos, líquidos o gaseosos. Los dos primeros, como es lógico, deben ser de un tamaño suficientemente pequeño como para no sedimentar, sino formar aerosoles, lo que se obtiene sólo cuando las partículas tienen diámetros del orden de 30 micras o menos.

Entre los contaminantes sólidos tenemos el humo, hollín y cenizas, provenientes de las combustiones; y el polvo natural o producido por barrido, demoliciones, etc. Los procesos industriales envían al aire fluoruros, óxidos de hierro y aluminio, cemento, sulfuros, sulfatos, carbonatos, bicarbonatos y otros, que constituyen a menudo sólo daños y molestias localizadas.

El contaminante líquido más importante está constituido por las nieblas de ácido sulfúrico, formadas principalmente por oxidación del anhídrido sulfuroso, a las que se atribuyen una proporción considerable de los daños a la salud ocasionados por la contaminación del aire.

En cuanto a los gases, los más importantes son el anhídrido sulfuroso; el monóxido de carbono, residuo de las combustiones incompletas y componente importante de los gases de los tubos de escape de los automóviles; los óxidos de nitrógeno formados cuando el aire se expone a altas temperaturas; los hidrocarburos, etc. A estas substancias debemos agregar los diversos subproductos de la industria química que, aunque menores en cantidad, pueden complicar seriamente los problemas por su interacción con los contaminantes más habituales.

Los gases enumerados en el párrafo anterior corresponden a las substancias vaciadas directamente en la atmósfera y que permanecen en ella en su forma original. Muchos, sin embargo, pueden reaccionar entre sí, catalizados

por la energía radiante del sol, especialmente la radiación ultravioleta, para formar nuevos productos, que a veces pueden ser aún más perjudiciales Así, la interacción entre los óxidos de nitrógeno, el anhídrido sulfuroso, los hidrocarburos de petróleo, etc., permite la formación de cantidades apreciables de ozono, un oxidante muy activo; anhídrido sulfúrico, que por combinación con la humedad del aire forma las nieblas de ácido sulfúrico; y substancias orgánicas oxidadas, como los peroxiacetilnitratos, a los que se atribuyen muchas de las propiedades oxidantes y molestias del smog de Los Angeles..

Evolución de los Contaminantes en la Atmósfera

Como se ha dicho anteriormente, la atmósfera tiene una importante capacidad autopurificadora sin la cual la vida en una ciudad industrial sería imposible. La eliminación de los contaminantes se produce generalmente, en una primera fase, por arrastre y dispersión. Pueden además reaccionar químicamente para transformarse en substancias inocuas.

Así, por ejemplo, las partículas más gruesas tienden a desaparecer por sedimentación. En presencia de vientos son arrastradas fuera de las ciudades y dispersadas convenientemente. Las partículas más finas, que constituyen el polvo en suspensión, pueden ser también dispersadas por el viento o constituirse en núcleos de condensación, en torno a los cuales se forman las gotas de agua que se transformarán posteriormente en lluvia, consiguiendo así también su eliminación. Las partículas líquidas presentan generalmente cierta capacidad de aglomeración, transformándose poco a poco en partículas más grandes, y por lo tanto más pesadas, que caen por sí mismas.

En cuanto a las substancias gaseosas éstas pueden ser dispersadas por el viento y las turbulencias atmosféricas, entre las cuales juegan un papel importante las corrientes producidas por convección térmica, y pueden ser absorbidas por el vapor de agua y de lluvia, cayendo finalmente a tierra. Se eliminan además por transformaciones químicas. El anhídrido sulfuroso, por ejemplo, se oxidará a anhídrido sulfúrico, que debido a su gran

higroscopicidad absorberá agua para transformarse en niebla y ser luego arrastrado por las lluvias. Al caer a tierra reaccionará para transformarse en sulfatos inocuos. Esta última reacción puede ocurrir también en el aire mismo, cuando existen substancias alcalinas como el amoníaco. Una suerte similar sufrirán productos como los ácidos clorhídrico, fluorhídrico, etc., mientras que el ácido sulfhídrico se oxida a sulfúrico.

En cuanto al monóxido de carbono se supone, sin que todavía se tenga un conocimiento completo de la forma en que reacciona, que se va oxidando a anhídrido carbónico, dejando de constituir un contaminante propiamente tal. El ozono y otros oxidantes, por su misma capacidad de reaccionar, tienden a combinarse con substancias orgánicas y de otra índole, con lo cual desaparecen, aunque a veces a costa de transformarse en productos aún más irritantes.

Consecuencias para la Economía

No resulta sencillo hacer una estimación de los daños económicos que ocasiona la contaminación del aire y que provienen de la corrosión y destrucción de materiales; mayores necesidades de lavado de ropas, edificios, etc.; destrucción o disminución de las cosechas, perjuicios a la ganadería; destrucción de edificios antiguos, especialmente los de piedra caliza; disminución de la visibilidad con serios perjuicios para el tránsito aéreo y automotriz; etc. En los EE.UU. e Inglaterra se han hecho algunas estimaciones, que hacen llegar estos daños a una suma de 11 000 000 000 de dólares por año en el primer país y a cerca de 800 000 000 en el segundo, cifras que van en constante aumento y que por sí solas inducen a reforzar las medidas de control que se están adoptando en un esfuerzo cada vez mayor para disminuir la gravedad del problema.

A estas cantidades debemos agregar las que se utilizan en actividades de control y que llegan en todo el mundo a apenas algunas decenas de millones de dólares. La magnitud que ha alcanzado el problema, sin embargo, ha incrementado la preocupación de los gobiernos de los países más

industrializados. Durante la década recién pasada, por ejemplo, las autoridades federales de los EE.UU. han comenzado a prestarle cada vez mayor atención y a destinar sumas mayores a las actividades preventivas y de investigación.

Consecuencias para la Salud

Los esfuerzos de los investigadores no han permitido, hasta la fecha, demostrar en forma clara la existencia de una correlación entre la salud de los habitantes de una ciudad y la cantidad de contaminantes presentes en su atmósfera. Vale la pena recordar tal vez la gran complejidad de los diversos factores que afectan a la salud de una comunidad y como en un problema algo similar, pero con muchas menos variables, el de las relaciones entre el tabaco y la salud, sólo después de grandes esfuerzos y de la inversión de sumas muy elevadas se ha podido llegar a conclusiones que parecen ser valederas. Existen, sin embargo, indicios fuertes que permiten aseverar que la contaminación del aire puede constituir un factor importante de riesgos a la salud. Mencionaremos brevemente algunos:

1) En los casos de Londres y Donora, a los que ya se ha hecho referencia, si bien no es posible asegurar que las muertes y enfermedades han sido ocasionadas por determinado contaminante tampoco se ha podido descartar esta posibilidad ni encontrar otra explicación adecuada.

2) En una investigación hecha por el autor en la ciudad de Sao Paulo, Brasil, se encontró que entre 1952, fecha en que comenzó la industrialización de la ciudad, y 1960, la tasa de mortalidad por bronquitis había aumentado en casi 3 veces, llegando a ser 7 veces mayor que en Río de Janeiro, ciudad de características similares pero no industrializada y con índices de contaminación inferiores.

3) Investigaciones realizadas en Londres comparando los índices de mortalidad general con los de la contaminación del aire muestran una similitud extraordinaria entre sus variaciones lo que hace muy probable la existencia de una relación de causa a efecto entre ambos.

4) Las muertes por bronquitis crónica están en aumento constante en las ciudades y países con mayores índices de contaminación atmosférica, llegando actualmente a casi el 10% del total de todas las muertes en Inglaterra.

5) Las muertes por enfisema pulmonar entre los varones, en los EE.UU., han aumentado de 1.5 por 100 000 en 1950 a casi 8 por 100 000 en 1959. Estas muertes ocurren principalmente en las grandes ciudades. Por otra parte las tasas de prevalencia de esta enfermedad están en constante aumento y en 1960 el 6.9% de las personas que recibían compensaciones tuvieron un diagnóstico de enfisema pulmonar. Investigaciones realizadas demuestran que las personas que padecen de esta enfermedad se agravan considerablemente con el aumento de los índices de contaminación.

Se podría citar ejemplos similares, que considerados individualmente significan poco pero que en su conjunto justifican plenamente la preocupación de las autoridades sanitarias locales e internacionales.

Evaluación de la Contaminación Atmosférica

Dada la complejidad de la mezcla de contaminantes que se pueden encontrar en la atmósfera de una ciudad el problema de su evaluación puede ser difícil. Esto se agrava por las variaciones en el espacio y el tiempo que sufren sus concentraciones, tanto en razón de la desuniformidad de su emisión como por las condiciones climatológicas y meteorológicas propias de cada ciudad. Debemos recordar, sin embargo, que todos tienen su origen en procesos similares, y que son afectados en forma parecida por las variables meteorológicas, por lo que la medición de algunos de ellos puede estimarse como un indicio de la proporción que puede esperarse de los demás.

De acuerdo a la complejidad e intensidad de un problema los métodos de evaluación pueden ser sencillos o incluir gran cantidad de estaciones de

muestreo e instrumental, con aparatos registradores automáticos y computación electrónica para su tabulación adecuada. Es posible, sin embargo, llegar a obtener datos suficientes para un programa de control mediante la medición de algunos índices cuyos valores pueden obtenerse por métodos simples que no requieren gran cantidad de equipo ni personal.

Los contaminantes y características que se evalúan más frecuentemente incluyen:

Polvo sedimentable	Corrosividad
Sólidos en suspensión	Visibilidad
Anhídrido sulfuroso	Velocidad y dirección del viento
Hidrocarburos	
Oxidos de nitrógeno	Humedad y temperatura del aire
Ozono	
Oxidantes totales	Actividad solar

Si se dispone de laboratorios adecuados se puede analizar los diversos componentes de los sólidos en suspensión, especialmente su contenido en materia orgánica, plomo y otros metales, material combustible, radioactividad, substancias cancerígenas, etc. En igual forma, cuando las características de las emisiones lo justifican, pueden determinarse otros contaminantes como fluoruros; óxidos de hierro, aluminio y zinc; polvo de cemento, etc.

Red Panamericana de Muestreo Normalizado de la Contaminación del Aire

Una de las actividades importantes iniciada por la Organización Panamericana de la Salud en el campo de la Contaminación del Aire fue la puesta en marcha de una red de estaciones de muestreo que, trabajando con métodos normalizados que permitiesen las comparaciones, fuese incluyendo las principales ciudades de la Región. Este proyecto tenía dos objetivos fundamentales:

(1) Subsanar la escasez de información cuantitativa recogiendo datos básicos que permitiesen estudiar comparativamente la situación en las ciudades incluidas y contribuyesen a determinar las tendencias del problema.

(2) Despertar un mayor interés en las ciudades participantes con el objeto de contribuir a la formación en cada una de ellas de una estructura administrativa bien organizada, dotada de los profesionales capacitados necesarios para tomar a su cargo las actividades de evaluación, prevención y control.

Después de analizar los métodos utilizados en diversos lugares, se decidió adaptar los empleados por Inglaterra y otros países europeos, estudiados y patrocinados por el Comité Técnico de la Comisión Económica para Europa. Presentan la ventaja de su bajo costo y gran sencillez en su montaje y manejo, lo que los hace especialmente apropiados para las etapas iniciales de nuevos programas. Los tres contaminantes que se decidió medir constituyen buenos indicadores de las condiciones existentes y permiten, si se dispone de un número suficiente de mediciones, llegar a determinar las tendencias del problema.

El programa incluyó originalmente la determinación de:

(a) Polvo sedimentable. Promedio mensual.
(b) Polvo en suspensión. Promedio diario.
(c) Anhídrido sulfuroso. Promedio diario.

Posteriormente se agregó en algunas estaciones un método, todavía en su etapa experimental, para la determinación de la corrosividad atmosférica en promedios mensuales.

Los métodos utilizados son, en lo fundamental, los siguientes:

Polvo sedimentable. Se deja abierto al aire durante un mes un frasco de plástico. Al término del período se lleva al laboratorio y se separa el polvo recolectado, secándolo y pesándolo. Los resultados se expresan en miligramos por cm^2 por 30 días.

Polvo en suspensión. Mediante un sistema que incluye una bomba y un medidor de volumen se hace pasar aire durante 24 horas a través de una hoja de papel filtro. Se mide fotoeléctricamente la pérdida de reflectividad del papel. La concentración de polvo en suspensión, expresada en microgramos por m^3, se deduce de una curva patrón.

Anhídrido sulfuroso. El conjunto utilizado para el método anterior se complementa con un frasco lavador para gases. El aire, después de pasar por el papel filtro, burbujea en una solución de peróxido de hidrógeno que retiene el anhídrido sulfuroso y lo oxida a ácido sulfúrico. Se determina volumétricamente el aumento de acidez. Se calcula la concentración atmosférica promedio en microgramos por m^3.

Corrosividad. Se expone al aire durante un mes dos discos de acero normalizados, de aproximadamente 70 milímetros de diámetro. El aumento de peso promedio, producido por oxidación y corrosión, se utiliza como una indicación de la corrosividad de la atmósfera.

Durante 1966 y los primeros meses de 1967 se adquirieron los equipos necesarios para 10 estaciones de muestreo, se preparó un Manual de Operaciones, se visitaron varios países con el objeto de hacer los contactos necesarios, y se elaboraron convenios que estableciesen las bases de cooperación entre los respectivos gobiernos y la Organización Panamericana de la Salud. Simultáneamente se estudiaron los sitios más adecuados para la instalación de las estaciones en cada ciudad y se trató de despertar el interés de los países participantes en la ampliación de los programas mediante la adquisición y puesta en funcionamiento de estaciones adicionales. Esto se veía facilitado por el bajo costo. El equipo completo para una primera estación se puede adquirir a un costo de US$1,050. Estaciones adicionales en una misma ciudad cuestan sólo US$500, ya que no es necesario adquirir el equipo de análisis. El costo anual de mantención es de menos de US$100 por estación. No se necesita más que el apoyo de un laboratorio mínimo para la realización de los análisis, 2 días-técnico por mes y 30 minutos adicionales por día para el cambio de los filtros y soluciones.

La primera estación comenzó a funcionar en el mes de junio de 1967. En noviembre ya se tenía en funcionamiento 8 de las 10 originalmente planeadas. Posteriormente diversos países instalaron, con fondos propios, estaciones adicionales en las ciudades participantes, destacándose entre ellos México, que a la fecha cuenta con un total de 11. Al 31 de octubre de 1971, la Red Panamericana cuenta ya con 37 estaciones instaladas en 19 ciudades de 13 países. Su distribución es la siguiente:

País	Ciudad	No. de estaciones
Argentina	Buenos Aires	2
	Córdoba	2
Bolivia	La Paz	1
Brasil	Belo Horizonte	1
	Porto Alegre	1
	Recife	1
	Río de Janeiro	1
	Sao Paulo	1
Colombia	Bogotá	1
	Bucaramanga	1
Costa Rica	San José	1
Cuba	La Habana	2
Chile	Santiago	1
El Salvador	San Salvador	1
Jamaica	Kingston	1
México	México	11
Perú	Lima	3
Uruguay	Montevideo	1
Venezuela	Caracas	4
		37

La Red continúa en ampliación permanente. Colombia está a punto de expandirla considerablemente, hasta llegar en el presente año a un total de 19 estaciones distribuidas en 6 ciudades. Se espera que otros países, como

Argentina, Perú y Venezuela, amplíen también pronto sus operaciones. Se estima que a fines de 1972 la Red comprenderá aproximadamente un total de 100 estaciones. Este número permitirá, probablemente, alcanzar un conocimiento razonable del problema y de sus tendencias.

Aparte de las estaciones de la Red existen otros programas de evaluación en algunas ciudades latinoamericanas. Río de Janeiro y Sao Paulo tienen un número importante de estaciones en las que se recoge muestras mensuales de polvo sedimentable y anhídrido sulfuroso, este último con un método diferente al utilizado en la Red, determinando también, en algunos casos, otros contaminantes. Buenos Aires, Caracas, La Habana y México, entre otras, mantienen igualmente programas adicionales de mediciones.

Interpretación de los Resultados

El conocimiento de los efectos que sobre la salud, el bienestar y la economía pueden tener las diversas concentraciones de contaminantes atmosféricos es todavía escaso. Debido a esto, no existe consenso entre especialistas e investigadores sobre lo que debe considerarse como una atmósfera limpia. Las legislaciones de los pocos países del mundo que han promulgado normas sobre esta materia presentan una gran diversidad, tanto entre los niveles que se consideran permisibles, como en el número de contaminantes que se estima necesario incluir en las normas y en la forma de expresar las concentraciones. Puede examinarse al respecto la obra "Air Pollution", de A.C. Stern, y el informe de un Simposio Inter-Regional de la Organización Mundial de la Salud, celebrado en Ginebra, Suiza, en octubre de 1970.

La Agencia de Protección Ambiental de los Estados Unidos (Environmental Protection Agency) promulgó en abril del presente año nuevas normas, estableciendo límites para diversos contaminantes, entre ellos los que siguen para polvo en suspensión y anhídrido sulfuroso.

Polvo en suspensión

Patrón primario, para la protección de la salud de las personas:

75 microgramos por m^3, como promedio geométrico anual, y

260 microgramos por m^3, como valor máximo para 24 horas, que no debe excederse más de una vez por año.

Patrón secundario, para la prevención de efectos sobre el suelo, agua, vegetación, materiales, animales, clima, visibilidad y confort y bienestar personal:

60 microgramos por m^3, como promedio geométrico anual, y

150 microgramos por m^3, como valor máximo para 24 horas, que no debe excederse más de una vez por año.

Anhídrido sulfuroso

Patrón primario:

80 microgramos por m^3, como promedio aritmético anual, y

365 microgramos por m^3, como valor máximo para 24 horas, que no debe excederse más de una vez por año.

Patrón secundario:

60 microgramos por m^3, como promedio aritmético anual,

260 microgramos por m^3, como valor máximo para 24 horas, que no debe excederse más de una vez por año, y

1300 microgramos por m^3, como valor máximo para 3 horas, que no debe excederse más de una vez por año.

Estas son normas bastante estrictas, aunque en algunos Estados de este mismo país se había fijado con anterioridad límites aún más bajos. Los valores establecidos en otros países suelen ser más elevados, llegando los promedios hasta cifras cinco o más veces más altas.

Poco después de iniciar las operaciones de la Red Panamericana de Muestreo se estimó conveniente sugerir algunos niveles de referencia que permitiesen interpretar más fácilmente los resultados recogidos. Después de estudiar la legislación vigente hasta 1967, los resultados obtenidos por otros programas de mediciones y lo que se conocía sobre los efectos de la contaminación del aire sobre la salud, el bienestar y la economía, se consideró adecuado recomendar los siguientes valores;

Polvo sedimentable	0.5	mg/cm^2/30 días
Polvo en suspensión	100	microgramos/m^3
Anhídrido sulfuroso	70	microgramos/m^3

Con estas cifras no se pretende establecer límites internacionales, función que va más allá de la capacidad de un organismo aislado. Su objetivo exclusivo es establecer una base de comparación que permita señalar, siquiera aproximadamente, la calidad de la atmósfera de una ciudad en función de los resultados obtenidos en las estaciones de la Red. Debe entenderse muy claro que no pretenden ser más que un nivel de referencia con el cual se comparen los promedios mensuales calculados en base a los análisis de las muestras recogidas por las estaciones de la Red. En la medida en que estas mediciones promedio estén por encima de estos valores, la atmósfera respectiva estará más contaminada. En igual forma, si son más bajas, se podrá considerar que el problema es menos serio mientras más alejadas estén de las cifras señaladas. La observación más importante será la de la tendencia que señalen estos promedios, cuando sea posible determinarla. Una tendencia al aumento periódico señalará la urgencia que tiene la adopción de medidas de prevención y control que impidan un mayor deterioro de la calidad del aire e intenten corregir la situación ya existente.

Análisis de los resultados de la Red Panamericana

Alrededor de la mitad de las estaciones tienen resultados correspondientes a 3 años de mediciones, lo que permite tratar de extraer algunas conclusiones. Este período no debe considerarse, sin embargo, suficientemente

satisfactorio. La influencia de las condiciones meteorológicas sobre los niveles de contaminantes atmosféricos es muy alta y, en algunas ciudades, puede distorsionar los resultados. La importancia de una medición permanente y prolongada reside precisamente en que permite la observación bajo diferentes condiciones meteorológicas, reflejando en forma cada vez más clara la tendencia que siguen las concentraciones.

En el cuadro que sigue se presentan las estaciones de la Red en el orden decreciente del promedio aritmético de los promedios mensuales de las concentraciones de cada uno de los tres contaminantes medidos. En la primera columna, con los resultados para Polvo Sedimentable, aparece una estación menos debido a que la Santiago 2 no tiene mediciones suficientes para este contaminante.

ESTACIONES DE LA RED PANAMERICANA DE MUESTREO DE LA CONTAMINACION DEL AIRE EN EL ORDEN DECRECIENTE DEL PROMEDIO ARITMETICO DE LOS PROMEDIOS MENSUALES DE LAS CONCENTRACIONES DE CONTAMINANTES

1967 – 1970

Polvo sedimentable

	Estaciones	Promedio general ($mg/cm^2/30$ días)	
1	Mexico 3	3 26	
2	Mexico 2	3 09	
3	México 10	2 11	
4.	Córdoba	1 81	
5	Buenos Aires 1	1 56	
6	Mexico 5	1 67	
7	Montevideo	1.62	
8	Caracas 1	1 55	
9	Mexico 7	1.54	
10	Mexico 1	1 48	
11.	Mexico 4	1.39	
12	Bogotá	1 31	
13	Sao Paulo	1 16	
14.	México 6	1 14	
15	B Aires 2-3-4	1 12	
16.	Mexico 9	1 12	
17.	Porto Alegre	1 09	
18	México 8	1 04	
19	La Habana	0 74	
20	Kingston	0 69	
21	Caracas 4	0 66	
22	Río de Janeiro	0 64	
23	Santiago 1	0 64	
24	Lima	0 52	N R.
25	San Salvador	0 46	
26.	Caracas 3	0.39	
27.	Caracas 2	0.38	
28.	-------		

Polvo en suspensión

Estaciones	Promedio general (microg/m^3)	
Sao Paulo	169 0	
Buenos Aires	167 4	
México 3	145 3	
B Aires 2-3-4	125 7	
La Habana	112 8	
Río de Janeiro	107 6	
México 6	105 4	N.R.
México 1	99.6	
Santiago 2	97 4	
México 7	96.6	
México 10	93 8	
Santiago 1	93 1	
Montevideo	86 7	
México 2	85 4	
México 8	80 2	
Mexico 4	77.2	
Bogotá	76.1	
Caracas 1	76.1	
San Salvador	72 3	
México 5	62.0	
México 9	50.1	
Córdoba	43.4	
Kingston	40 9	
Lima	32.9	
Porto Alegre	21.6	
Caracas 4	15.0	
Caracas 3	14.6	
Caracas 2	13.8	

Anhidrido sulfuroso

Estaciones	Promedio general (microg/m^3)	
Mexico 10	146 6	
Caracas 3	135 6	
México 3	129 2	
México 1	112 7	
México 9	92 6	
Santiago 1	81 0	
Sao Paulo	77 1	
México 6	74.1	
México 8	73 9	
Santiago 2	72.4	
La Habana	72 1	
México 7	71 9	N R
México 5	59 5	
México 2	54.8	
Rio de Janeiro	51.3	
Mexico 4	50 8	
Montevideo	40 7	
Buenos Aires 1	38 2	
Bogotá	36 4	
Porto Alegre	23 9	
B Aires 2-3-4	22.2	
Caracas 2	19 2	
Caracas 1	16 1	
Caracas 4	15.2	
Kingston	10 8	
Córdoba	8.3	
Lima	8.0	
San Salvador	7.6	

Control de la Contaminación Atmosférica

Presentaremos someramente los fundamentos básicos de los métodos de control de la contaminación del aire:

1) El control de la contaminación del aire es en primer lugar un problema económico. Su solución depende de la decisión que adopte cada comunidad, y las respectivas autoridades, en cuanto al precio que está dispuesta a pagar por disfrutar de una atmósfera limpia, exenta de polvo y de substancias tóxicas, y que no atente contra la salud y el bienestar de sus miembros.

2) El control de la contaminación atmosférica debe hacerse en las fuentes de emisiones, ya que no es posible purificar el aire una vez que éste ha sido contaminado. Esto significa actuar sobre generadores de vapor, procesos industriales, plantas termoeléctricas, incineradores de basuras municipales y domésticos, sistemas de calefacción y agua caliente de edificios de departamentos, vehículos para el transporte público y privado, quemazón de hojas secas y otros residuos, materias en putrefacción, etc. En cualquier ciudad de tamaño mediano el número de emisores de contaminantes es bastante elevado, por lo que la tarea de controlarlos puede llegar a ser de magnitud apreciable.

3) Es preferible iniciar la labor de control cuando el problema todavía no adquiere seriedad. Esto permite abordarlo con menos personal y en su totalidad, dado el menor número de emisores, y da la oportunidad a los profesionales que lo tienen a su cargo de conocer en forma práctica y en el terreno las soluciones más adecuadas.

4) Uno de los buenos sistemas consiste en reemplazar o mejorar los combustibles, eliminando el azufre y los gases más volátiles que contienen. La tecnología moderna posee los medios para realizar esta labor, y aunque ello representa una elevación en el costo, éste es

menor que los mayores gastos que el público debe afrontar a causa de la contaminación atmosférica.

5) Existen métodos tecnológicamente adecuados para el control de los diversos tipos de aerosoles, por lo que no hay razón para permitir la emisión al aire de polvos, humos, nieblas y otras partículas perjudiciales. Si bien a veces el costo de estas instalaciones puede ser elevado, esto suele ocurrir sólo en el caso de industrias de gran envergadura, con capacidad económica para afrontarlos. Una vez más, por otra parte, el costo es menor que los perjuicios que ocasionarán los contaminantes si son emitidos libremente.

6) Existen métodos razonablemente adecuados para el control de las emisiones de anhídrido sulfuroso de plantas de tostación de minerales y otras que lo lanzan en forma relativamente concentrada. Estos métodos pueden incluso ser económicamente interesantes y producir ganancias a los propietarios.

7) No existen aún métodos económicamente convenientes para controlar el anhídrido sulfuroso contenido en los gases de combustión. Sin embargo, tanto en Inglaterra como en EE.UU., y Alemania, y seguramente también en otros países, se están haciendo interesantes experiencias que permiten abrigar esperanzas de solución.

8) Los efectos que producen las chimeneas dependen principalmente de la cantidad de contaminantes que emiten y de la topografía y meteorología del lugar donde están instaladas. Su mayor elevación es generalmente de alto costo y a menudo constituye una solución sólo aparente, sin efectos reales sobre los niveles de contaminación, o contribuye sólo a trasladar los problemas de un punto a otro, sin eliminarlos.

9) El problema de la emisión de humos visibles de los motores diesel tiene una solución tecnológica fácil, aunque difícil de aplicar desde el punto de vista administrativo. Ello significa un control

permanente y constante sobre numerosos ómnibus y camiones, lo que no siempre es posible realizar, especialmente en nuestros países, dada la crónica escasez de personal capacitado y el habitual déficit de los medios de transporte públicos y privados.

10) Las soluciones adecuadas para sistemas de incineración deben aplicarse mientras éstos están en la etapa de proyecto y construcción. Es muy difícil impedir posteriormente la emisión de contaminantes de incineradores mal diseñados, salvo que se les clausure, prohibiendo su funcionamiento.

Perspectivas futuras

Los EE.UU. y algunas naciones europeas han comenzado a tomar conciencia de la gravedad del problema de la contaminación atmosférica y, presionados por las respectivas comunidades, han iniciado una acción vigorosa, al menos en algunas ciudades. Las actividades pioneras de Los Angeles, Pittsburgh, Londres, nos señalan claramente las posibilidades de disminuir esta gravedad. En América Latina, los proyectos que se está tratando de poner en práctica, y las actividades de carácter permanente de la Organización Panamericana de la Salud, permiten vislumbrar la iniciación de programas adecuados de control.

Los resultados de las mediciones realizadas parecen mostrar en forma clara que los conjuntos metropolitanos de la América Latina y el Caribe comienzan a sufrir los efectos graves que la contaminación atmosférica ha representado para las ciudades de los países más desarrollados, que no comprendieron a tiempo el significado real de este nuevo factor de agresividad ambiental. De las catorce ciudades para las cuales se dispone de mediciones continuadas, por lo menos cinco parecen tener su atmósfera ya seriamente contaminada, mientras que otras cinco sobrepasan regularmente de los niveles de referencia. Los Gobiernos y las comunidades deben analizar cuidadosamente esta situación y adoptar en forma urgente las medidas que cada caso requiere. El aire es un derecho y una necesidad básica de todo ser vivo. Parece, sin

embargo, que el aire puro y realmente adecuado para nuestras necesidades vitales se está convirtiendo en un recurso cada vez más escaso. Como todo recurso tiene un precio, y la calidad del que tengamos a nuestra disposición dependerá de lo que estemos dispuestos a pagar. Las comunidades que no se preocupen de preservar cuidadosamente la atmósfera que las rodea encontrarán inevitablemente que el precio del aire puro puede llegar a hacerse muy elevado al tener que incluir en él los costos de una gran organización estatal, de los equipos para el control de las emisiones, el mayor precio por mejores combustibles, etc., o tendrá que aceptar una atmósfera contaminada y, como consecuencia, pobres condiciones de salud y una degradación general de la calidad de la vida misma.

Al intentar hacer un uso más conveniente de nuestros recursos de aire podemos utilizar dos métodos diferentes: El preventivo o el correctivo. El más adecuado, que debe iniciarse cuando la atmósfera aún no está contaminada, es el preventivo, cuyo propósito es mantener por lo menos la calidad existente del aire comunal. Es la solución más fácil y menos costosa, y debería ponerse en práctica en toda ciudad antes de que el problema se presente, o durante sus etapas más tempranas. La responsabilidad de la prevención de la contaminación del aire debería entregarse a un Departamento de Control, con obligaciones y atribuciones bien definidas.

Debería asignársele un presupuesto y una planta de personal adecuados a la tarea que debe realizar y se debería preparar, promulgar y aplicar en forma efectiva una legislación que realmente sea capaz de prevenir la aparición del problema, sin que represente una rémora para el desarrollo económico. Simultáneamente deberían iniciarse actividades de investigación destinadas, entre otras cosas, a conocer la capacidad de la atmósfera urbana para absorber y eliminar contaminantes mediante la dispersión natural. Una de las principales tareas debería ser la de mantener un contacto estrecho y permanente con las instituciones a cargo de la planificación física y el desarrollo económico. Esto permitiría conocer de antemano la iniciación de actividades que pudiesen representar el vaciamiento de nuevas cantidades de contaminantes a la atmósfera y, tanto o más importante, brindaría la posibilidad de guiar los

esfuerzos de planificación en una dirección adecuada, que impida la aparición de problemas debido a fuertes concentraciones industriales, aumento indiscriminado del número de vehículos automotores, uso de malos combustibles, crecimiento desmedido de las ciudades, etc.

Cuando la atmósfera ya está deteriorada las actividades de prevención no son suficientes y deberán utilizarse métodos correctivos, destinados a eliminar los problemas existentes y a restaurar una calidad adecuada del aire. La inversión será mucho más elevada, ya que se necesitará más personal para las actividades inspectivas y el estudio de las soluciones más convenientes. La revisión de nuevas instalaciones y la inspección de emisores potenciales deberá ser más completa y estricta. La legislación tendrá que ser más detallada y restrictiva. El costo total será mucho mayor.

Desgraciadamente, la mayor parte de los países deja pasar la oportunidad de usar el primer método, más sencillo y barato. Rara vez se adoptan medidas para prevenir la aparición de un problema. Contribuye a esto, tal vez, la falsa noción de que la contaminación del aire es un símbolo de progreso. Hasta este momento ninguna ciudad latinoamericana parece haber hecho el propósito firme de luchar por conservar su atmósfera permanentemente pura. Por el contrario, sólo se destinan recursos cuando las quejas de la comunidad lo hacen inevitable. Los métodos correctivos son por ello los más habituales pero, en un programa verdaderamente útil, debería haber una estrecha correlación con las acciones preventivas necesarias para impedir deterioros adicionales.

El control de la contaminación del aire es una tarea larga, pesada y difícil y sus resultados sólo serán notorios después de varios años. No hay instalaciones capaces de disminuir el problema en un porcentaje significativo. Más aún, la iniciación de un programa exige despertar el interés de las autoridades y de la comunidad, las que esperarán resultados rápidos y probablemente expresarán su decepción al no obtenerlos, criticando la aparente inefectividad. Tanto los profesionales a cargo del control, como las autoridades responsables y la comunidad toda, deben estar preparados para

esto y dispuestos a no descorazonarse fácilmente. La contaminación del aire nunca se presenta bruscamente. No puede esperarse tampoco que la solución surja de un día para otro. Debemos tener presente que ningún país, ni siquiera aquellos con muchos más recursos que los nuestros, ha sido capaz de controlar este problema en un corto período. Sólo recientemente unas pocas ciudades, con suficientes recursos presupuestarios y de personal, comienzan a mostrar resultados. No hay muchas razones para esperar que la situación en América Latina sea diferente, pero debería aprovecharse al máximo la experiencia de otros países.

Este, sin embargo, es un desafío que debe ser afrontado. Las ciudades que han cometido el error de permitir el deterioro de su atmósfera deben decidirse a adoptar de inmediato las medidas de corrección necesarias para asegurar a sus actuales y futuros habitantes el aire limpio al que tienen derecho. Aquéllas más afortunadas, que todavía disponen de aire de una calidad razonablemente buena, deben comenzar de inmediato la lucha para preservar esta condición. El primer paso es tomar la decisión de querer realmente resolver el problema y de estar dispuestos a pagar el precio que ello signifique.

Noviembre de 1971.

EFECTOS DE LA CONTAMINACION ATMOSFERICA EN LA SALUD DEL HOMBRE.

* Dra. Blanca Raquel Ordóñez M.S.P.

Es conveniente que en primer término se establezca la definición de contaminación atmosférica que más conviene para la presente exposición, y que es la propuesta por la Asociación Americana de Salud Pública La enuncia como "la presencia en la atmósfera extramuros de uno o más contaminantes, en tales cantidades o de tal duración que resulte perjudicial para el hombre, los animales, las plantas o las propiedades, o que simplemente interfiera con el disfrute, el confort o el curso normal de las actividades humanas". (1).

Por definición, exclusivamente nos referiremos a la contaminación atmosférica extramuros, es decir que no abordaremos lo que pueda ocurrir dentro de industrias o de otros medios cerrados. Además, hemos de limitarnos en otros dos aspectos excluir lo que ocurre con otros seres vivos u objetos inanimados y centrar la atención en los efectos sobre el hombre, por otra parte, analizaremos sólo la contaminación artificial o sea -

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aquella motivada por la actividad humana, excluyendo la que en la actualidad se ha considerado menos imporante la contaminación natural

Una vez hechas estas aclaraciones habremos de considerar dos situaciones diferentes, la contaminación aguda de las comunidades y el fenómeno crónico

La contaminación aguda se presenta aisladamente, en determinadas poblaciones en las que se reúnen condiciones excepcionales topográficas, meteorológicas y de contaminación atmosférica Dichos fenómenos de contaminación aguda se han estudiado retrospectivamente y en forma exhaustiva, por lo que se tiene un panorama bastante completo de lo ocurrido Así, son muy conocidos los registrados en la Costa Oriental de Prusia en los años de 1924-1927, en el Valle de Mosa, Bélgica, en 1930 en Donora, Pensylvania, E U.A en 1948, en Poza Rica, México en 1950, en Londres, Inglaterra en 1952, en New York, E U.A en 1953, en estas dos últimas ciudades citadas, en Rotterdam y en Hamburgo en 1962 y los menos trascendentes descritos en Detroit, E U A , y en Yokohama y Osaka, Japón

En estos sitios con condiciones geográficas propicias, los accidentes agudos ocurrieron en invierno, casi siempre a temperaturas de menos de 0^{o} C , en días en los que además, se observó el fenómeno de inversión de la temperatura en la atmósfera, lo que impidió que los contaminantes ascendieran Por otra parte, intervino también la falta de precipitación pluvial

La fuente de contaminantes atmosféricos en esos casos casi siempre fué múltiple, pero mientras en algunos accidentes el factor principal fué la calefacción doméstica, como en Londres; en otros, como en el Valle de Mosa y en Poza Rica, las industrias aportaron la mayor cantidad de contaminantes, los que se acumularon en cantidades elevadas debido a los fenómenos meteorológicos antes señalados

En algunos sitios como en Londres, la mortalidad fue elevada Las defunciones se produjeron entre personas de edad avanzada, que padecían alguna enfermedad crónica del corazón o de los pulmones, especialmente entre los que tenían antecedentes de bronquitis crónica.

El número de personas que enfermaron sin llegar a fallecer fue muy grande, pero no se pudo precisar retrospectivamente, dado que algunos casos fueron benignos Los cuadros clínicos se caracterizaron por irritación química de las mucosas expuestas ojos, nariz, garganta y en general del aparato respiratorio

Puede decirse que conforme avanza la tecnología, dichos accidentes pueden prevenirse, ya que conociendo los fenómenos topográficos, pueden llegarse a predecir las alteraciones meteorológicas propiciatorias, y a calcular con antelación, a través de los muestreos continuos, la emisión diaria de contaminantes

Pero más que los problemas de salud originados por accidentes agudos, que tienen una epidemiología especial, resultan mucho más importantes, tanto para las autoridades sanitarias como para la población en general, los consecutivos a la exposición durante largo plazo, en concentraciones habituales y en situaciones meteorológicas normales, ya que ellos son los que realmente se tienen que afrontar en la mayoría de los países

Debe señalarse que aunque existen numerosas publicaciones que abordan el tema de efectos de la contaminación -- crónica sobre la salud, los resultados presentados en un buen - número de ellas carecen de bases científicas serias Otros, analizan el problema en grupos seleccionados, expuestos exprofeso a determinado ambiente y no en las condiciones habituales de la población.

Solamente de un número reducido de investigaciones se pueden sacar conclusiones definidas, en virtud de que es sumamente difícil determinar el daño que en verdad origina la contaminación en las condiciones habituales, requiriéndose para -- ello estudios epidemiológicos formales, que eliminen la acción - de muchos otros factores que puedan estar influyendo en la salud.

Debe insistirse en que los datos publicados sobre - daños a trabajadores en industrias, de ningún modo pueden extrapolarse a la población general, ya que dentro de la industria el problema lo constituye casi siempre un contaminante, cuya concentración llega a ser más elevada que la que se tiene en los - medios de población abierta. Esta última se halla expuesta a un

complejo de contaminantes y no solamente a uno.

Por otra parte, el riesgo de la exposición en los - lugares de trabajo es generalmente de sólo ocho horas, mientras que la población general lo está durante las 24 horas del día. Además los trabajadores industriales suelen ser adultos en relativamente buenas condiciones de salud, mientras que la población - general está constituída, además, por grupos especialmente lábiles como enfermos, ancianos y niños

Aunque no resulta muy apropiado examinar separadamente los efectos de cada uno de los contaminantes, ya que - como se dijo, en el medio abierto no actúan en forma aislada, los trataremos, sin embargo, más o menos individualmente con el fin de describir mejor sus mecanismos de acción

La acción puede ser directa o indirecta La directa, o sea la que se produce al entrar en contacto los contaminantes - con el organismo, es más importante que la indirecta, ésta, se - produce por interferencia de los rayos solares

El contacto de las impurezas del ambiente con el - cuerpo humano casi siempre se produce en la superficie de la piel

y de las mucosas expuestas, esto es, las de los ojos, de la nariz, de los senos paranasales, de la faringe, de la laringe, del árbol traqueobronquial y del parénquima pulmonar. Estas mucosas - pueden ser irritadas por los contaminantes o bien ser tan sólo - la puerta de entrada de contaminantes que circulan por el orga - nismo y se depositan en algún órgano, produciendo efectos inmediatos o actuando por acumulación En otras ocasiones, las mucosas y la piel, sin ser irritadas son sensibilizadas, lo que origina la aparición de fenómenos alérgicos al contacto de los contaminantes

Los del primer grupo, o sean los contaminantes -- irritantes, puede subdividirse en dos en reductores como el - anhídrido sulfuroso y las partículas de polvo en suspensión, y en oxidantes como el ozono y los ácidos nitrosos. Entre los del segundo grupo, de agentes que circulan en la sangre y que pueden o no acumularse, están el monóxido de carbono, el plomo, el - 3-4 benzopireno, los hidrocarburos policíclicos, los fluoruros, etc Y en el tercer grupo, actuando como alergenos, se encuentran productos orgánicos derivados de los seres vivos como -- plantas, levaduras, mohos, pelos, plumas, caspas, etc.

Los estudios epidemiológicos sobre efectos en la salud del anhídrido sulfuroso y las partículas de polvo en --

suspensión, son los más serios y más numerosos Cada vez más se tiende a estudiar ambos conjuntamente, dada la gran interacción observada. Al parecer, el anhídrido sulfuroso en sí no tiene propiedades irritantes, pero puede transformarse en ácido sulfúrico o en otros derivados sulfurosos que tienen ese poder irritante Las partículas en suspensión parecen tener una acción catalítica que favorece este fenómeno Además, las partículas de agua en suspensión actúan conjuntamente con los dos contaminantes mencionados, favoreciendo el aumento de síntomas respiratorios, así, se ha observado que cuando existe neblina (fog) los síntomas respiratorios se incrementan (2).

Las partículas en suspensión son importantes no tan sólo por la acción catalítica comentada, sino porque pueden depositarse en el tracto respiratorio bajo. Este hecho está condicionado a algunas características de dichas partículas como es su tamaño· la partícula grande tiende a sedimentarse, por lo tanto tiene menos oportunidad de ingresar al aparato respiratorio, y si llega a entrar, se retiene en las vías respiratorias superiores sin alcanzar los pulmones. Interesa también la naturaleza en sí de la partícula en suspensión "el polvo blanco" tiene menos importancia que el "polvo negro", producto de la combustión del carbón o sus derivados (fósiles).

La trascendencia de la partícula en suspensión, mayor aún que el anhídrido sulfuroso en sí, ha sido demostrada por Lawther en Inglaterra y por Cederlof en Escandinavia (3), así, los estudios del primero evidenciaron que el descenso muy marcado de partículas en suspensión, sin ningún cambio en la concentración de anhídrido sulfuroso de la atmósfera de Londres en los últimos años, ha hecho reducir notablemente los síntomas respiratorios de los pacientes con enfermedad crónica respiratoria.

Los resultados de estas y otras investigaciones epidemiológicas sobre el efecto en seres humanos del anhídrido sulfuroso y las partículas en suspensión, se sintetizan en el cuadro No. 1.

Se ha demostrado el efecto de la contaminación aumentando síntomas, especialmente la expectoración de los enfermos bronquíticos crónicos; así como disminuyendo la función respiratoria, especialmente en niños y en ancianos. Como se ve en el cuadro, los niveles en los que se ha demostrado alguna acción de dichos contaminantes en grupos lábiles de la población como son enfermos crónicos respiratorios, niños y ancianos, varía notablemente de un estudio a otro. Ello depende no sólo de la técnica

utilizada para evaluar los fenómenos contaminación o enfermedad, sino también de las características propias de cada lugar y de sus habitantes.

Los contaminantes atmosféricos del tipo de oxidantes, han sido menos estudiados. En este grupo entran el ozono y diversos óxidos nitrosos cuya acción nociva se relaciona más que nada con su capacidad de producir ozono, amén de favorecer el de la contaminación fotoquímica Provocan irritación de ojos, nariz y garganta, y aumento de síntomas en grupos de enfermos asmáticos y con insuficiencia respiratoria -- crónica.

En el cuadro No 2 aparecen los resultados obtenidos en diversos estudios, los que aparentemente son contradictorios, este hecho indica la necesidad de seguir realizando investigaciones epidemiológicas para poder llegar a establecer los máximos permisibles sobre bases más firmes.

De los contaminantes que se absorven y pueden causar enfermedades generales, resalta en primer término el monóxido de carbono.

Su principal acción se produce al combinarse - con la hemoglobina de la sangre y formar la carboxihemoglobina; este derivado impide la oxigenación de los tejidos, sufriendo los más lábiles de ellos, como los del sistema nervioso central, -- por ejemplo.

Cuando las concentraciones del monóxido de carbono en el aire inspirado son altas y sostenidas por un período - suficientemente largo, la persona manifiesta dolor de cabeza, - mareos y puede llegar al estado de coma y hasta a la muerte por el daño del sistema nervioso central, sin embargo, dichas con-- centraciones nunca se han hallado en el ambiente habitual de las ciudades. Por otra parte, existe suficiente evidencia de que en- personas sanas no se alcanzan niveles de concentración sanguínea de carboxihemoglobina lo suficientemente elevada para producir daño

Hay, no obstante, ciertos estudios que señalan que el monóxido de carbono contenido en el ambiente pudiera - ser perjudicial para algunas personas con enfermedades del - sistema nervioso central, del sistema cardiorespiratorio o --

con anemias severas. Incluso pudiera acontecer que la - letalidad aumentara entre determinados enfermos, como por ejemplo en casos hospitalizados por infarto del miocardio. (24)

De la misma manera, el daño encontrado entre fumadores pudiera llegar a ser serio, ya que las concentraciones de carboxihemoglobina halladas en su sangre, son hasta 10 y 20 veces superiores a las encontradas en - no fumadores, estando ambos expuestos al mismo medio - ambiente.

Por otra parte, empieza a hablarse de alteraciones psicomotoras muy difíciles de demostrar y alteraciones del electroencéfalograma de ardua interpretación, que pudieran ser causadas por el monóxido de carbono. Este efecto en particular es de temer, en personas sometidas a la influencia de depresores del sistema nervioso central como el alcohol y las drogas enervantes.

Finalmente, debe señalarse el hecho de que el monóxido de carbono no se acumula, por lo que la -- mayoría de los autores descartan la posibilidad de una intoxicación crónica con dicha substancia. En el cuadro No. 3

aparece la síntesis de los estudios reportados sobre efectos del monóxido de carbono sobre salud que han sido hallados en laboratorios, no en el medio ambiente habitual. Y en el No. 4, los niveles de carboxihemoglobina en sangre que se alcanzan, con diversas concentraciones de monóxido de carbono atmosférico, al nivel del mar. En términos generales, se trata de evitar concentraciones en sangre del 5% o más, es decir, que no deben permitirse niveles atmosféricos por encima de 30 partes por millón al nivel del mar.

Otro contaminante atmosférico que se absorve, y cuya acción sobre seres humanos ha sido muy discutida, - es el plomo.

Cuando el plomo ingresa al organismo se almacena en los tejidos y llega a producir, en individuos muy expuestos, disminución de la síntesis de la hemoglobina, así como daño renal y hepático, retraso mental en niños y alteraciones de la fecundidad y del embarazo Pero por supuesto que las concentraciones de plomo que producen estos efectos no se alcanzan en el ambiente atmosférico habitual.

El plomo del medio normal proviene tanto de los

vehículos de motor como de otras fuentes; así, también existe en el agua de bebida, en los alimentos y en el tabaco. Se encuentra aún en los pueblos menos civilizados.

Los estudios realizados hasta la fecha concluyen que no hay evidencia de que el plomo emitido por los vehículos de motor esté produciendo en la actualidad efectos adversos, aún en las ciudades con mayor tránsito automovilístico. Así pues, deben tomarse en cuentra otras fuentes para calcular la cantidad de plomo a la que está expuesto el hombre en cada sitio y en diferentes épocas.

Por lo que se refiere al benzopireno y a los hidrocarburos policíclicos, se ha observado que tiene propiedades carcinogénicas en los animales de laboratorio, así como en individuos que trabajan en ciertas industrias, bajo condiciones especiales de exposición pero esto no indica, según los informes de los expertos de la Organización Mundial de la Salud, que las pequeñas cantidades halladas en la actualidad en el medio urbano, tengan algún efecto apreciable en la frecuencia de cáncer del pulmón. Aunque muchas investigaciones han sugerido la relación entre el cáncer del pulmón y

la contaminación atmosférica en las ciudades, esta correlación no se puede sostener cuando se analizan otras variables, como condiciones socioeconómicas, facilidades de diagnóstico y sobre todo, tabaquismo.

Como es sabido, las fuentes importantes del benzopireno e hidrocarburos policíclicos para el hombre, en el medio habitual, son los vehículos de motor y el humo del tabaco, pero mientras que el efecto del tabaco en la producción de cáncer del pulmón está perfectamente establecido, numerosos estudios epidemiológicos no han podido encontrar hasta ahora relación entre las emisiones de los vehículos y esta enfermedad, por lo que el concenso entre los científicos es en el sentido de que si llegara a contribuir en alguna forma a la producción de esta enfermedad, su papel sería en todo caso insignificante, comparado con el del cigarrillo.

Esto es, en síntesis, lo que hasta ahora se ha establecido científicamente de los diversos contaminantes atmosféricos. Otros daños atribuibles tienen pocas bases serias, por lo que deben tomarse con reserva y esperar a que se --

confirmen o se desechen por investigaciones más sólidas.

Por lo que se refiere a nuestro país, no hay - hasta la fecha resultados de ningún estudio que demuestre -- científicamente que la contaminación atmosférica esté produciendo daño a la salud

Frecuentemente se extrapolan los resultados - hallados en otros países al nuestro. Pero aún considerando - niveles de contaminantes prevalentes, no es posible aplicar - los resultados hallados en otros sitios, ya que las características del medio ambiente, del agente o sea de los contaminantes y del huésped o sea la población, difieren notablemente de una nación a otra.

Así, por ejemplo, emisiones de contaminantes - similares actuan en la salud de manera diferente si hay o no partículas de agua suspendidas en la atmósfera o si hay una mayor o menor fuente solar que favorezca cambios fotoquí-- micos de los contaminantes Por otra parte, concentraciones iguales de partículas en suspensión actuan en el hombre de - manera diferente según su tamaño y su naturaleza (polvo -- "blanco" o polvo "negro"), características que desde luego -

varían entre los países.

En lo relativo a salud, nuestro país ha de hacerse dos consideraciones en primer lugar, que debemos realizar estudios epidemiológicos propios para valorar nuestro problema desde el punto de vista médico. En segundo lugar, que dichos resultados deben ponderarse y considerarse dentro de toda la gama de -- problemas de salud que nuestro país confronta, para poder establecer las prioridades en la lucha contra las enfermedades que más - afecten a la población.

En relación al primer punto, la Academia Nacional de Medicina, conjuntamente con otras dependencias oficiales,- descentralizadas y privadas, viene realizando un estudio epidemiológico longitudinal en grupos lábiles de la población del D.F , a -- partir del mes de noviembre de 1970, y que concluirá en el próximo mes de marzo. Dicha investigación, con bases científicas serias, - con la asesoría de los más destacados organismos internacionales - y expertos en la materia, proporcionará valiosos resultados a mediados de 1972 y ayudará a establecer los límites de contaminantes - que permitan proteger la salud de nuestra población

México, D.F., noviembre de 1971

CUADRO # 3

NIVELES DE CARBOXIHEMOGLOBINA Y SUS EFECTOS EN LA SALUD.

% de carbox hemoglobina	E F E C T O S	AUTOR
0.4 - 0.8	Pruebas psicológicas normales en no fumadores.	Coburn.1969(25) Sjostrand. Escandinavia. 1949(26)
2 - 3	No fumadores muestran alteraciones en la discriminación.	Beard. 1967 (27)
	Posible efecto en los tiempos de nadadores.	MacMillan. U.S.A.1969(28)
	Ningún efecto en corredores de largas distancias.	Wayne. 1967. (29)
4.5	Aumento de síntomas en agentes de tránsito.	Babayants. URSS.1962(30)
	Aumento de la admisión de oxigeno en no fumadores.	Chevalier. 1966.(31)
5 - 10	Posible alteración en personas con enfermedades cardiorespiratorias.	Ayres.1965(32, 33) Cohen.1969(24)
	Alteración de pruebas psicomotoras.	Schulte,1963(34)
	Ninguna alteración de pruebas psicomotoras usando otras técnicas.	Stewart. 1970 (35)
	Aumento de la hemoglobina.	Hofreuter. 1962 (36) Ramsy.1967(37)
	Ningún aumento en la hemoglobina.	Lindgram. Escandinavia.1961(38)
13 - 20	Dolor de cabeza, falta de coordinación manual.	Stewart.1970(39)
	Alteraciones del electroencefalograma.	Hosko,1970(40)

FUENTE: Organización Mundial de la Salud.- Ginebra, Suiza.1971

CUADRO # 1

NIVELES AMBIENTALES DE ANHIDRIDO SULFUROSO Y PARTICULAS EN SUSPENSION Y SUS EFECTOS EN LA SALUD.

Anhídrido sulfuroso. Ugm/M^3.	Partículas en suspensión. ugm/M^3	EFECTOS	AUTOR
1000 *	1000 *	Exacerbación de síntomas en paciente con enfermedad crónica respiratoria	Waller y Lawther. Londres 1955 y 1957. (4,5)
605 500	317 250	Ligero aumento de síntomas respiratorios a los niveles más altos señalados por el método de control	Lawther. Londres 1970. (3)
600 500	420 100	Descenso progresivo en la producción de flemas con los niveles más bajos.	Speizer. 1969. (6)
300 30	200 120	Aumento en la producción de flemas y disminución de la capacidad vital a los niveles más altos.	Holland. Inglaterra y U.S.A. 1965 (7, 8, 9)
130	138	Aumento de síntomas respiratorios en niños por arriba de esos niveles.	Douglas. Inglaterra. 1966 (10)
120	100	Aumento de enfermedades respiratorias y descenso de la capacidad vital en niños.	Lunn. Inglaterra, 1967 (11)
105 80	400 180	Aumento de síntomas respiratorios en mujeres no fumadoras de 65 y más años y en los niveles superiores.	A Petrilli Italia, 1966 (12)
55 35	180 132	Aumento de síntomas respiratorios y ligera disminución de la capacidad vital a los niveles más altos en hombres y mujeres de 25 a 74 años.	Ferris. Alemania, 1971. (13)

Promedio anual. Generalmente en 24 horas.

FUENTE: Organización Mundial de la Salud. Ginebra. 1971.

CUADRO # 2

NIVELES DE OXIDANTES TOTALES EXPRESADOS COMO OZONO EN EL MEDIO AMBIENTE Y SUS EFECTOS SOBRE LA SALUD

ugm/M^3	ppm	EFECTOS	AUTOR
1200-1600	0 6-0 8(2 hs.)	Reducción de la capacidad y función pulmonar.	Silvermann. 1970. (14) Young 1964(15)
540-440	0.27-0 22	Ningún efecto en jóvenes - sanos del sexo masculino	Holland. 1968 (16)
300	0.15	Ataques más comunes en - personas asmáticas.	Schoettlin 1961.(17)
320-200	0.16-0.10	Ningún efecto en niños escolares.	McMillan. U.S.A.1969(18)
200	0.10	Irritación de ojos.	Renzetta. U.S.A.1957(19) Richardson 1958 (20)
		Disminución de la función pulmonar en personas con enfermedad crónica respiratoria.	Motley. U.S.A.1959 (21)
		Disminución de la efectividad en corredores de grandes distancias.	Wayne,1967. (22)
		Ningún efecto en el ausentismo escolar por causa - de enfermedades respiratorias.	Wayne, 1969 (23)

FUENTE· Organización Mundial de la Salud. Ginebra, Suiza. 1971

CUADRO # 4

NIVELES DE CARBOXIHEMOGLOBINA EN SANGRE SEGUN DIFERENTES CONCENTRACIONES DE MONOXIDO DE -- CARBONO EN EL AMBIENTE.*

Concentraciones ambientales de CO.		Carboxihemoglobina
mg/m^3	ppm.	%
117	100	15
70	60	10
35	30	5
23	20	3.3
12	10	1.7

* A nivel del mar.

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" LAS BASES PARA LA ELABORACION DE REGLAMENTOS PARA EL CONTROL DE LA CONTAMINACION ATMOSFERICA EN MEXICO "

H. Bravo A.*

La publicación de la Ley Federal para la prevención de la contaminación ambiental - en el Diario Oficial, en marzo de 1971, y su implementación al través de Reglamentos es una de las tareas para hacer esta Ley funcional. Los conceptos para desarrollar estos reglamentos deben ser seleccionados para evitar frenar nuestro crecimiento industrial y, a la vez, la deterioración de nuestro ambiente.

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En Marzo de 1971, en el Diario Oficial, fué publicada la " Ley Federal para la Prevención y el Control de la contaminación ambiental " . Esta Ley, en su carácter genérico, da las bases generales para prevenir y controlar la contaminación ambiental y hace referencia a la -- contaminación del aire, aguas y suelos.

Para hacer efectiva esta Ley, es necesario elaborar reglamentos específicos para prevenir y controlar la contaminación ambiental.

La contaminación atmosférica, basándonos en la definición de contaminantes que aparece en la Ley Federal -- mencionada anteriormente dice:

"Contaminante" Definición:

Toda materia o substancia, sus combinaciones o compuestos o derivados químicos y biológicos tales como humos, polvos, gases, cenizas, bacterias, resíduos y desperdicios o cualesquiera otros que al incorporarse o adicionarse al aire puedan alterar o modificar sus características naturales o las del ambiente, así como toda forma de energia como calor, radioactividad, ruidos, que al - operar sobre o en el aire alteren su estado normal.

Sería muy complicado si se tratase de elaborar reglamentos en forma global; por lo que es necesario elabo

difusión toma como parámetros importantes: 1) la altura de la descarga de contaminantes, 2) problemas relacionados a la topografía del lugar y 3) condiciones meteorológicas.

a) El uso de la teoría de difusión se basa en la altura calculada de la chimenea en relación a la velocidad y dirección del viento, además de la temperatura de descarga del efluente y otros parámetros que influyen en la concentración esperada del contaminante en cuestión, en la propiedad que rodea la fuente.
La concentración media del contaminante en la pluma es razonablemente bien explicada en una distribución Gaussiana para la cual la concentración máxima en el suelo es dada por:

$$\chi = \frac{\sigma_z}{\sigma_y} \frac{2Q}{\pi e u h^2} = 0.164 \frac{Q}{u h^2}$$

Donde Q es el flujo al cual el contaminante es emitido; u es la velocidad media del viento a la altura de la fuente, h es la altura efectiva de la fuente (definida como la suma de la altura real de la chimenea h_s, y la elevación de la pluma h); $\frac{\sigma_z}{\sigma_y}$ es la relación

.....

rar dichos reglamentos lo más específicos posible para - contaminantes seleccionados a través de prioridades de - diversas clases.

Los procesos industriales de contaminación más evidentes son los productores de humos y polvos, para los - cuales existe la tecnología adecuada de control y se han estudiado sus costos de implementación.

Los reglamentos en México deben basarse en la mejor técnología conocida hasta la fecha y poniendo especial - atención al costo de su implementación, y como principal objetivo: proteger la salud de todos los habitantes y -- sus bienes.

Estos reglamentos deben fundamentarse en tres puntos esenciales:

a) educación

b) cooperación

c) legislación

Existen varios criterios para elaborar las reglamentaciones con el fin de controlar la contaminación atmosférica. Dos son los que se anotarán:

a) Uso de las teorías de difusión y dispersión (chimeneas altas)

b) Control en la fuente de emisión de contaminantes

El criterio que aplica las teorías de dispersión y

La reglamentación basada en el segundo criterio - (control en la fuente) puede ser elaborado, por - ejemplo, si se trata de un reglamento para controlar emisiones de partículas, tomando en cuenta:

a) El peso de proceso en tons/hora vs. emisión permitida en Kilogramos por m^3 normal.

b) Opacidad de la pluma, o bien la estimación de la densidad de humo, usando la carta Ringelmann.

Este caso se aplica a fuentes de combustión. La norma que se puede aplicar es la carta Ringelmann, la cual proporciona una observación de la apariencia de la densidad de humo de la pluma al compararse con la escala Ringlemann, o bien se relaciona a opacidad en base a que una pluma con 100% de opacidad evita la transmitancia de toda luz, normas del 20% de opacidad son algunas veces usadas.

Para evaluar el programa de control, si es efectivo o no, se deben conocer los niveles de los contaminantes en la atmósfera, por controlar, antes y - después de la aplicación. Esto se lleva a cabo - por medio de un adecuado programa de monitoreo atmosférico.

de la dispersión vertical a la dispersión horizontal; la cual, en una atmósfera de gradiente neutral es - mas o menos 0.7 por un período promedio de 30 minutos.

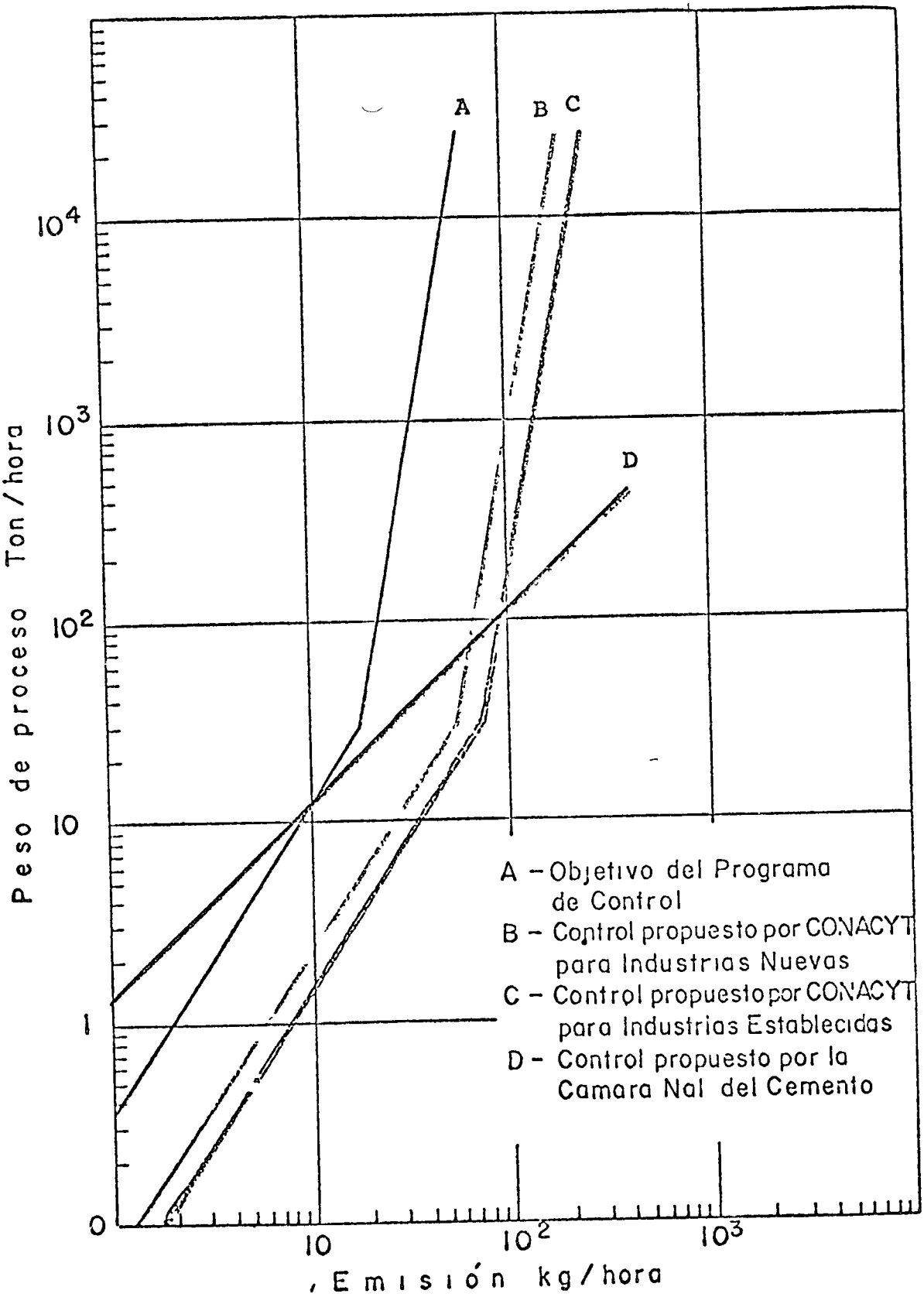
Una medida del proceso de difusión en un dado caso es dada por Q/χ llamado coeficiente efectivo de - ventilación y tiene las dimensiones de flujo volumétrico (L^3/t).[1]

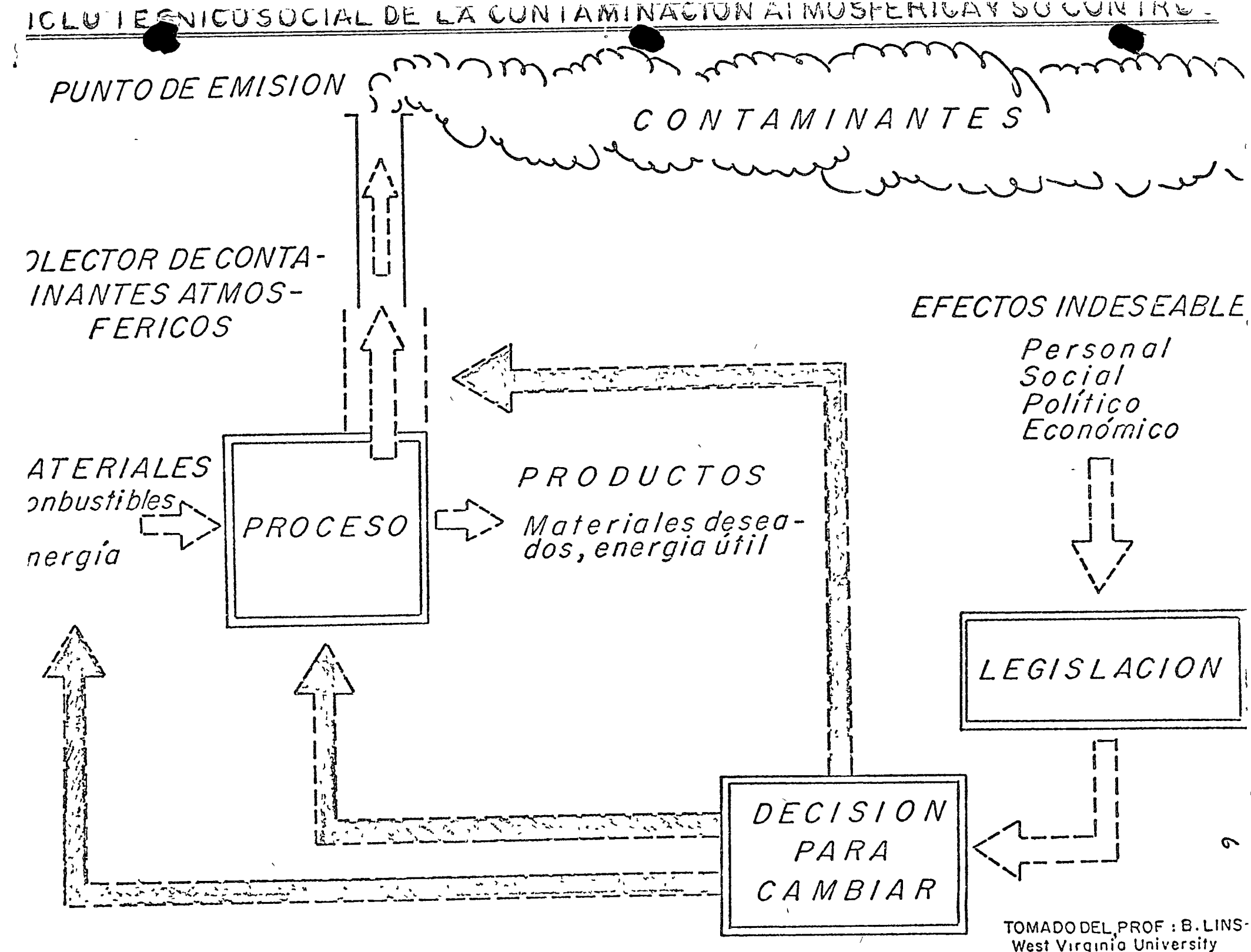
Para el caso anterior sería:

$$\frac{Q}{\chi} = 6.1\ uh^2 = 6.1\ u(h_s + \Delta h)^2$$

b) Control en la fuente de emisión:

La reglamentación basada en este criterio es difícil de aplicar por la dificultad de identificar, en un momento dado, una fuente de contaminación cuando existen más de una que emite el mismo contaminante. Este criterio se basa en que el control de los contaminantes, debe efectuarse en la fuente, Fig. 1. Este criterio es efectivo puesto que facilita la -- identificación de la parte de proceso, materia prima o fuente de energía que emite la contaminación, haciendo posible la selección adecuada de métodos de control.


A
B C
D
10^4
10^3
10^2
10
1
0
Peso de proceso Ton / hora
10
10^2
10^3
, Emisión kg / hora
A – Objetivo del Programa de Control
B – Control propuesto por CONACYT para Industrias Nuevas
C – Control propuesto por CONACYT para Industrias Establecidas
D – Control propuesto por la Camara Nal del Cemento



TOMADO DEL PROF : B. LINS-
West Virginia University

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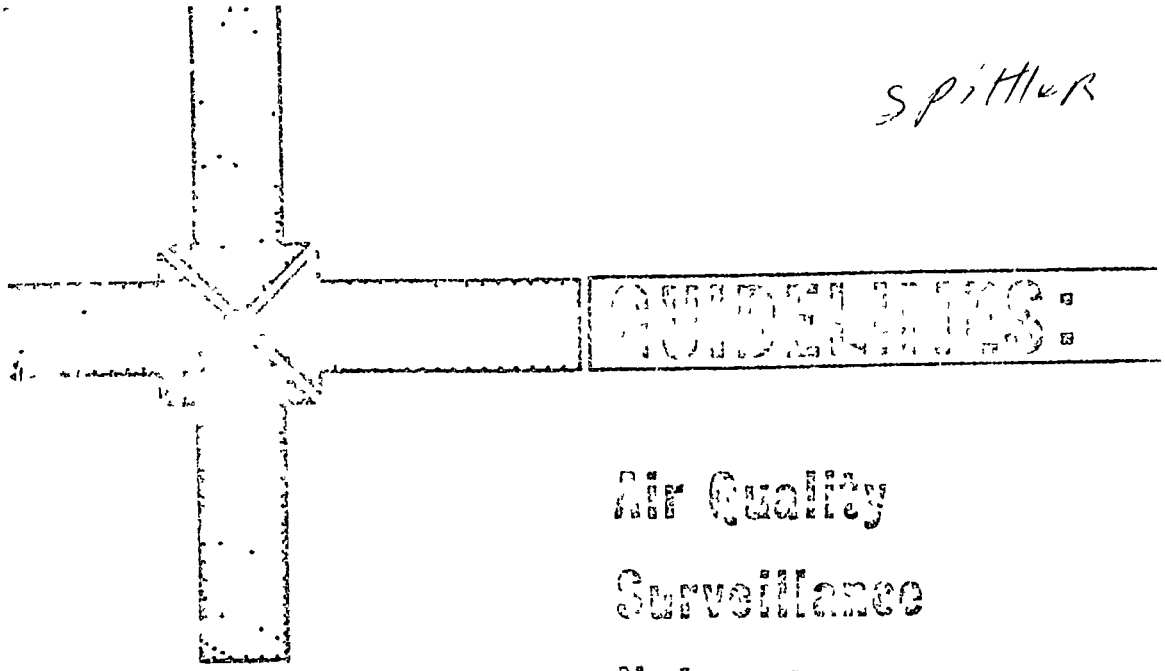

Air Quality Surveillance Networks

U. S. ENVIRONMENTAL PROTECTION AGENCY

GUIDELINES: AIR QUALITY SURVEILLANCE NETWORKS

ENVIRONMENTAL PROTECTION AGENCY
Office of Air Programs
Research Triangle Park, North Carolina
May 1971

For sale by the Superintendent of Documents U S Government Printing Office
Washington, D C 20402 Price 20 cents
Stock Number 5503-0010

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Office of Air Programs Publication No. AP-98

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GUIDELINES: AIR QUALITY SURVEILLANCE NETWORKS

INTRODUCTION

Air Quality Control Regions have been designated for the entire United States. For these regions an inherent part of the control effort is the development of an air quality surveillance program In some areas, existing networks will be modified or expanded, in others, new surveillance programs must be developed. Although past efforts were concerned primarily with sulfur dioxide and particulates, regional surveillance programs will need to be expanded to include other pollutants such as carbon monoxide, nitrogen dioxide, nonmethane hydrocarbons, and oxidants.

The guidelines presented here will assist State and local agencies in setting up air quality surveillance programs. The development of an air quality surveillance program includes determining the number and location of sampling sites, selecting appropriate instrumentation, and establishing a data information system. Experience and technical judgment are essential for determining the number and location of sampling sites because adequate mathematical models or other methods have not been formulated.

The development and implementation of the system must by necessity involve a trade-off between what is considered desirable from a strictly technical point of view and what is feasible with the available resources. An ideal network will in almost all instances require more resources than are available. In light of this, the design discussed in this paper

centers on a minimally adequate surveillance network - a network less than ideal, yet capable of meeting the major surveillance requirements. The basic difference between a minimally adequate surveillance network and the ideal is that the minimal network has fewer and perhaps less sophisticated instruments. Designers of the network should attempt to maximize the effectiveness of the minimally adequate network through careful selection of sampling sites, scheduling of variable sampling frequencies, and possible use of mechanical (integrated) as well as automatic (continuous) samplers.

Because of limited resources, some air quality control regions may be required to build up to an adequate surveillance network over a period of time. The surveillance network established under conditions of limited resources would be the starting point upon which a future network could be built. In such cases a schedule for expansion should be compiled early to allow for systematic buildup and to guide the allocation of resources.

This report deals with four major aspects of regional surveillance: (1) objectives of surveillance, (2) design of a minimally adequate surveillance network, (3) laboratory requirements, and (4) data acquisition and analysis.

OBJECTIVES OF REGIONAL SURVEILLANCE

Regional air quality surveillance networks are inherent parts of the implementation plans currently required for sulfur oxides, particulates, carbon monoxide, hydrocarbons, oxidants, and nitrogen oxides. Generally, surveillance networks for all of these pollutants must be established in a region. Although each pollutant requires separate analysis, the collection of samples can be generalized into two groups (1) a particulate network, which is the source of information for suspended particulates, and (2) a gas network, which consists of sampling devices for CO, SO_2, NO, NO_2, nonmethane and total hydrocarbons, and oxidants The need for surveillance for each pollutant will depend on the amount of pollution present within the region. For example, whereas one region may require extensive surveillance, of, say, oxidants, the relative absence of this pollutant in another region may preclude such an extensive surveillance effort.

Air quality surveillance within a region must provide information to be used as a basis for the following actions:

1. To judge compliance with and/or progress made toward meeting ambient air quality standards
2. To activate emergency control procedures to prevent air pollution episodes.
3. To observe pollution trends throughout the region including the nonurban areas (Information on the nonurban areas is needed to evaluate whether air quality in the cleaner portions of a region is deteriorating significantly and to gain knowledge about background levels.)
4. To provide a data base for application in evaluation of effects, urban, land use, and transportation planning; development and evaluation of abatement strategies, and development and validation of diffusion models.

DESIGN OF AN AIR QUALITY SURVEILLANCE NETWORK

An air quality surveillance program is composed of three distinct but interrelated elements. sampling networks, laboratory support, and data acquisition and analysis. With automatic (continuous) instrumentation the need for routine laboratory support is greatly reduced, but a problem of data transmission, validation, and reduction is introduced. Network design entails such considerations as the number and type of stations needed, their locations, frequency of sampling, and duration of collection period for each sample. The kind of network specified for a given region will also determine the requirements for laboratory sampling and analysis procedures, laboratory support, and data acquisition and analysis systems.

The two general types of networks required for regional air quality surveillance are (1) a particulate network and (2) a gaseous network.

The particulate network should be composed primarily of high-volume samplers (Hi-Vols) and tape samplers. The Hi-Vols are used to collect total suspended particulates (TSP), which may be subsequently fractionated into trace elements and compounds. Tape samplers provide an indication of suspended particulate loading over periods of less than 24 hours, primarily for use during air pollution episodes The total particulate network design, i.e., number and location of Hi-Vol stations, will most likely be determined by the sampling requirements for TSP. The extent to which the Hi-Vol samples are analyzed for a particular constituent depends upon local circumstances. It is important to note that practical field

techniques are being perfected for measuring the respirable size fractions of TSP.

The gas network may be composed of a mixture of mechanized and automated sampling devices. For some pollutants, such as sulfur dioxide, nitrogen oxides, and oxidants, both types of samplers may be used Where pollution levels are substantial, the urban core network will typically be composed of automatic sampling stations, with the mechanical stations being relegated to areas of lower concentrations between widely spaced automated stations.

Information Required for Network Design

Knowledge of the existing pollution levels and patterns within the region is essential in network design The areas of highest pollution levels must be defined, together with geographical and temporal variations in the ambient levels. Isopleth maps of ambient concentrations derived from past sampling efforts and/or from diffusion modeling are the best tools for determining the number of stations needed and for suggesting the station locations Additionally, information on meteorology, topography, population distribution, present and projected land uses, and pollution sources is extremely helpful in network design. In fact, where isopleth maps are not available, such information, which can usually be obtained readily from organizations such as the Bureau of Census, National Weather Service, and local planning agencies, provides the basis for initial design.

In the absence of isopleth maps, information on emission densities and/or land use can be used together with wind-rose data to pinpoint areas of expected higher concentrations Topographical maps provide additional information on wind flow and pollution dispersion characteristics Maps of population distribution are essential in locating key stations for monitoring during episodes.

In some cases adequate information for network design will not be available, the resulting networks will need to be modified as more information and experience are obtained.

Network Size

The number of sampling stations required depends primarily on the existing pollution levels, their variability, and the size of the region. The number of sampling stations must

be adequate to allow definition of the area or areas where ambient concentrations may be expected to exceed air quality standards Information on air quality in other areas, including the nonurban portions of the region, should also be gathered

A first approximation of the number of stations required in a region may be obtained from Figure 1, in which the number of stations is shown as a function of total population. The curves in Figure 1 show a spread suggesting a minimum and a maximum number of stations for each population class depending on the extent and degree of pollution. For example, a region of 1 million inhabitants with a severe SO_2 problem may require up to 25 samplers, whereas one of similar size with a minimal SO_2 problem would require only 10 samplers Although the curves should provide good estimates for application to population- or motor-vehicle-related pollutants such as CO, HC, NO_x, and oxidant (ozone), they do not necessarily apply as well to SO_2 and particulate matter. For the latter pollutants, industrial complexity and fuel-use patterns in the region strongly influence the pollution levels and thus affect network size regardless of the population.

Surveillance of SO_2 and NO_x requires an additional decision concerning the mixture of mechanical and automatic samplers. A first approximation can again be obtained from Figure 1. The curve for mechanical samplers provides the estimate for the total number of SO_2 samplers needed. The difference between the estimates for mechanical and automatic samplers is the actual number of mechanical samplers required.

Figure 1 is intended only as a general guide to network size. The curves are based on a qualitative evaluation of cities of different population classes in terms of their existing networks, pollution patterns, and geographic distribution of sources The relationship between population and network size was derived from such investigations combined with experience and knowledge In general, population is a good index to network size and such data are easily obtainable. There are, however, certain situations, such as the relative absence of SO_2 pollution in the western portion of the United States, in which these curves are not applicable. In these cases, more specific information on sources and emissions is essential before network size can be determined.

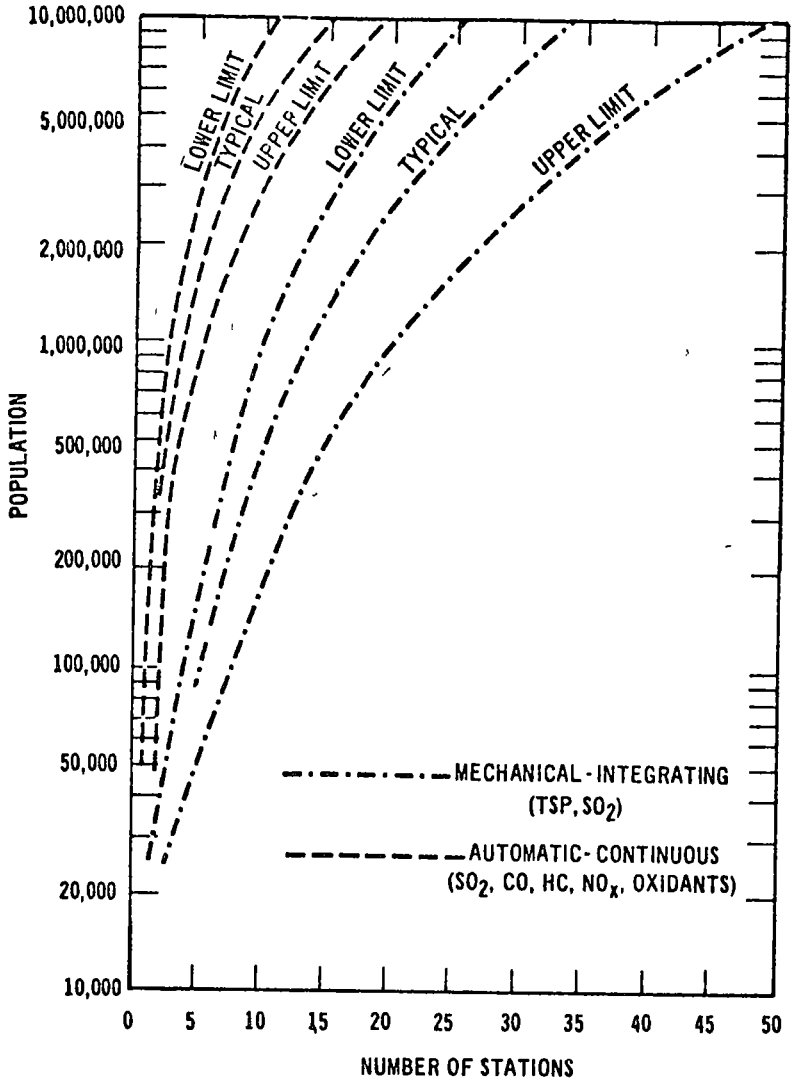

Figure 1. Region population versus number of stations.

Another approach for approximating the number of stations required within a region incorporates information on existing levels of pollution as a function of the area of the region. Where isopleth maps are available, they should be used for estimating network size. At the present time, use of the mathematical approach is limited to the design of surveillance networks for suspended particulates and sulfur dioxide.

The equation for estimating network size relates the number of stations to the degree of pollution and the land area of the region. It is based on the fact that more stations are needed in zones where ambient air pollutant concentrations may be expected to exceed the ambient air quality standards and that the concentrations influence the number of stations The equation considers distinct areas· the area, X, where the pollution levels are higher than the ambient air quality standard, the area, Y, where pollution levels are above background but lower than the standard, and the area, Z, where existing concentrations are at background levels. In these calculations all air quality data are expressed in terms of annual averages. The total number of samplers, N, required for the entire region is obtained by summing the estimated numbers of samplers for each of the three subareas.

$$N = N_x + N_y + N_z \tag{1}$$

The subareas are described as follows:

$$N_x = 0.0965 \frac{C_m - C_s}{C_s} X \tag{1a}$$

$$N_y = 0.0096 \frac{C_s - C_b}{C_s} Y \tag{1b}$$

$$N_z = 0.0004 Z \tag{1c}$$

Where:

C_m = Value of maximum isopleth* (with a contour interval of 10), $\mu g/m^3$

*Table 1 provides estimated background values for total suspended particulates and SO_2 for use when isopleth information is not available.

Table 1. TSP AND SO_2 VALUES FOR NONURBAN BACKGROUND TERM IN EQUATION 1

($\mu g/m^3$)

	Proximate[a]	Intermediate[b]	Remote[c]
Total suspended particulate	45	40	20
Sulfur dioxide	20	10	5

[a]Proximate values based upon NASN stations in the following states: Connecticut, Delaware, District of Columbia, Maryland, Massachusetts, New Jersey, New York, Pennsylvania, Rhode Island.

[b]Intermediate values for all other states.

[c]Remote values based upon NASN stations in the following states: Colorado, Idaho, Michigan, Minnesota, Montana, Nebraska, Nevada, New Hampshire, New Mexico, North Dakota, Utah, Wisconsin, Wyoming.

C_s = Ambient air quality standard, $\mu g/m^3$

C_b = Value of the minimum isopleth (again with a contour interval of 10), $\mu g/m^3$

X = Area wherein concentrations are higher than ambient air quality standard, km^2

Y = Area wherein concentrations are above background but less than ambient standard, km^2

Z = Area wherein concentrations are at background levels, km^2

Use of these equations requires the division of the region into three zones on the basis of isointensity lines representing the ambient air quality standard and the background value appropriate for the region. The land areas of each zone are determined from the isopleth map, as are the maximum and minimum concentrations in the region. Note once more that concentration values used in the equation are annual averages. The above equations should not be used to estimate the numbers of background stations where regions encompass excessively large unpopulated areas. No more than four or five background stations should be necessary in any region.

The equation for determining number of stations was derived from an in-depth analysis of the relationship between pollution levels and patterns, geometric distribution of sources, meteorology, and land area in the National Capital Interstate Air Quality Control Region. The equation was verified by application to several other cities in the United States with various population and pollutant distributions. As mentioned earlier, it is applicable only to SO_2 and TSP networks. The same general approach, with different constants, can be applied to determine the size of networks for the measurement of other pollutants. These constants will be developed when more data become available.

Station Location

Selecting the locations of stations and samplers involves decisions regarding (1) distribution of samplers within the region and (2) specific site selection for each station. The first decision requires consideration of surveillance objectives, overall pollution patterns, and the needs for governmental jurisdictional coverage. Selection of the particular site is based upon representativeness of the area and other practical aspects such as housing the samplers, electric power, and security from vandalism.

The information required for selecting sampler location is essentially the same as that for determining network size, i.e., isopleth maps, population density maps, source locations. Following are suggested guidelines:

1. The priority area is the zone of highest pollutant concentration within the region. One or more stations are to be located in this area.
2. Close attention should be given to densely populated areas within the region, especially when they are in the vicinity of heavy pollution.
3. For assessing the quality of air entering the region, stations must also be situated on the periphery of the region. Meteorological factors such as frequencies of wind direction are of primary importance in locating these stations.
4. For determining the effects of future development on the environment, sampling should be undertaken in areas of projected growth.

5. A major objective of surveillance is evaluation of the progress made in attaining the desired air quality. For this purpose, sampling stations should be strategically situated to facilitate evaluation of the implemented control tactics.

6. The National Air Surveillance Network (NASN) sampling sites within a region should be included as an integral part of the proposed network. It is expected the appropriate agency will take over and continue to operate this station(s) at the existing site to provide continuity of air quality at a given location.

7. Some information of air quality should be available to represent all portions of the region.

The air quality surveillance network should consist of stations that are situated primarily to document the highest pollution levels in the region, to measure population exposure, to measure the pollution generated by specific classes of sources, and to record the nonurban levels of pollution. Many stations will be capable of meeting more than one of these criteria, e.g., a station located in a densely populated area besides measuring population exposure could also document the changes in pollutant concentrations resulting from new control strategy employed in the area.

Although the sampler locations depend on many factors, some idea of sampler distribution may be obtained from Tables 2 and 3, which show sampler location as a function of network size. Table 2 summarizes distribution of mechanical samplers, such as Hi-Vols, Table 3 shows distribution of automatic samplers. With respect to locations shown in Tables 2 and 3 it will be necessary to consider wind patterns, source locations, and distribution of emissions in selecting approximate locations for these sites. For example, stations in the highly populated area should be so situated that they can accurately assess the pollution impact under different meteorological conditions. Although both types of stations follow the same general pattern, the tendency is for wider distribution of mechanical sampling stations.

It is the intent of these guidelines to suggest that a simple network be developed to measure the concentration of as many pollutants as possible. It is likely that common sites, although not necessarily ideal for each pollutant, may be

Table 2. DISTRIBUTION OF MECHANICAL (INTEGRATED) SAMPLING STATIONS[a]

Total number of stations	Number of stations in		
	Center city/ industrial	Residential zones	Nonurban
1	1	-	-
2	1	1	-
3	2	1	-
4	2	2	-
5	2	2	1
10	5	3	2
15	8	5	2
20	12	6	2
25	14	8	3
30	17	10	3

[a]Includes Hi-Vol sampler and SO_2, NO_2, and oxidant (ozone) collecting devices.

Table 3. DISTRIBUTION OF AUTOMATIC (CONTINUOUS) SAMPLING STATIONS[a]

Total number of stations	Number of stations in:		
	Center city/ industrial	Residential zones	Nonurban[b]
1	1	-	-
2	1	1	-
3	2	1	-
4	2-3	1-2	-
5	3	2	-
6	4	2	-
10	6	4	-
15	10	5	-

[a]Includes SO_2, CO, HC, NO, NO_2, and oxidant (ozone).

[b]Where ozone damage has been identified in nonurban areas, surveillance may be necessary.

selected to provide adequate coverage for the pollutants of concern. Each pollutant, however, should be considered individually during the design phase to pinpoint pockets of high pollution that otherwise might be overlooked.

The final task in determining sampler placement is to find a specific location with the proper facilities for operating the sampler. Availability of space and power, accessibility, security, and representativeness of the site determine the precise location.

Sampling Frequency

The sampling frequencies for mechanical samplers and the averaging times for automatic samplers are dictated by the ambient air quality standards. If, for instance, standards are set in terms of days, hours, or minutes, then the sampling frequencies must be in the same averaging time.

Although standards for TSP and SO_2 are prescribed in terms of annual averages and maximum daily concentrations, it is impractical to operate the entire network on a daily basis. Adequate coverage may be maintained with intermittent sampling at frequencies calculated statistically for desired levels of precision. Suggested sampling frequencies are presented in Table 4, which relates frequency of sampling to the degree of pollution, ranging from every third day sampling in the highly polluted zones to once every sixth day in the nonurban zones. Twenty-four-hour sampling should be from midnight to midnight to represent calendar days and to permit direct utilization of the sampling data with standard daily meteorological summaries.

Sampling Site Characteristics

The preceding sections gave guidelines for the general distribution of sampling stations within a region. The selection of a particular site for a single sampler or a complex station is equally important. It is essential that the sampler be situated to yield data representative of the location without undue influence from the immediate surroundings. No definitive information is available concerning how air quality measurements are affected by the nearness of buildings, height from ground, and the like. There are, however, general guidelines that should be considered in site selection:

1. Uniformity in height above ground level is desirable for the entire network within the region. Some exceptions may include canyons, high-rise apartments, and sites for special-purpose samplers.
2. Constraints to airflow from any direction should be avoided by placing inlet probes at least 3 meters from

Table 4. FREQUENCY OF SAMPLING BY INSTRUMENT TYPE WITHIN AREA

	Type of instrument	Frequency of sampling						
		Areas above standard			Other urban areas			Nonurban areas
		Continuous	Every third day	Every sixth day	Continuous	Every third day	Every sixth day	Every sixth day
Particulates								
Total suspended particulate[a]	M[b]		M	M		M	M	M
Polycyclic organic matter	M		M	M		M	M	
Gases								
SO_2	M/A[c]	A		M		M	M	M
CO	A	A			A			
Non-methane HC	A	A			A			
NO_2	M/A	A	M	M	A		M	
NO_x ($NO + NO_2$)	M/A	A	M	M	A			
Oxidant (O_3)	M/A	A	M		A			

[a] Spot-tape samplers provide an indication of TSP on a less than 24-hour basis.

[b] M represents mechanical samplers

[c] A represents automatic samplers.

buildings or other obstructions. Inlet probes should be placed to avoid influence of convection currents.

3. The surrounding area should be free from stacks, chimneys, or other local emission points.

4. An elevation of 3 to 6 meters is suggested as the most suitable for representative sampling, especially in residential areas. Placement above 3 meters prevents most reintrainment of particulates, as well as the direct influence of automobile exhaust.

Methodology and Instrumentation

Information on types of instrumentation, its use, specificity, and associated costs is summarized in Table 5.

Development of instruments and techniques for sampling and analysis is progressing rapidly. Numerous instruments and techniques are now available for sampling and analysis. Standard methods are under development by the Air Pollution Control Office and the Intersociety Committee.* Until such standard methods are prescribed, the preferred methods of sampling and analyses are those for which a large body of data is available. Recommended reference methods are described in the Federal Register (April 30, 1971) with the National Ambient Air Quality Standards for SO_2, CO, NO_x, oxidant, hydrocarbons, and particulate matter. Acceptable methods for sampling and analysis are those that have been compared with standard or reference methods and have proved comparable in collection efficiency and in specificity. Whatever method is chosen, caution should be exercised to purchase instruments that have been thoroughly field tested.

Continuous production of valid data requires that instruments be properly maintained. This includes calibration prior to installation and on a routine basis thereafter. Most modern continuous instruments provide for automatic dynamic

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*Member societies are: Air Pollution Control Association (APCA), American Council of Governmental Industrial Hygienists (ACGIH), American Industrial Hygiene Association (AIHA), American Public Health Association (APHA), American Society of Mechanical Engineers (ASME), American Society for Testing and Materials (ASTM), and Association of Official Analytical Chemists (AOAC).

Table 5. CLASSIFICATION OF AIR POLLUTION SAMPLING TECHNIQUES

Type	Use	Specificity	Common averaging time	Relative cost[a]	Required training of personnel[b]	Remarks
Mechanical Hi-Vol	Integrated quantification	Total suspended particulate and multiple specific pollutants	24 hours	Moderate	Moderate	Detailed chemical analysis of Hi-Vol and gas samples require sophisticated laboratory trained chemists, and is costly
Gas sampler	Integrated quantification of gas	SO_2, NO_2	24 hours	Moderate	High	
Spot tape sampler	Relative soiling index	Unknown	2 hours	Low	Low	Provides only a rough, relative index of particulate soiling.
Automatic Gas	Continuous analysis of gaseous pollutants	Single gas or group of related gases	Continuous sample integration usually 1-15 months	Moderate to high	Moderate to high	Continuous measurements allow use of any desired averaging time by computation Accuracy is generally much better than other methods Calibration is simplified Data is available instantaneously
Particulate sorting (automatic tape)	Continuous analysis of soiling rate	Unknown	(Same as above)	Moderate	Moderate	

[a] Low refers to $0-$500, Moderate refers to $500-$2000, and High refers to above $2000

[b] Low requires common maintenance, Moderate requires a technician, and High requires an experienced technician or professional with professional support staff

calibration at least daily. Dynamic calibration either by permeation devices or gaseous mixtures is preferred. Static calibration is subject to stoichiometric factors and does not take into account collection efficiency of the continuous sampling instrument.

LABORATORY OPERATIONS

Support of the surveillance networks will require laboratory operations of varying levels of complexity. The requirements for laboratory support, in terms of size and complexity, will be dictated by the pollutants of interest in the region, size of the networks, and the degree of pollution. The laboratory should be equipped for analyses of samples for at least TSP, SO_2, NO_2, and oxidant and should provide for calibration of all collecting and measuring devices and preparation of reagents.

Some regions will require laboratory capability for analyses of trace elements, fluorides, and other pollutants. In large laboratories with requirements for a large number of analyses, automated laboratory procedures should be considered.

DATA ACQUISITION AND ANALYSIS

The design of a network must be accompanied by design of a system of data acquisition and analysis that considers the flow of data and their use.

To insure uniformity of data across the country and also to assist State and local agencies in data handling and analyses, the Environmental Protection Agency is expanding the National Aerometric Data Information Service (NADIS). This service encompasses the operation of a National Aerometric Data Bank, the systematic gathering of all aerometric data, and the provision for data dissemination in the form of summaries and special analyses. State and local agencies will routinely submit all air quality data collected to the National Aerometric Data Bank quarterly. All data should be expressed in the SAROAD format. A SAROAD Users Manual gives detailed instructions for coding data in the SAROAD format.

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METHOD FOR THE DETERMINATION OF SUSPENDED PARTICULATES IN THE ATMOSPHERE (HIGH VOLUME METHOD)

1. Principle and Applicability

1.1 Air is drawn into a covered housing and through a filter by means of a high-flow-rate blower at a flow rate (1.13 to 1.70 m^3/min.; 40 to 60 ft^3/min.) that allows suspended particles having diameters of less than 100 µm (Stokes equivalent diameter) to pass to the filter surface.[1] Particles within the size range of 100 to 0.1 µm diameter are ordinarily collected on glass fiber filters. The mass concentration of suspended particulates in the ambient air (µg/m^3) is computed by measuring the mass of collected particulates and the volume of air sampled.

1.2 This method is applicable to measurement of the mass concentration of suspended particulates in ambient air. This method does not control the flow of air during sampling and for this reason is most applicable to trend measurement. The size of the sample collected is usually adequate for other analyses.

2. Range and Sensitivity

2.1 When the sampler is operated at an average flow rate of 1.70 m^3/min. (60 ft^3/min.) for 24 hours, an adequate sample will be obtained even in an atmosphere having concentrations of suspended particulates as low as 1 µg/m^3. If particulate levels are unusually high, a satisfactory sample may be obtained in 6 to 8 hours or less. For determination of average concentrations of suspended particulates in ambient air, a standard sampling period of 24 hours is recommended.

2.2 Weights are determined to the nearest milligram, air flow rates are determined to the nearest 0.03 m^3/min. (1.0 ft^3/min.), times are determined to the nearest 2 min., and mass concentrations are reported to the nearest microgram per cubic meter.

3. Interferences

3.1 Particulate matter that is oily, such as photochemical smog or wood smoke, may block the filter and cause a rapid drop in air flow at a nonuniform rate. Dense fog or high humidity can cause the filter to become too wet and severely reduce the air flow through the filter.

3.2 Glass-fiber filters are comparatively insensitive to changes in relative humidity, but collected particulates can be hygroscopic.[2]

4. Precision, Accuracy, and Stability

4.1 At an average mass concentration of 128 µg/m^3 of particulate matter in ambient air, the standard deviation is 4 µg/m^3 (corresponding to a relative standard deviation of 3%); at an average of 77 µg/m^3, the standard deviation is 3 µg/m^3 (corresponding to a relative standard deviation of 4%).[3]

4.2 The accuracy with which the sampler measures the true average concentration depends upon the constancy of the air flow rate through the sampler. The air flow rate is affected by the concentration and the nature of the dust in the atmosphere. Under these conditions the error in the measured average concentration may be in excess of ± 50% of the true average concentration, depending on the amount of reduction of air flow rate and on the variation of the mass concentration of dust with time during the 24-hour sampling period.[4]

5. Apparatus

5.1 Sampling

5.1.1 Sampler - The sampler consists of three units: (1) the face plate and gasket, (2) the filter adapter assembly, and (3) the motor unit. Figure 1 shows an exploded view of these parts, their relationship to each other, and how they are assembled. The sampler must be capable of passing environmental air through a 406 ± cm2 (63 in.^{2}) portion of a clean 20.3 by 25.4 cm (8- by 10-in.) glass-fiber filter at a rate of at least 1.70 m^3/min. (60 ft^3/min.). The motor must be capable of continuous operation for 24-hour periods with input voltages ranging from 110 to 120 volts, 50-60 cycles alternating current and must have third-wire safety ground. The housing for the motor unit may be of any convenient construction so long as the unit remains air-tight and leak-free. The life of the sampler motor can be extended by lowering the voltage by about 10% with a small "buck or boost" transformer between the sampler and power outlet.

5.1.2 Sampler Shelter - It is important that the sampler be properly installed in a suitable shelter. The shelter is subjected to extremes of temperature, humidity, and all types of air pollutants. For these reasons the materials of the shelter must be chosen carefully. Properly painted exterior plywood or heavy gauge aluminum serve well. The sampler must be mounted vertically in the shelter so that the glass-fiber filter is parallel with the ground. The shelter must be provided with a roof so that the filter is protected from precipitation and debris. The internal arrangement and configuration of a suitable shelter with a gable roof are shown in Figure 2. The clearance area between the main housing and the roof at its closest point should be 580.5 ± 193.5 cm^2 (90 ± 30 in.^{2}). The main housing should be rectangular, with dimensions of about 29 by 36 cm (11-1/2 by 14 in.).

5.1.3 Rotameter - Marked in arbitrary units, frequently 0 to 70, and capable of being calibrated. Other devices of at least comparable accuracy may be used.

5.1.4 Orifice Calibration Unit - Consisting of a metal tube 7.6 cm (3 in.) ID and 15.9 cm (6-1/4 in.) long with a static pressure tap 5.1 cm (2 in.) from one end. See Figure 3. The tube end nearest the pressure tap is flanged to about 10.8 cm (4-1/4 in.) OD with a male thread of the same size as the inlet end of the high-volume air sampler. A single metal plate 9.2 cm (3-5/8 in.) in diameter and 0.24 cm (3/32 in.) thick with a central orifice 2.9 cm (1-1/8 in.) in diameter is held in place at the air inlet end with a female threaded ring. The other end of the tube is flanged to hold a loose female threaded coupling, which screws onto the inlet of the sampler. An 18-hole metal plate, an integral part of the unit, is positioned between the orifice and sampler to simulate the resistance of a clean glass-fiber filter.

5.1.5 Differential Manometer - Capable of measuring to at least 40 cm (16 in.) of water.

5.1.6 Positive Displacement Meter - Calibrated in cubic meters or cubic feet, to be used as a primary standard.

5.1.7 Barometer - Capable of measuring atmospheric pressure to the nearest mm.

5.2 Analysis

5.2.1 Filter Conditioning Environment - Balance room or desiccator maintained at 15 to 35°C and less than 50% relative humidity.

5.2.2 Analytical Balance - Equipped with a weighing chamber designed to handle unfolded 20.3 by 25.4 cm (8- by 10-in.) filters and having a sensitivity of 0.1 mg.

5.2.3 Light Source - Frequently a table of the type used to view X-ray films.

5.2.4 Numbering Device - Capable of printing identification numbers on the filters.

6. Reagents

6.1 Filter Media - Glass-fiber filters having a collection efficiency of at least 99% for particles of 0.3 μm diameter, as measured by the DOP test, are suitable for the quantitative measurement of concentrations of suspended particulates,[5] although some other medium, such as paper, may be desirable for some analyses. If a more detailed analysis is contemplated, care must be exercised to use filters that contain low background concentrations of the pollutant being investigated. Careful quality control is required to determine background values of these pollutants.

7. Procedure

7.1 Sampling

7.1.1 Filter Preparation - Expose each filter to the light source and inspect for pinholes, particles, or other imperfections. Filters with visible imperfections should not be used. A small brush is useful for removing particles. Equilibrate the filters in the filter conditioning environment for 24 hours. Weigh the filters to the nearest milligram; record tare weight and filter identification number. Do not bend or fold the filter before collection of the sample.

7.1.2 Sample Collection - Open the shelter, loosen the wing nuts, and remove the face plate from the filter holder. Install a numbered, pre-weighed, glass-fiber filter in position (rough side up), replace the face plate without disturbing the filter, and fasten securely. Undertightening will allow air leakage, over-tightening will damage the sponge-rubber face-plate gasket. A very light application of talcum powder may be used on the sponge-rubber face-plate gasket to prevent the filter from sticking. During inclement weather the sampler may be removed to a protected area for filter change. Close the roof of the shelter, run the sampler for about 5 min., connect the rotameter to the nipple on the back of the sampler, and read the rotameter ball with rotameter in a vertical position. Estimate to the nearest whole number. If the ball is fluctuating rapidly, tip the rotameter and slowly straighten it until the ball gives a constant reading. Disconnect the

rotameter from the nipple; record the initial rotameter reading and the starting time and date on the filter folder. (The rotameter should never be connected to the sampler except when the flow is being measured.) Let the sampler run for the desired time (usually 24 hours) and take a final rotameter reading. Record the final rotameter reading and ending time and date on the filter folder. Remove the face-plate as described above and carefully remove the filter from the holder, touching only the outer edges. Fold the filter lengthwise so that only surfaces with collected particulates are in contact, and place in a manila folder. Record on the folder the filter number, location, and any other factors, such as meteorological conditions or razing of nearby buildings, that might affect the results. If the sample is defective, void it at this time. In order to obtain a valid sample, the high-volume sampler must be operated with the same rotameter and tubing that were used during its calibration.

7.2 Analysis - Equilibrate the exposed filters for 24 hours in the filter conditioning environment, then re-weigh. After they are weighed, the filters may be saved for detailed chemical analysis.

7.3 Maintenance

7.3.1 Sampler Motor - Replace brushes before they are worn to the point where motor damage can occur.

7.3.2 Face-Plate Gasket - Replace when the margins of samples are no longer sharp. The gasket may be sealed to the face-plate with rubber cement or double-sided adhesive tape.

7.3.3 Rotameter - Clean as required, using alcohol.

8. Calibration

8.1 Purpose - Since only a small portion of the total air sampled passes through the rotameter during measurement, the rotameter must be calibrated against actual air flow with the orifice calibration unit. Before the orifice calibration unit can be used to calibrate the rotameter, the orifice calibration unit itself must be calibrated against the positive displacement primary standard.

8.1.1 Orifice Calibration Unit - Attach the orifice calibration unit to the intake end of the positive displacement primary standard and attach a high-volume motor blower unit to the exhaust end of the primary standard. Connect one end of a differential manometer to the differential pressure tap of the orifice calibration unit and leave the other end open to the atmosphere. Operate the high-volume motor blower unit so that a series of different, but constant, air flows (usually six) are obtained for definite time periods. Record the reading on the differential manometer at each air flow. The different constant air flows are obtained by placing a series of load plates, one at a time, between the calibration unit and the primary standard. Placing the orifice before the inlet reduces the pressure at the inlet of the primary standard below atmospheric; therefore, a correction must be made for the increase in volume caused by this decreased inlet pressure. Attach one end of a second differential manometer to an inlet pressure tap of the primary standard and leave the other open to the atmosphere. During each of the constant air flow measurements made above, measure the true inlet pressure of the primary standard with this second differential manometer. Measure atmospheric pressure and temperature. Correct the measured air volume to true air volume as directed in 9.1.1, then obtain true air flow rate, Q, as directed in 9.1.3. Plot the differential manometer readings of the orifice unit versus Q.

8.1.2 High-Volume Sampler - Assemble a high-volume sampler with a clean filter in place and run for at least 5 min. Attach a rotameter, read the ball, adjust so that the ball reads 65, and seal the adjusting mechanism so that it cannot be changed easily. Shut off motor, remove the filter, and attach the orifice calibration unit in its place. Operate the high-volume sampler at a series of different, but constant, air flows (usually six). Record the reading of the differential manometer on the orifice calibration unit, and record the readings of the rotameter at each flow. Measure atmospheric pressure and temperature. Convert the differential manometer reading to m^3/min., Q, then plot rotameter reading versus Q.

8.1.3 Correction for Differences in Pressure or Temperature - See Appendix B.

9. Calculations

9.1 Calibration of Orifice

9.1.1 True Air Volume - Calculate the air volume measured by the positive displacement primary standard.

$$V_a = \frac{(P_a - P_m)}{P_a} (V_M)$$

V_a = True air volume at atmospheric pressure, m^3

P_a = barometric pressure, mm Hg

P_m = pressure drop at inlet of primary standard, mm Hg

V_M = volume measured by primary standard, m^3

9.1.2 Conversion Factors

inches Hg x 25.4 = mm Hg

inches water x 73.48 x 10^{-3} = inches Hg

cubic feet air x 0.0284 = cubic meters air

9.1.3 True Air Flw Rate

$$Q = \frac{V_a}{T}$$

Q = flow rate, m^3/min.

T = time of flow, min.

9.2 Sample Volume

9.2.1 Volume Conversion - Convert the initial and final rotameter readings to true air flow rate, Q, using calibration curve of 8.1.2.

9.2.2 Calculate volume of air sampled

$$V = \frac{Q_i + Q_f}{2} \times T$$

V = air volume sampled, m^3

Q_i = initial air flow rate, $m^3/min.$

Q_f = final air flow rate, $m^3/min.$

T = sampling time, min.

9.3 Calculate mass concentration of suspended particulates

$$S.P. = \frac{(W_f - W_i) \times 10^6}{V}$$

S.P. = mass concentration of suspended particulates, $\mu g/m^3$

W_i = initial weight of filter, g

W_f = final weight of filter, g

V = air volume sampled, m^3

10^6 = conversion of g to μg

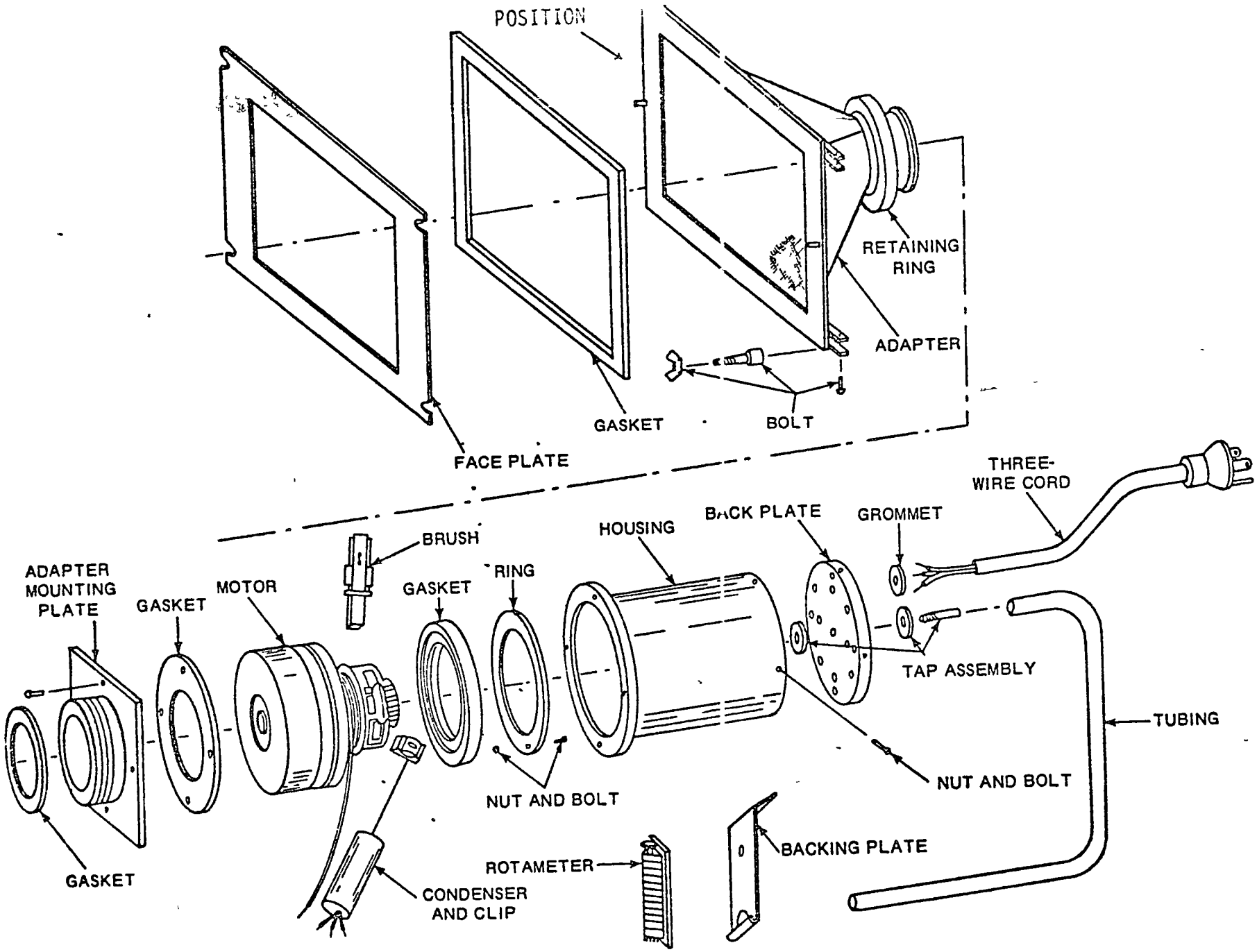

Figure 1. Exploded view of typical high-volume air sampler parts.

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4 Harrison, W. K., Nader, J. S., and Fugman, F. S., "Constant Flow Regulators for High-Volume Air Sampler", Am. Ind. Hyg. Assoc. J. 21, 114-120 (1960).

5. Pate, J. B., and Tabor, E. C., "Analytical Aspects of the Use of Glass-Fiber Filters for the Collection and Analysis of Atmospheric Particulate Matter", Am. Ind. Hyg. Assoc. J. 23, 144-150 (1962).

APPENDICES

A. Alternative Equipment.

A modification of the high-volume sampler incorporating a method for recording the actual air flow over the entire sampling period has been described, and is acceptable for measuring the concentration of suspended particulates (Henderson, J. S., Eighth Conference on Methods in Air Pollution and Industrial Hygiene Studies, 1967, Oakland, California). This modification consists of an exhaust orifice meter assembly connected through a transducer to a system for continuously recording air flow on a circular chart. The volume of air sampled is calculated by the following equation:

$$V = Q \times T$$

Q = average sampling rate, $m^3/min.$

T = sampling time, min.

The average sampling rate, Q, is determined from the recorder chart by estimation if the flow rate does not vary more than 0.11 $m^3/min.$ (4 $ft^3/min.$) during the sampling period. If the flow rate does vary more than 0.11 m^3 (4 $ft^3/min.$) during the sampling period, read the flow rate from the chart at 2-hour intervals and take the average.

B. Pressure and Temperature Corrections.

If the pressure or temperature during high-volume sampler calibration is substantially different from the pressure or temperature during orifice calibration, a correction of the flow rate, Q, may be required. If the pressures differ by no more than 15% and the temperatures differ by no more than 100% (°C), the error in the uncorrected flow rate will be no more than 15%. If necessary, obtain the corrected flow rate as directed below. This correction applies only to orifice meters having a constant orifice coefficient. The coefficient for the calibrating orifice described in 5.1.4 has been shown experimentally to be constant over the normal operating range of the high-volume sampler (0.6 to 2.2 $m^3/min.$; 20 to 78 $ft^3/min.$). Calculate corrected flow rate:

$$Q_2 = Q_1 \left[\frac{T_2 \, P_1}{T_1 \, P_2} \right]^{1/2}$$

Q_2 = corrected flow rate, $m^3/min.$

Q_1 = flow rate during high-volume sampler calibration (Section 8.1.2) $m^3/min.$

T_1 = absolute temperature during orifice unit calibration (Section 8.1.1), °K or °R

P_1 = barometric pressure during orifice unit calibration (Section 8.1.1), mm Hg

T_2 = absolute temperature during high-volume sampler calibration (Section 8.1.2), °K or °R

P_2 = barometric pressure during high-volume sampler calibration (Section 8.1.2), mm Hg

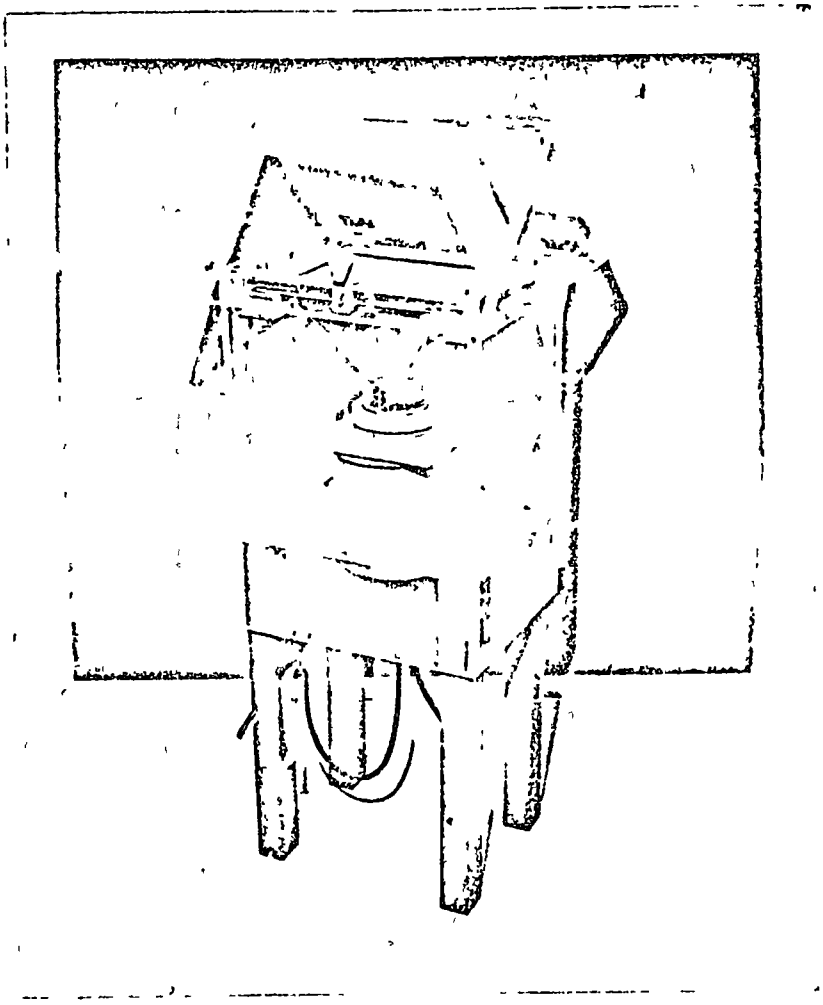

Figure 2. Assembled sampler and shelter (clear plastic is for display purposes and is not recommended for shelter construction).

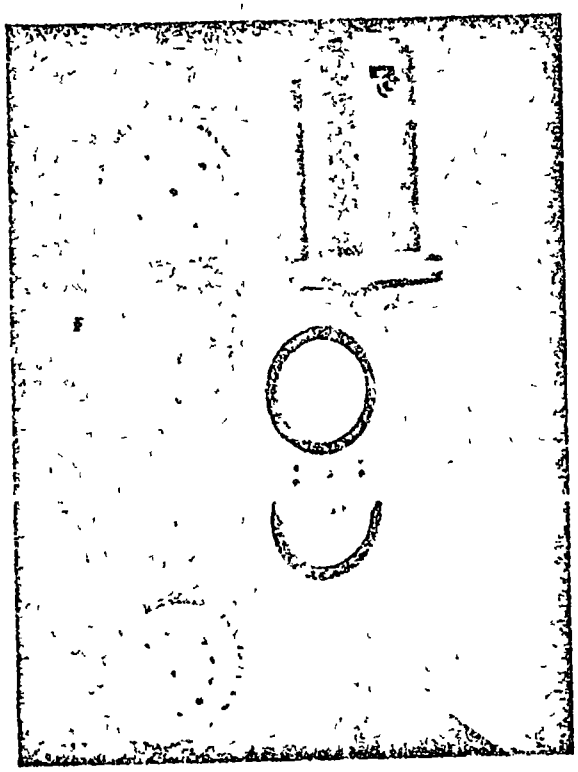

Figure 3. Orifice calibration unit.

METHOD FOR THE DETERMINATION OF SULFUR DIOXIDE IN THE ATMOSPHERE (PARAROSANILINE METHOD)

1. PRINCIPLE AND APPLICABILITY

1.1 Sulfur dioxide is absorbed from air in a solution of potassium tetrachloromercurate (TCM). A dichlorosulfitomercurate complex, which resists oxidation by the oxygen in the air, is formed.[1,2] Once formed, this complex is stable to strong oxidants (e.g., ozone, oxides of nitrogen). The complex is reacted with pararosaniline and formaldehyde to form intensely colored pararosaniline methyl sulfonic acid.[3] The absorbance of the solution is measured spectrophotometrically.

1.2 The method is applicable to the measurement of sulfur dioxide in ambient air using sampling periods up to 24 hours.

2. RANGE AND SENSITIVITY

2.1 Concentrations of sulfur dioxide in the range of 25 to 1048 $\mu g/m^3$ (0.01 to 0.40 ppm) can be measured under the conditions given. One can extrapolate to concentrations below 25 $\mu g/m^3$ by sampling larger volumes of air, but only if the absorption efficiency of the particular system is first determined. Higher concentrations can be analyzed by using smaller gas samples, a larger collection volume, or a suitable aliquot of the collected sample. Beer's Law is followed through the working range from 0.03 to 1.0 absorbance units (0.8 to 27 µg of sulfite ion in 25 ml final solution computed as SO_2).

2.2 The lower limit of detection of sulfur dioxide in 10 ml TCM is 0.75 µg (based on twice the standard deviation) representing a concentration of 25 $\mu g/m^3$ SO_2 (0.01 ppm) in an air sample of 30 liters.

3. INTERFERENCES

3.1 The effects of the principal known interferences have been minimized or eliminated. Interferences by oxides of nitrogen are eliminated by sulfamic acid,[4,5] ozone by time-delay,[6] and heavy metals by EDTA (ethylenediaminetetraacetic acid, disodium salt) and phosphoric acid.[4,6] At least 60 µg Fe(III), 10 µg Mn(II), and 10 µg Cr(III) in 10 ml absorbing reagent can be tolerated in the procedure. No significant interference was found with 10 µg Cu(II) and 22 µg V(V).

4. PRECISION, ACCURACY, AND STABILITY

4.1 Relative standard deviation at the 95% confidence level is 4.6% for the analytical procedure using standard samples.[5]

4.2 After sample collection the solutions are relatively stable. At 22°C losses of sulfur dioxide occur at the rate of 1% per day. When samples are stored at 5°C for 30 days, no detectable losses of sulfur dioxide occur. The presence of EDTA enhances the stability of SO_2 in solution, and the rate of decay is independent of the concentration of SO_2.[7]

5. APPARATUS

5.1 Sampling

5.1.1 Absorber - Absorbers normally used in air pollution sampling are acceptable for concentrations above 25 $\mu g/m^3$ (0.01 ppm). An all-glass midget impinger, as shown in Figure 1, is recommended for 30-min. samples.

For 24-hour sampling, assemble a larger impinger from the following parts:

Polypropylene 2-port tube closures, special manufacture (available from Bel-Art Products, Pequannock, New Jersey).

Glass impingers, 6 mm tubing, 6 inches long, one end drawn to small diameter such that No. 79 jewelers drill will pass through, but No. 78 jewelers drill will not. (Other end fire polished.)

Polypropylene tubes, 164 by 32 mm (Nalgene or equal).

5.1.2 Pump - Capable of maintaining an air pressure differential greater than 0.7 atmosphere at the desired flow rate.

5.1.3 Air Flowmeter or Critical Orifice - A calibrated rotameter or critical orifice capable of measuring air flow within ± 2%. For 30 minute sampling, a 22-gauge hypodermic needle 1 inch long may be used as a critical orifice to give a flow of about 1 liter/minute. For 24 hour sampling, a 27 gauge hypodermic needle 3/8 inch long may be used to give a flow of about 0.2 liter/minute. Use a membrane filter to protect the needle.

5.2 Analysis

5.2.1 Spectrophotometer - Suitable for measurement of absorbance at 548 nm with an effective spectral band width of less than 15 nm. Reagent blank problems may occur with spectrophotometers having greater spectral band width. The wavelength calibration of the instrument should be verified. If transmittance is measured, this can be converted to absorbance:

$$A = \log_{10} (1/T)$$

6. REAGENTS

6.1 Sampling

6.1.1 Distilled water - Must be free from oxidants.

6.1.2 Absorbing Reagent [0.04 M Potassium Tetrachloromercurate (TCM)] - Dissolve 10.86 g mercuric chloride, 0.066 g EDTA (Ethylenediaminetetraacetic acid, disodium salt), and 6.0 g potassium chloride in water and bring to mark in a 1000-ml volumetric flask. (Caution: highly poisonous. If spilled on skin, flush off with water immediately). The pH of this reagent should be approximately 4.0, but it has been shown that there is no appreciable difference in collection efficiency over the range of pH 5 to pH 3.7 The absorbing reagent is normally stable for 6 months. If a precipitate forms, discard the reagent.

6.2 Analysis

6.2.1 Sulfamic Acid (0.6%) - Dissolve 0.6 g sulfamic acid in 100 ml distilled

6.2.2 Formaldehyde (0.2%) - Dilute 5 ml formaldehyde solution (36-38%) to 1000 ml with distilled water. Prepare daily.

6.2.3 Stock Iodine Solution (0.1 N) - Place 12.7 g iodine in a 250-ml beaker; add 40 g potassium iodide and 25 ml water. Stir until all is dissolved, then dilute to 1000 ml with distilled water.

6.2.4 Iodine Solution (0.01 N) - Prepare approximately 0.01 N iodine solution by diluting 50 ml of stock solution to 500 ml with distilled water.

6.2.5 Starch Indicator Solution - Triturate 0.4 g soluble starch and 0.002 g mercuric iodide (preservative) with a little water, and add the paste slowly to 200 ml boiling water. Continue boiling until the solution is clear; cool, and transfer to a glass-stoppered bottle.

6.2.6 Stock Sodium Thiosulfate Solution (0.1 N) - Prepare a stock solution by dissolving 25 g sodium thiosulfate ($Na_2S_2O_3 \cdot 5H_2O$) in 1000 ml freshly boiled, cooled, distilled water and add 0.1 g sodium carbonate to the solution. Allow the solution to stand 1 day before standardizing. To standardize, accurately weigh, to the nearest 0.1 mg, 1.5 g primary standard potassium iodate dried at 180°C and dilute to volume in a 500-ml volumetric flask. To a 500-ml iodine flask, pipet 50 ml of iodate solution. Add 2 g potassium iodide and 10 ml of 1 N hydrochloric acid. Stopper the flask. After 5 minutes, titrate with stock thiosulfate solution to a pale yellow. Add 5 ml starch indicator solution and complete the titration. Calculate the normality of the stock solution:

$$N = \frac{W}{M} \times 2.80$$

N = normality of stock thiosulfate solution
M = volume of thiosulfate required, ml
W = weight of potassium iodate, grams

$$2.80 = \frac{10^3 \text{ (conversion of g to mg)} \times 0.1 \text{ (fraction iodate used)}}{35.67 \text{ (equivalent weight of potassium iodate)}}$$

6.2.7 Sodium Thiosulfate Titrant (0.01 N) - Dilute 100 ml of the stock thiosulfate solution to 1000 ml with freshly boiled distilled water.

Normality = Normality of Stock Solution X 0.100.

6.2.8 Standardized Sulfite Solution For Preparation of Working Sulfite-TCM Solution - Dissolve 0.30 g sodium metabisulfite ($Na_2S_2O_5$) or 0.40 g sodium sulfite (Na_2SO_3) in 500 ml of recently boiled, cooled, distilled water. (Sulfite solution is unstable; it is therefore important to use water of the highest purity to minimize this instability). This solution contains the equivalent of 320 to 400 µg/ml of SO_2. The actual concentration of the solution is determined by adding excess iodine and back-titrating with standard sodium thiosulfate solution. To back-titrate, pipet 50 ml of the 0.01 N iodine into each of two 500-ml iodine flasks (A and B). To flask A (blank) add 25 ml distilled water, and to flask B (sample) pipet 25 ml sulfite solution. Stopper the flasks and allow to react for 5 min. Prepare the working sulfite-TCM Solution (6.2.9) at the same time iodine solution is added to the flasks. By means of a buret containing standardized 0.01 N thiosulfate, titrate each flask in turn to a pale yellow. Then add 5 ml starch solution and continue the titration until the blue color disappears.

6.2.9 Working Sulfite-TCM Solution - Pipet accurately 2 ml of the standard solution into a 100 ml volumetric flask and bring to mark with 0.04 M TCM. Calculate the concentration of sulfur dioxide in the working solution:

$$\mu g\ SO_2/ml = \frac{(A - B)\ (N)\ (32{,}000)}{25} \times 0.02$$

A = volume thiosulfate for blank, ml
B = volume thiosulfate for sample, ml
N = normality of thiosulfate titrant
32,000 = milliequivalent wt., µg
25 = volume standard sulfite solution, ml
0.02 = dilution factor

This solution is stable for 30 days if kept at 5°C (refrigerator). If not kept at 5°C, prepare daily.

6.2.10 Purified Pararosaniline Stock Solution (0.2% nominal)

6.2.10.1 Dye Specifications - The pararosaniline dye must meet the following performance specifications: (1) the dye must have a wavelength of maximum absorbance at 540 nm when assayed in a buffered solution of 0.1 M sodium acetate-acetic acid; (2) the absorbance of the reagent blank, which is temperature-sensitive (0.015 absorbance unit/°C), should not exceed 0.170 absorbance unit at 22°C with a 1-cm optical path length, when the blank is prepared according to the prescribed analytical procedure and to the specified concentration of the dye; (3) the calibration curve (Section 8.2.1) should have a slope of 0.030 ± 0.002 absorbance units/µg SO_2 at this path length when the dye is pure and the sulfite solution is properly standardized.

6.2.10.2 Preparation of Stock Solution - A specially purified (99-100% pure) solution of pararosaniline, which meets the above specifications, is commercially available in the required 0.20% concentration (Harleco*). If this cannot be obtained, the stock solution may be prepared by dissolving 0.200 g of the purified dye in 100 ml of 1 N hydrochloric acid in a 100 ml glass stoppered graduated cylinder. (See Scaringelli, et. al.[4] for the purification and assay procedures).

6.2.11 Pararosaniline Reagent - To a 250-ml volumetric flask, add 20 ml stock pararosaniline solution. Add an additional 0.2 ml stock solution for each per cent the stock assays below 100%. Then add 25 ml 3 M phosphoric acid and dilute to volume with distilled water. This reagent is stable for at least 9 months.

7. PROCEDURE

7.1 Sampling - Procedures are described for short term (30 min.) and for long term (24 hours) sampling. One can select different combinations of sampling rate and time to meet special needs. Sample volumes should be adjusted, so that linearity is maintained between absorbance and concentration over the dynamic range.

7.1.1 30-Minute Sampling - Insert a midget impinger into the sampling system, Figure 1. Add 10 ml TCM solution to the impinger. Collect sample at 1 liter/min. for 30 minutes using either a rotameter, as shown in Figure 1, or a critical orifice, as shown in Figure 1a, to control flow. Shield the absorbing reagent

*Hartmen-Leddon, 60th & Woodland Ave., Philadelphia, Pennsylvania 19143

from direct sunlight during and after sampling by covering the impinger with aluminum foil, to prevent deterioration. Determine the volume of air sampled by multiplying the flow rate by the time in minutes and record the atmospheric pressure and temperature. Remove and stopper the impinger. If the sample must be stored for more than a day before analysis, keep it at 5°C in a refrigerator (see 4.2).

7.1.2 24-Hour Sampling - Place 15-20 ml TCM solution in a midget impinger or 50 ml in a larger impinger and collect the sample at 0.2 liter/min. for 24 hours. Make sure no entrainment of solution results with the impinger. During collection and storage protect from direct sunlight. Record the total volume of sample by multiplying the flow rate by the time in minutes. The correction of 24 hour measurements for temperature and pressure is extremely difficult and is not ordinarily done. However, the accuracy of the measurement will be improved if meaningful corrections can be applied. If storage is necessary, refrigerate at 5°C (see 4.2).

7.2 Analysis

7.2.1 Sample Preparation - After collection, if a precipitate is observed in the sample, remove it by centrifugation.

7.2.1.1 30-Minute Sample - Transfer the sample quantitatively to a 25-ml volumetric flask; use about 5 ml distilled water for rinsing. Delay analyses for 20 min. to allow any ozone to decompose.

7.2.1.2 24-Hour Sample - Dilute the entire sample to 25 ml for the midget impinger or 50 ml for the larger impinger, with absorbing solution. Pipet one-tenth of the sample into a 25-ml volumetric flask for chemical analyses. Bring volume to 10 ml with absorbing reagent. Delay analyses for 20 min. to allow any ozone to decompose.

7.2.2 Determination - For each set of determinations prepare a reagent blank by adding 10 ml unexposed TCM solution to a 25-ml volumetric flask. Prepare a control solution by adding 2 ml of working sulfite-TCM solution and 8 ml TCM solution to a 25-ml volumetric flask. To each flask containing either sample, control solution, or reagent blank, add 1 ml 0.6% sulfamic acid and allow to react 10 min. to destroy the nitrite from oxides of nitrogen. Accurately pipet in 2 ml 0.2% formaldehyde solution, then 5 ml pararosaniline solution. Start a laboratory timer that has been set for 30 minutes. Bring all flasks to volume with freshly boiled and cooled distilled water and mix thoroughly. After 30 min. and before 60 min., determine the absorbances of the sample (denote as A), reagent blank (denote as A_o) and the control solution at 548 nm using 1-cm optical path length cells. Use distilled water, not the reagent blank, as the reference. (NOTE! This is important because of the color sensitivity of the reagent blank to temperature changes which can be induced in the cell compartment of a spectrophotometer.) Do not allow the colored solution to stand in the absorbance cells, because a film of dye may be deposited. Clean cells with alcohol after use. If the temperature of the determinations does not differ by more than 2°C from the calibration temperature (8.2), the reagent blank should be within 0.03 absorbance unit of the y-intercept of the calibration curve (8.2). If the reagent blank differs by more than 0.03 absorbance unit from that found in the calibration curve, prepare a new curve.

7.2.3 Absorbance Range - If the absorbance of the sample solution ranges between 1.0 and 2.0, the sample can be diluted 1:1 with a portion of the reagent blank and read within a few minutes. Solutions with higher absorbance can be diluted up to six-fold with the reagent blank in order to obtain on-scale readings within 10% of the true absorbance value.

8. CALIBRATION AND EFFICIENCIES

8.1 Flowmeters and Hypodermic Needle - Calibrate flowmeters and hypodermic needle[8] against a calibrated wet test meter.

8.2 Calibration Curves

8.2.1 Procedure with Sulfite Solution - Accurately pipet graduated amounts of the working sulfite-TCM solution (such as 0, 0.5, 1, 2, 3, and 4 ml) into a series of 25-ml volumetric flasks. Add sufficient TCM solution to each flask to bring the volume to approximately 10 ml. Then add the remaining reagents as described in 7.2.2. For maximum precision use a constant-temperature bath. The temperature of calibration must be maintained within ± 1°C and in the range of 20 to 30°C. The temperature of calibration and the temperature of analysis must be within 2 degrees. Plot the absorbance against the total concentration in µg SO_2 for the corresponding solution. The total µg SO_2 in solution equals the concentration of the standard (Section 6.2.9) in µg SO_2/ml times the ml sulfite solution added (µg SO_2 = µg/ml SO_2 x ml added). A linear relationship should be obtained, and the y-intercept should be within 0.02 absorbance unit of the zero standard absorbance. For maximum precision determine the line of best fit using regression analysis by the method of least squares. Determine the slope of the line of best fit, calculate its reciprocal and denote as B_s. B_s is the calibration factor. (See Section 6.2.10.1 for specifications on the slope of the calibration curve). This calibration factor can be used for calculating results provided there are no radical changes in temperature or pH. At least one control sample containing a known concentration of SO_2 for each series of determinations, is recommended to insure the reliability of this factor.

8.2.2 Procedure with SO_2 Gas - See Appendix

8.3 Sampling Efficiency - Collection efficiency is above 98%; efficiency may fall off, however, at concentrations below 25 µg/m^3.[9,10]

9. CALCULATIONS

9.1 Conversion of Volume - Convert the volume of air sampled to the volume at reference conditions of 25°C and 760 mm Hg. (On 24 hour samples, this may not be possible.)

$$V_s = V \times \frac{P}{760} \times \frac{298}{t + 273}$$

V_s = volume of air at 25°C and 760 mm Hg, liters
V = volume of air sampled, liters
P = barometric pressure, mm Hg
t = temperature of air sample, °C

9.2 Sulfur Dioxide Concentration

9.2.1 When sulfite solutions are used to prepare calibration curves, compute the concentration of sulfur dioxide in the sample by the following formula:

$$SO_2,\ \mu g/m^3 = \frac{(A - A_o)\ (10^3)\ (B_s)}{V_s}$$

A = sample absorbance,
A_o = reagent blank absorbance,
10^3 = conversion of liters to cubic meters
V_s = the sample volume corrected to 25°C and 760 mm Hg, liters

$$B_s = \frac{1}{\text{Slope of calibration curve, absorbance units/}\mu g}$$ = calibration factor, µg/absorbance unit

9.2.2 When SO_2 gas standard atmospheres are used to prepare calibration curves, compute the sulfur dioxide in the sample by the following formula:

$$SO_2, \mu g/m^3 = (A - A_o) \times B_g$$

A = sample absorbance
A_o = reagent blank absorbance
B_g = (See Appendix)

9.2.3 Conversion of $\mu g/m^3$ to ppm - If desired, the concentration of sulfur dioxide may be calculated as ppm SO_2 at reference conditions as follows:

$$\text{ppm } SO_2 = \mu g\ SO_2/m^3 \times 3.82 \times 10^{-4}$$

10. REFERENCES

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APPENDIX

Calibration Procedure Using SO_2 Gas

1. General Considerations. Atmospheres containing accurately known amounts of sulfur dioxide at levels of interest can be prepared using permeation tubes. In the systems for generating these atmospheres, the permeation tube emits SO_2 gas at a known, low, constant rate, provided the temperature of the tube is held constant (± 0.1°C) and provided the tube has been accurately calibrated at the temperature of use. The SO_2 gas permeating from the tube is carried by a low flow of inert gas to a mixing chamber where it is accurately diluted with SO_2-free air to the level of interest and the sample taken. These systems are shown schematically in Figures 2 and 3 and have been described in detail by O'Keeffe and Ortman,[1] Scaringelli, Frey, and Saltzman,[2] and Scaringelli, O'Keeffe, Rosenberg, and Bell.[3]

2. Preparation of Standard Atmospheres. Permeation tubes may be prepared or purchased. Scaringelli, O'Keeffe, Rosenberg, and Bell[3] give detailed, explicit directions for permeation tube calibration. Tubes with a certified permeation rate are available from the National Bureau of Standards. Tube permeation rates from 0.2 to 0.4 µg/min, inert gas flows of about 50 ml/min, and dilution air flow rates from 1.1 to 15 l/min conveniently give standard atmospheres containing desired levels of SO_2 (27 to 380 µg/m^3; 0.01 to 0.15 ppm SO_2). The concentration of SO_2 in any standard atmosphere can be calculated as follows:

$$C = \frac{P \times 10^3}{R_d + R_i}$$

where: C = concentration of SO_2, µg/m^3 at reference conditions
P = tube permeation rate, µg/min
R_d = flow rate of dilution air, l/min at reference conditions
R_i = flow rate of inert gas, l/min at reference conditions

3. Sampling and Preparation of Calibration Curve. Prepare a series (usually six) of standard atmospheres containing SO_2 levels from 27 to 380 µg SO_2/m^3. Sample each atmosphere using similar apparatus and taking exactly the same air volume as will be done in atmospheric sampling. Determine absorbances as directed in 7.2. Plot the concentration of SO_2 in µg/m^3 (x-axis) against $A - A_o$ values (y-axis), draw the straight line of best fit and determine the slope. Alternatively, regression analysis by the method of least squares may be used to calculate the slope. Calculate the reciprocal of the slope and denote as B_g.

References for Appendix

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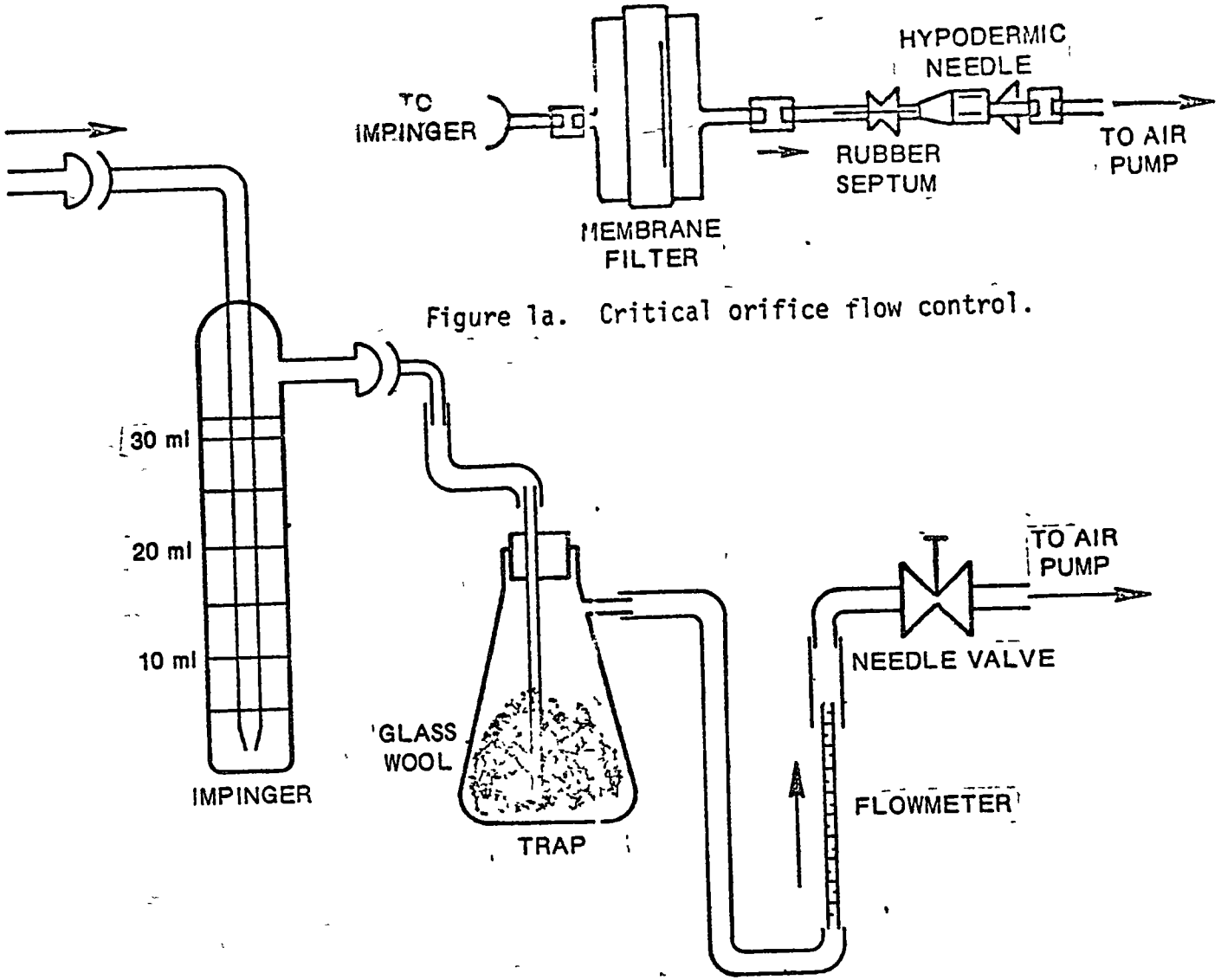


Figure 1a. Critical orifice flow control.

Figure 1. Sampling train.

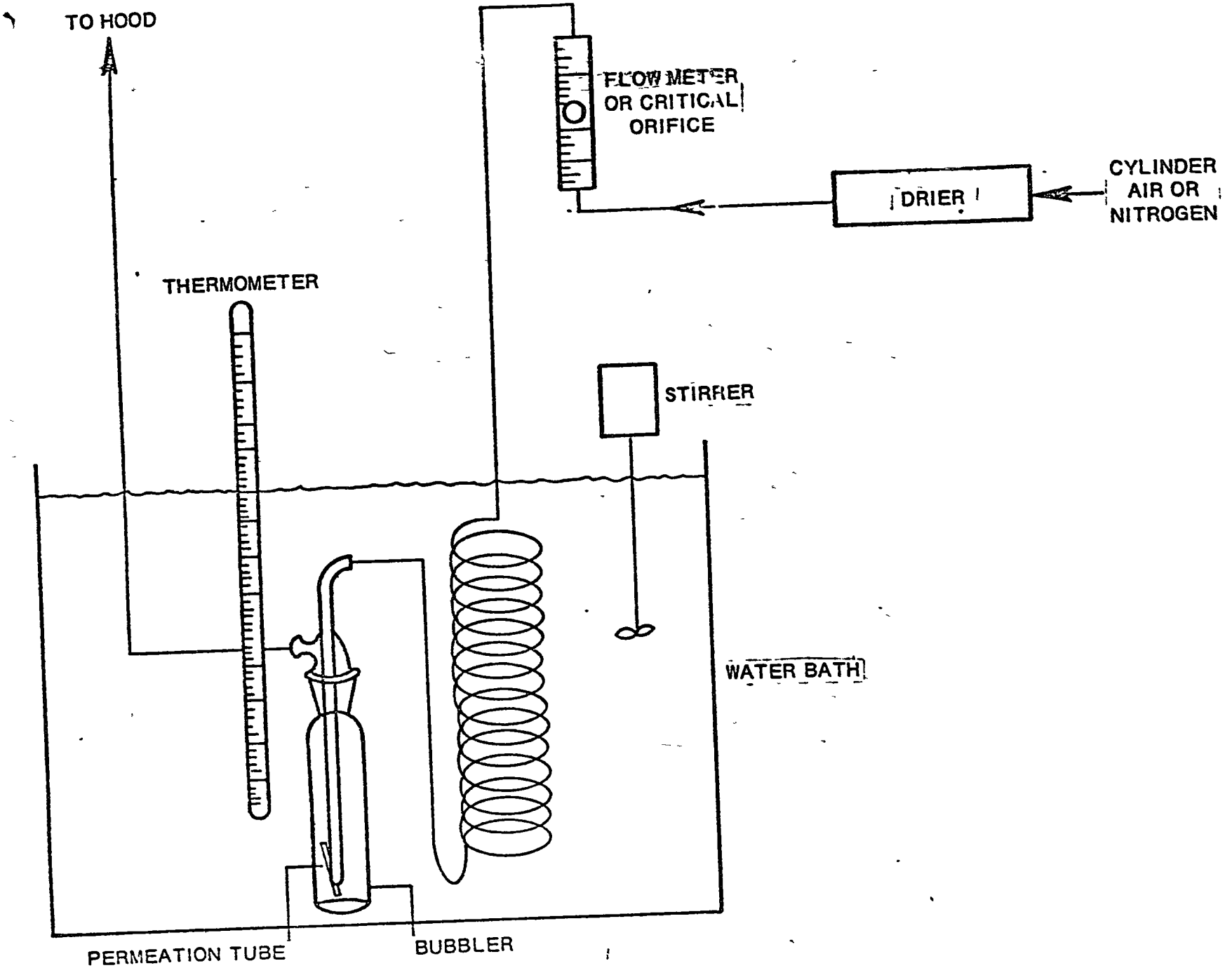


Figure 2. Apparatus for gravimetric calibration and field use.

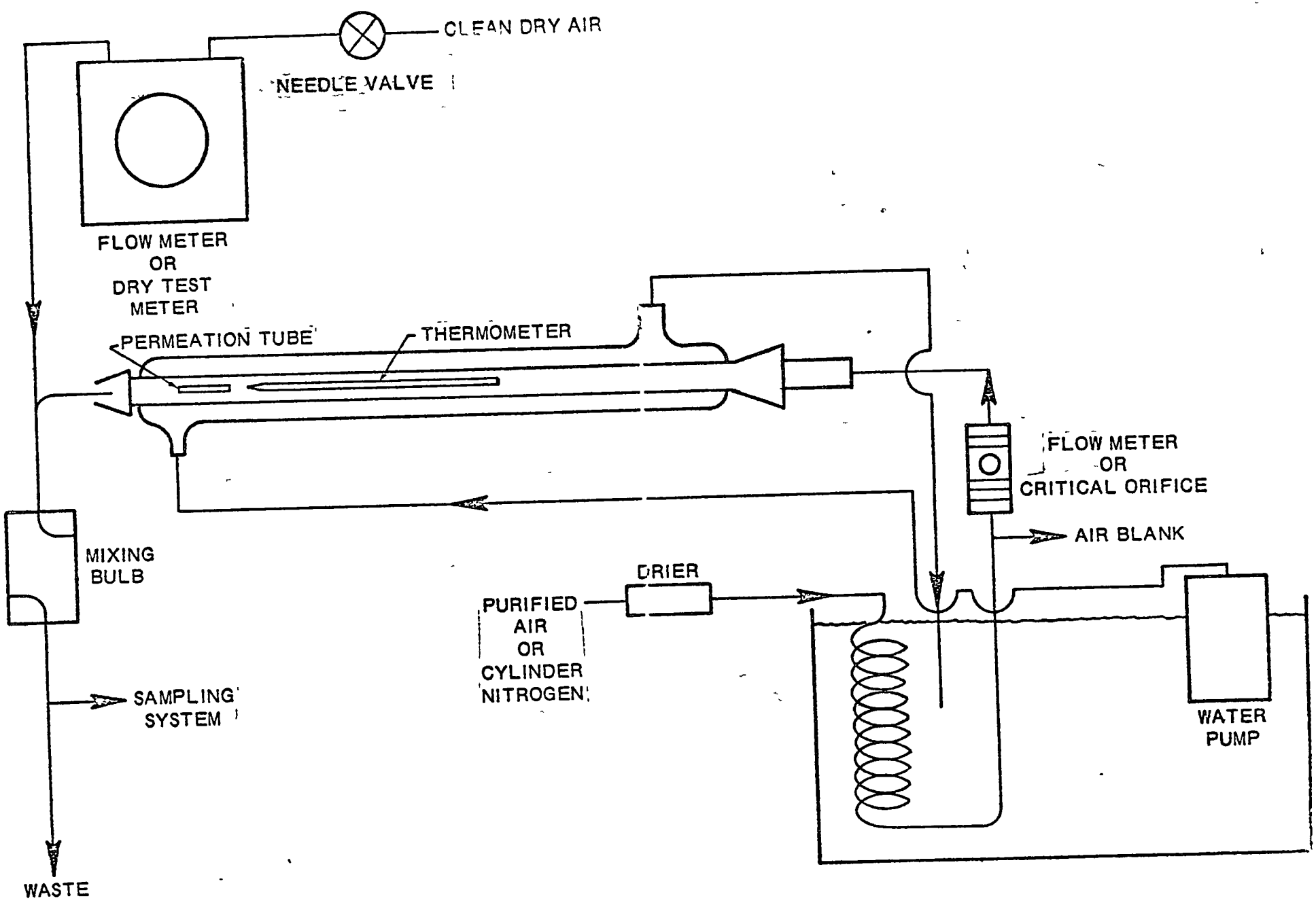


Figure 3. Permeation tube schematic for laboratory use.

IV

Tom, this will interest you
Ed Bolton

Continuous Monitoring

The Los Angeles County Air Pollution Control District is one of the leaders in watching air quality. Its continuous monitoring system, which this month will be expanded to include automatic telemetering, is among the most advanced in the country.

JOHN L. MILLS, Los Angeles County
Air Pollution Control District

In 1955, the Los Angeles County Air Pollution Control District initiated regulations[1] designed to prevent excessive build-up of atmospheric contaminants. Since then 71 first alerts have been called, but no second or third alerts.

In first-alert action, the Control Officer notifies the public through mass media and starts four lines of action:

1. Immediately stops all refuse burning in open fires, even those otherwise legal under exceptions from refuse-burning prohibitions.
2. Certain industries prepare for a shut-down, in the event a second alert is called. Shut-down plans must have been previously approved by the Control Officer.
3. Requests the public to stop all unessential vehicle operation and to use vehicles on a pool basis when possible.
4. Calls the Emergency Action Committee into session for advice if it appears that a second alert is likely. Public is also warned if a second alert seems imminent.

A second alert would limit or shut-down industry and halt all vehicular traffic except authorized emergency vehicles. If all these steps fail and a third alert is called, the Governor is requested to take action as set forth in the California Disaster Act.

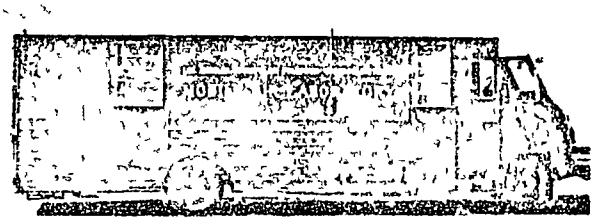
Air Monitoring Network

Obviously, such broad powers must be based on realistic and reliable information. To provide the Control Officer with necessary data, a network was established to continuously monitor atmospheric pollution. Whereas the emergency regulation called for a minimum of six sampling stations, the network has grown to 12, located throughout the county. We also have a fully-instrumented mobile station. See photo below.

Initially, the monitoring system included data on carbon monoxide, nitrogen oxides, sulfur oxides and ozone. Alert stages for these pollutants are shown in Table I. We have since added instruments to measure hydrocarbon concentrations and the filter-paper soiling capability of airborne particulates.

Each station is also equipped to measure and record wind speed and direction, temperature and relative humidity. Data are collected 24 hr./day, seven days a week.

A technician attends each station five days a week for routine maintenance, "zeroing" and "spanning" of instruments, and simple repairs. Another group of technicians regularly calibrate automatic equipment. Personnel from the District's Instrument Engineering and Maintenance Section repair and overhaul instruments when required. By the combined efforts of these people, instruments collect valid data for more than 95% of the total possible operating time.



MOBILE UNIT supplements 12 permanent sampling stations in county.

Measuring Sulfur Dioxide

A number of manufacturers supplied instrumentation for the monitoring network Over the years, our instrument engineers have modified most of the equipment to obtain more specific, reliable and reproducible data

Our SO_2 measuring devices operate on a conductivity principle The SO_2 in the ambient air is absorbed in distilled water in a contact column, and then oxidized to sulfuric acid by hydrogen peroxide. Conductivity changes are measured and recorded The increase is proportional to the SO_2 concentration in the atmosphere Instruments have either two or three linear scales that cover concentrations from zero to 15 ppm.

We have found many difficulties with these instruments, not the least of which is specificity For example, SO_2 units from various manufacturers do not record the same concentrations while measuring the same atmosphere [3] Also, they are affected by other electrically conductive air contaminants, resulting in readings higher and lower than the actual SO_2 amount One well-known problem is the effect of airborne ammonia from cattle feed lots, which produces a negative SO_2 reading.

Total Oxidant Instrument

Our ozone measuring unit is more correctly called a "total oxidant" instrument In operation, a continuous air sample is introduced into a contactor column, where ozone is absorbed in a neutral (pH 7.2), buffered solution of potassium iodide Ozone in the air converts the reagent to colored iodine, which can be measured by a dual-beam colorimeter Depth of color is a measure of ozone concentration The potassium iodide reagent is recirculated after it passes through a carbon filter.

The instrument's scale reads from zero to infinity. A concentration of 0 5 ppm is read at approximately 72% of chart width, and 1 0 ppm at about 90%.

The major problem with these instruments is that they do not measure ozone alone Rather, they read all oxidizing contaminants in the atmosphere, including NO_2, but not at a one-to-one ratio Reducing agents, moreover, will lower the oxidant reading. Fortunately, during the time of day when oxidant concentration hits its peak, ozone is the overwhelmingly predominant contributor. For practical purposes, therefore, ozone reading and that of total oxidants may be considered identical at peak concentrations.

Two Checks for NO_x

We make two measurements for oxides of nitrogen One determines NO_2 and the other NO Sum of the readings is the total oxides of nitrogen (NO_x).

A continuous air sample is passed through an absorption column, in which nitrogen dioxide reacts with a reagent to form a colored product The chemistry involves conversion of NO_2 to nitric and nitrous acids, with subsequent diazotization of sulfanilic acid in acetic acid solution and coupling with N - (1-naphthyl) - ethylenediamine dihydrochloride. Color is measured photometrically and recorded.

NO is determined similarly after it is oxidized with acid permanganate to NO_2 In the instrument, the measured air sample runs through two columns in series NO_2 is absorbed in the first, and the remaining NO is oxidized so it can be absorbed in the second column The used liquid reagent is decolorized in a carbon adsorption column The scale reads from zero to infinity, with 2 0 ppm. read as about 80% of chart width

One problem is that the conversion of 2 mols of NO_2 to 1 mol of HNO_2 and 1 mol of HNO_3 does not occur exactly at the stoichiometric ratio and thus a correction factor must be used Also, sufficiently pure NO_2 for standardization is not available.

Alert Stages for Toxic Air Pollutants—Table 1
Parts per million

	First alert	Second alert	Third alert
Carbon monoxide	100	200	300
Nitrogen oxides	3	5	10
Sulfur oxides	3	5	10
Ozone	0.5	1.0	1.5

CO and Hydrocarbons

In the carbon monoxide instruments, measurement depends on non-dispersive infrared absorption Two cells are used one for the sample and a second for reference The detector is a variable-capacitor type, sensitized for CO measurement The cell's output is conditioned and recorded on a strip chart The unit contains a complete gas handling system so that the air's CO content is recorded continuously

Instruments have either one or two linear scales, covering a range from zero to 300 ppm They sometimes give a false response to water vapor, and we have installed dryers on the incoming air stream.

We determine total hydrocarbons in the atmosphere by flame ionization The sample is exposed to a hydrogen flame in an electrostatic field, and the hydrocarbons are ionized Ions migrating to the eletctrodes produce a small electric current that is detected and recorded to give a continuous record of hydrocarbon concentration.

By passing the sample stream through activated carbon part of the time, hydrocarbons other than methane are removed In this way, the instrument is used to record both total hydrocarbons and methane With several scales, the unit covers a range from zero to 12,000 ppm

Readings from the flame ionization recorder are supposed to reflect the number of carbon atoms in

the hydrocarbon being measured But the instrument s responses are not that specific Values for hydrocarbons above methane are generally lower than the true values We feel these instruments leave a great deal to be desired.

Testing for Dirt

Automatic tape samplers are used for continuous monitoring and measuring of the atmosphere's soiling quality Here's how it works ambient air is drawn for a predetermined time, usually 50 min , through a limited area on a roll of paper filter tape, particulate matter deposits on the tape, and the tape automatically advances to expose fresh surfaces

The light reflectance and transmittance of the soiled spots on tape gives a measure of the relative "dirtiness" of the atmosphere

In addition to the instruments we have described here, some of our stations are equipped to measure solar radiation and beta radioactivity.

Data Reduction

To reduce the 24-hour data from 72 air-monitoring instruments and 130 meteorological units, we have a substantial staff—a senior data reduction technician, three technicians and two statistical clerks Data arrive at headquarters on strip charts from the field instruments The staff converts readings to tabular form, and then data are placed on interpreted punch cards for storage, random visual access and processing

In the next step, technicians make a series of computer print-outs for the District's evaluation and planning staff Typical data for ozone, collected during the height of the smog season, are shown in Fig 1 This type of data provides bases for total contamination studies, polluted air trajectory studies, contamination trends, source identification, studies of photochemical smog, effects of control measures, comparison of pollutant parameters with air quality standards and prediction of future requirements for new controls

These goals are achieved by three EDP programmer analysts, who write the special programs for the evaluation and planning staff The computations are complex They involve photochemical reaction rates, micro- and meso-meteorological calculations, insolation variations, diurnal variations, air parcel transport, contaminant input rates and geographical distribution of contaminants.

Telemetering Coming

This month we will install a telemetering system to provide headquarters with real-time readings of pollutant concentrations and meteorological data, as measured continuously at the 12 monitoring stations Instrument readings at the stations will be converted from analog to digital signals and transmitted by wire (seven stations) or microwave (five stations) to headquarters.

Equipment at headquarters will include a central data processing unit, a combination card reader/

AIR POLLUTION CONTROL DISTRICT - COUNTY OF LOS ANGELES — VA 12
OZONE BY KI / HOURLY AVERAGE / IN PPHM — STATION 60 — 8/69

DAY	HOUR PST 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	AVE	N	MAX
							1	1	3			18	23	27	24	9	3	1	1	1	1	1	1	1	5.8	21	28
1	1	1	1	1		1	1	2	6	11	13	15	23	23	26	27	20	14	8	3	2	2	2	2	8.9	23	27
2•	1	1	1	1		1	1	2	5	9	16	22	27	30	30	27	17	13	12	6	2	1	1	1	9.9	23	31
3•	1	1	1	1		1	1	2	5	9	16	22	27	30	30	27	17	13	12	6	2	1	1	1	9.9	23	31
4	1	1	1	1		1	2	3	7	14	23	35	42	42	40	32	28	21	15	8	3	3	2	2	14.2	23	43
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23•	1	1	1	1		1	1	2	4	10	17	19	22	26	30	23	21	16	5	2	1	1	1	1	9.0	23	32
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30•	2	2	3	3		4	4	6	9	14	20	27	33	33	26	21	16	11	6	3	2	2	2	2	10.9	23	36
31•	2	2	2	1		1	2	4	8	12	19	28	34	31	27	21	11	8	4	2	2	1	1	1	9.7	23	36
AVE	1	1	1	1		1	1	3	6	11	17	22	28	28	26	21	17	12	8	4	2	1	1	1	9.3		34
N	31	31	31	31		31	31	31	29	30	30	31	31	31	31	31	31	31	31	31	31	31	31	31		709	31
MAX	2	3	3	3		5	4	6	11	18	24	35	54	50	42	41	32	27	22	13	6	3	4	2	15.5		71

PRINT-OUT of ozone concentrations during smog season—Fig. 1

09/06/68 TIME PST	STA	OZONE PPM	CO PPM	NO2 PPM	NO PPM	NO+NO2 PPM	SO2 PPM	HC PPM	METH PPM	VAR W XXX	VAR X XXX	VAR Y XXX	VAR Z XXX	TEMP DEGF	RH %	WD DEG	WS MPH	
1200	001	0 24	007	0 12	0 01	0 13	0 05M	003	002	XXXX	XXXX	XXXX	XXXX	085	046	240	06.2	
	DOLA	0.29*	022*	0 32*	0 32*	0 52*	0 05*	008*	006*	XXXX*	XXXX*	XXXX*	XXXX*	085*				
	060	0.38M	007	0 02	0 01	0 03	0 03	004	003					095	026	260	05.3	*ALARM*
	AZUS	0.38*	011*	0 13*	0 07*	0 19*	0 04*	007*	005*					095*				
	069	0.35	009	0.15	0 01	0.16	0.02	003	002					096	024	150	07.8	
	BURK	0.35*	018*	0.40*	0 42*	0.56*	0.07*	008*	006*					096*				
	071	0 15	005	0.10	0.01	0.11	0.02	005	004					078	060	260	08.0	
	WLLA	0.20*	015*	0 30*	0.28*	0.50*	0.04*	010*	000*					080*				
	072	0 06	006	0 23	0 05	0 28	0 09	002	001					08	044	290	11.3	
	LGBH	0.17*	010*	0 44*	0.24*	0.54*	0.20*	005*	004*					082*				
	074	0.25	006	0 08	0 01	0 09	0 01	002	001					085	040	270	04.2	
	RESA	0.38*	011*	0 22*	0.26*	0 42*	0.02*	006*	005*					086*				
	075	0 40M	007	0.07	0.01	0 08	0 03	003	002					098	026	260	07.1	*ALARM*
	POMA	0 40*	011*	0 19*	0 28*	0.40*	0 05*	000*	005*					098*				
	076	0.06	004	0 16	0.04	0 20	0.01	004	003					074	062	230	09.2	
	LENX	0.08*	016*	0 26*	0.50*	0.55*	0 08*	010*	008*					075*				
	079	0.40	005	0 11	0 01	0 12	0.02	003	002					096	026	190	06.8	
	PASA	0 46*	017*	0 21*	0.15*	0.32*	0.03*	006*	005*					097*				
	080	0 23	004	0 14	0 01	0.15	0.09	004	003					088	050	220	08.3	
	SFSP	0.25*	012*	0 25*	0.22*	0 35*	0.20*	007*	006*					088*				
	081	0 10M	003	0.02	0 01	0 03	0.02	003	002					093	020	210	09.8	
	NEWH	0.10*	008*	0 12*	0.06*	0.15*	0 03*	005*	004*					093*				
	082	0 05	002	0 02	0 01	0.03	0 01	002	001					099	013	290	16.0	
	LANC	0.06*	005*	0 09*	0 05*	0 12*	0.02*	004*	003*					099*				

TELEMETERING system will give hourly reports like this—Fig. 2

punch, two wide-carriage input/output printers, an emergency printer for the radio room dispatcher and a 6 x 9-ft real-time display map The map will be located in a conference room that serves as the emergency action committee's command post

Map features include mountains and lowlands (in relief), major freeways and airports, county boundaries, major cities and the 12 monitoring stations Arrows will indicate wind direction at each station

Near by will be a control board for requesting any current reading, which will appear as three lighted numerals projected from the rear Pressing the right button will give the current reading at any station of O_3, CO, SO_2 NO, NO_2, NO_x, CH_4, total hydrocarbons, temperature, relative humidity and wind speed Another command will provide the day's maximum reading for any of the variables and the time it occurred at any chosen location.

Lights Signal Alert

When the concentration of any of the four critical contaminants (O_3, CO, SO_2 NO_x) reaches 70% of an alert level, the light at the station changes from white to yellow. If the alert stage is reached, the light goes from yellow to red and remains red until the pollutants concentration drops An audible alarm accompanies each light change.

The system will also feature hourly print-outs of readings plus special ones during an alert It has capacity to handle data from 16 instruments A sample hourly print-out is shown in Fig 2 The system is designed with a capacity to handle 32 monitoring stations, each with 16 instruments.

Once a day, the equipment automatically produces a print-out of the day's readings, including hourly averages, daily averages, maximum daily reading for each parameter and the time at which it occurred A punched card is also produced for each of these readings

We expect to always have a need for some data reduction technicians to check field charts against printed data and to fill information gaps caused by inevitable break downs There will be a gradual transition during which duties of most of the technicians will change, probably to that of air pollution analysts This will allow us to implement a planned program of relating data to atmospheric chemistry

In the future, we will focus on air contaminants present in much lower concentrations than those measured today Instruments are already needed to continuously detect and measure these pollutants They must be precise and specific in ppb, rather than ppm Further, refinements and changes are needed in today's instruments to correct their shortcomings and to increase sensitivity by ten to a hundredfold.

References

1 Rules and Regulations of the Los Angeles Country Air Pollution Control District, Reg VII, Rules 150—164
2 Ibid, Rule 156
3 Shikiya, J M and MacPhee, R D, Multi-Instrument Performance Evaluation of Conductivity-Type Sulfur Dioxide Analyzers, *J Air Pollution Control Assoc*, vol 19, p 943-945, Dec 1969

Meet the Author

John L Mills is director of technical services, Los Angeles Air Pollution Control District, Los Angeles, Calif 90013 He has a B ChE degree from the University of Minnesota, and was one of the original group when the District was activated in 1948 He had experience in both enforcement and engineering branches before his transfer to technical services Mr Mills is a registered Chemical Engineer in California

VII

1

City of Chicago

Department of Environmental Control

Mobile Monitorning Report

Southeast Side
Hydrogen Sulfide (H_2S)

Hydrogen sulfide concentrations were measured in the vicinity of 110th and Torrence from September 20, to October 1, 1971. Ceramic tiles coated with lead acetate were placed as shown in Figures 1 through 9, and checked periodically for color change. The color of the tiles were compared to standard colors which represent specific concentrations of hydrogen sulfide. Wind direction, starting and ending time and date, and total length of exposure for each of the sampling periods are given in Table 1. Average hydrogen sulfide concentrations, in parts per billion, and wind directions for each sample period are shown on the maps (Figs. 1 through 9). The locations of the coke ovens are shown in Figure 10.

Figure 1 shows the general characteristics of the H_2S problem in the area. There was no predominant wind direction for the period and the measured concentrations do not appear to correlate with proximity to an individual coke oven or wind direction. The locations of the coke ovens are shown in Figure 10, along with a real time recorded trace of the H_2S taken at the position indicated by the arrow head. This emission lasted for approximately twenty minutes with very little measurable H_2S either before or after.

The data in Figure 2 indicated that the H_2S emission is not continuous but rather is emitted in puffs. Continuous emission from all of the ovens should have given readings at all four of the north sites and at least one of the south sites.

The data in Figure 4 indicates that the two ovens east of Torrence are possible sources. In Figures 6 and 9, the effects of the oven west of Torrence is separated from the effects of the ovens east of Torrecne.

The data in Figures 3, 5, 7, and 8 have wind directions which preclude identifying any one of the three ovens as a prime source, but they do indicate that the emissions contain relatively high concentrations of H_2S.

The data shown in the Figures are concentrations, in parts per billion, averaged over the entire sample period. If the data was averaged only for the time the wind was in line with an oven and a sensor, the concentrations would be closer to 200 to 300 PPB. This still would not give an indication of the total concentration in a puff.

The data for figure 10 was recorded on a Houston Attas hydrogen sulfide analyzer. This analyzer also uses lead acetate tape, but has continuous read-out on a strip chart recorder.

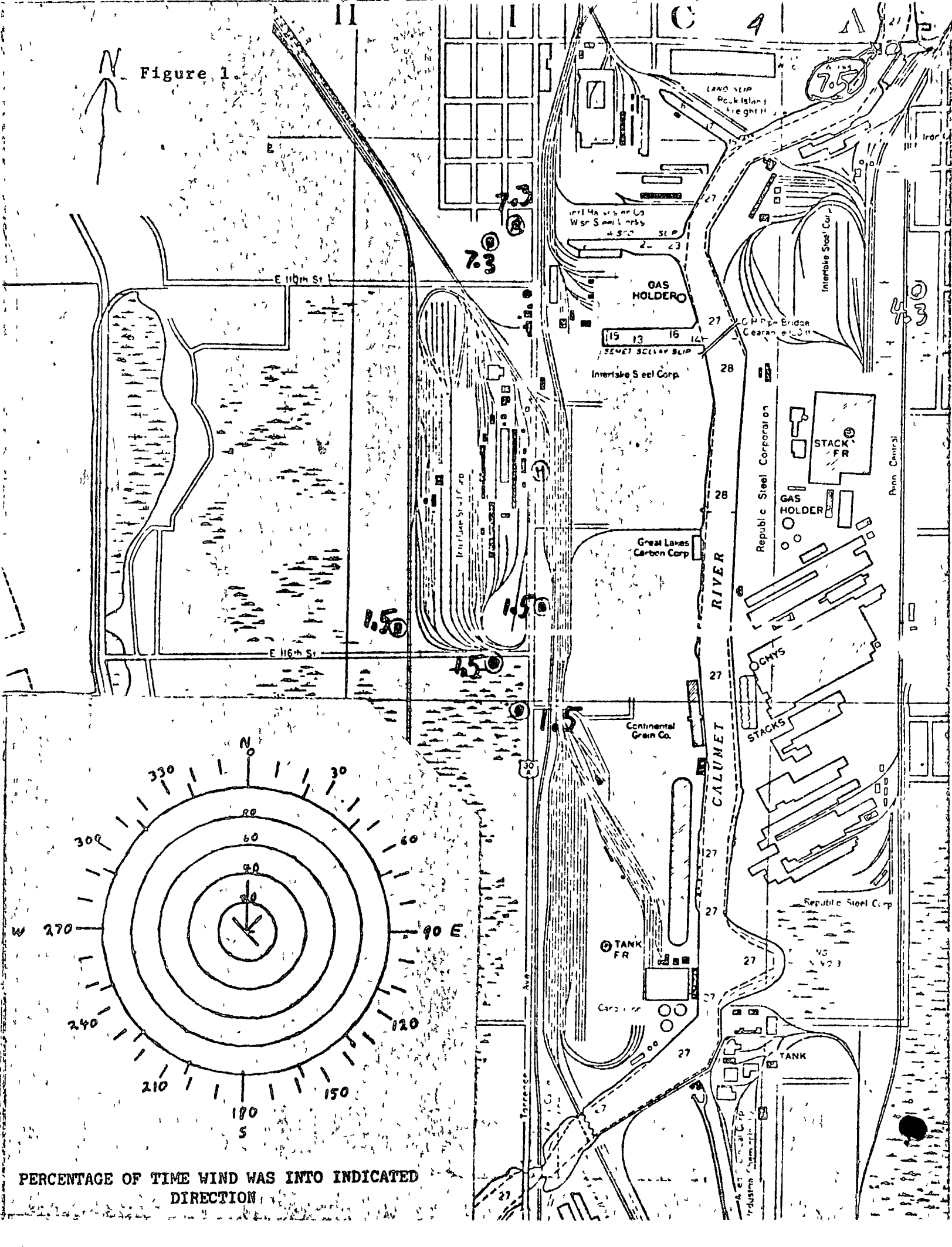
James J. Wood
11 NOV 71

PERCENTAGE OF TIME WIND WAS FROM A GIVEN DIRECTION

Start	1500 20/9-	1300 22/9-	1500 23/9-	1300 24/9-	1200 25/9-	1500 27/9-	1200 28/9-	0900 29/9-	1500 30/9-
Stop	1300 22/9	1500 23/9	1300 24/9	1200 25/9	1500 27/9	1200 28/9	0900 29/9	1500 30/9	1500 1/10
Total	46 hrs	26 hrs	22 hrs	23 hrs	51 hrs	21 hrs	21 hrs	30 hrs	24 hrs
N					1				
NNE							12	2	
NE		4					7	23	
ENE				15	4		5	17	
E		19		34	13			5	
ESE				11	17			2	
SE	17	15		34	22			10	
SSE				6	18	5		13	17
S	35	35	4.5		18	95	55	15	60
SSW					9		7	12	21
SW	15	4	4.5				7	2	2
WSW							2		
W	6.5	4					5		
WNW									
NW	13	19	32						
CALM	13		58						
	FIG. 1	FIG. 2	FIG. 3	FIG. 4	FIG. 5	FIG. 6	FIG. 7	FIG. 8	FIG. 9

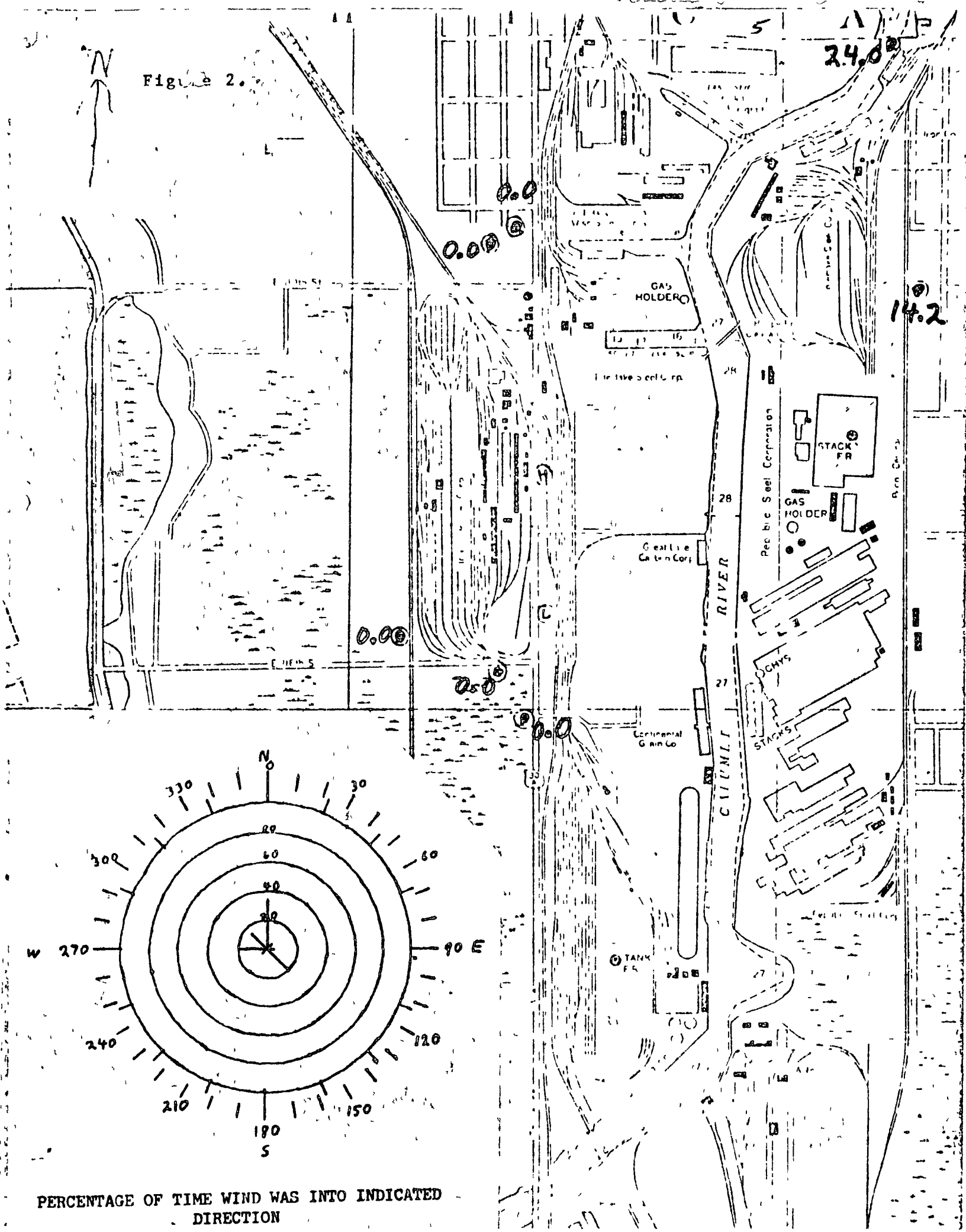
TABLE 1

Figure 1.



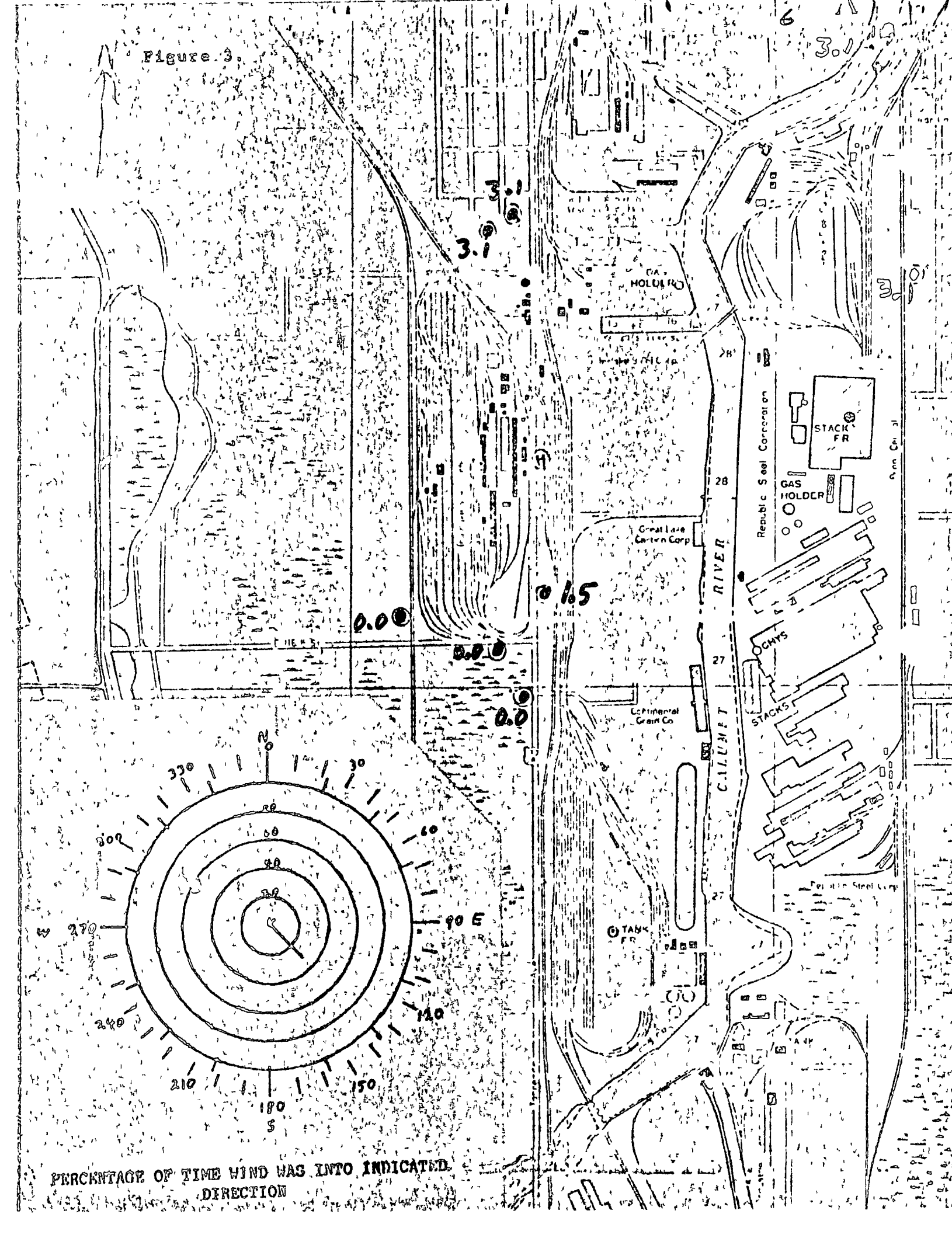
PERCENTAGE OF TIME WIND WAS INTO INDICATED DIRECTION

Figure 2.



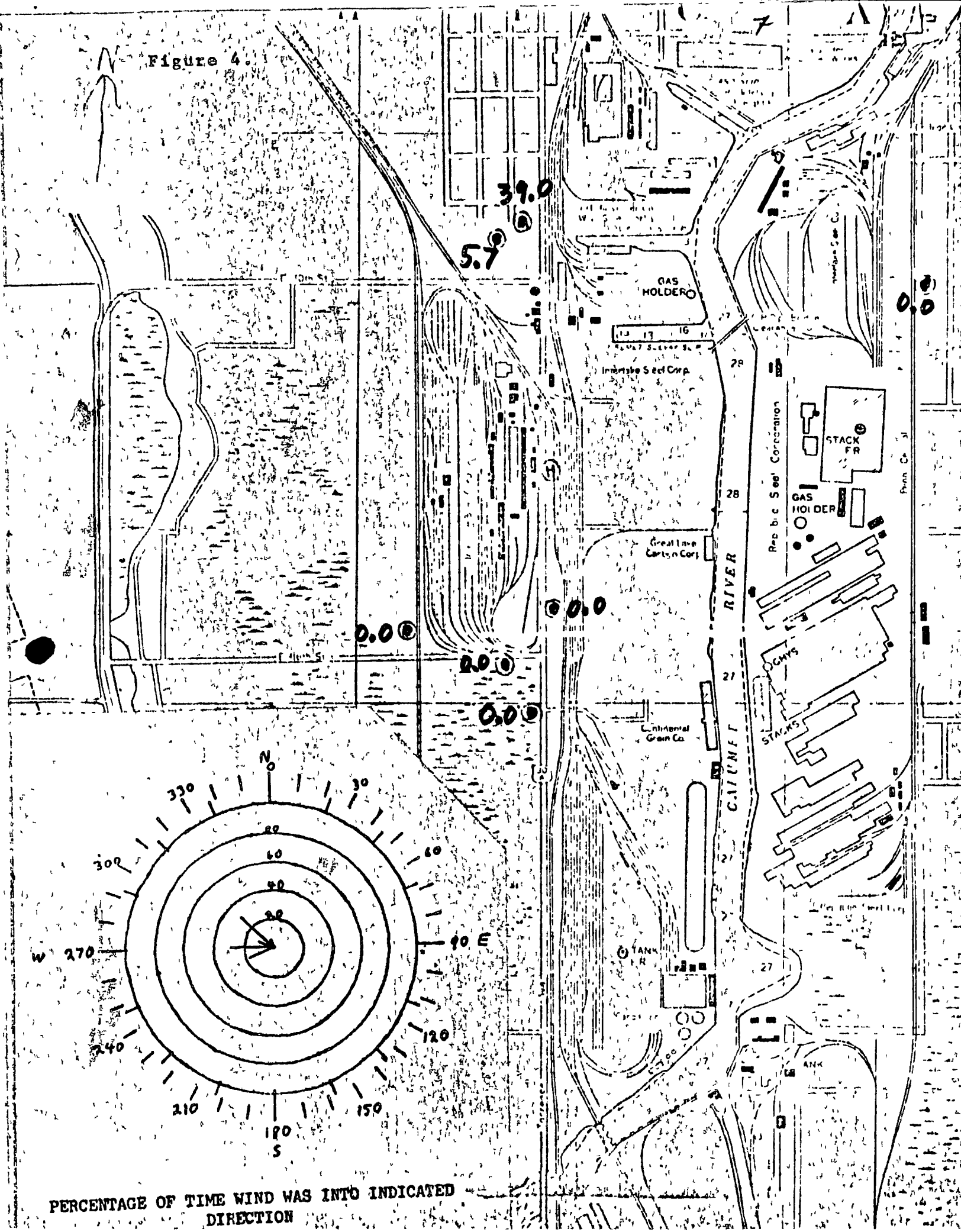
PERCENTAGE OF TIME WIND WAS INTO INDICATED DIRECTION

Figure 3.



PERCENTAGE OF TIME WIND WAS INTO INDICATED DIRECTION

Figure 4.



PERCENTAGE OF TIME WIND WAS INTO INDICATED DIRECTION

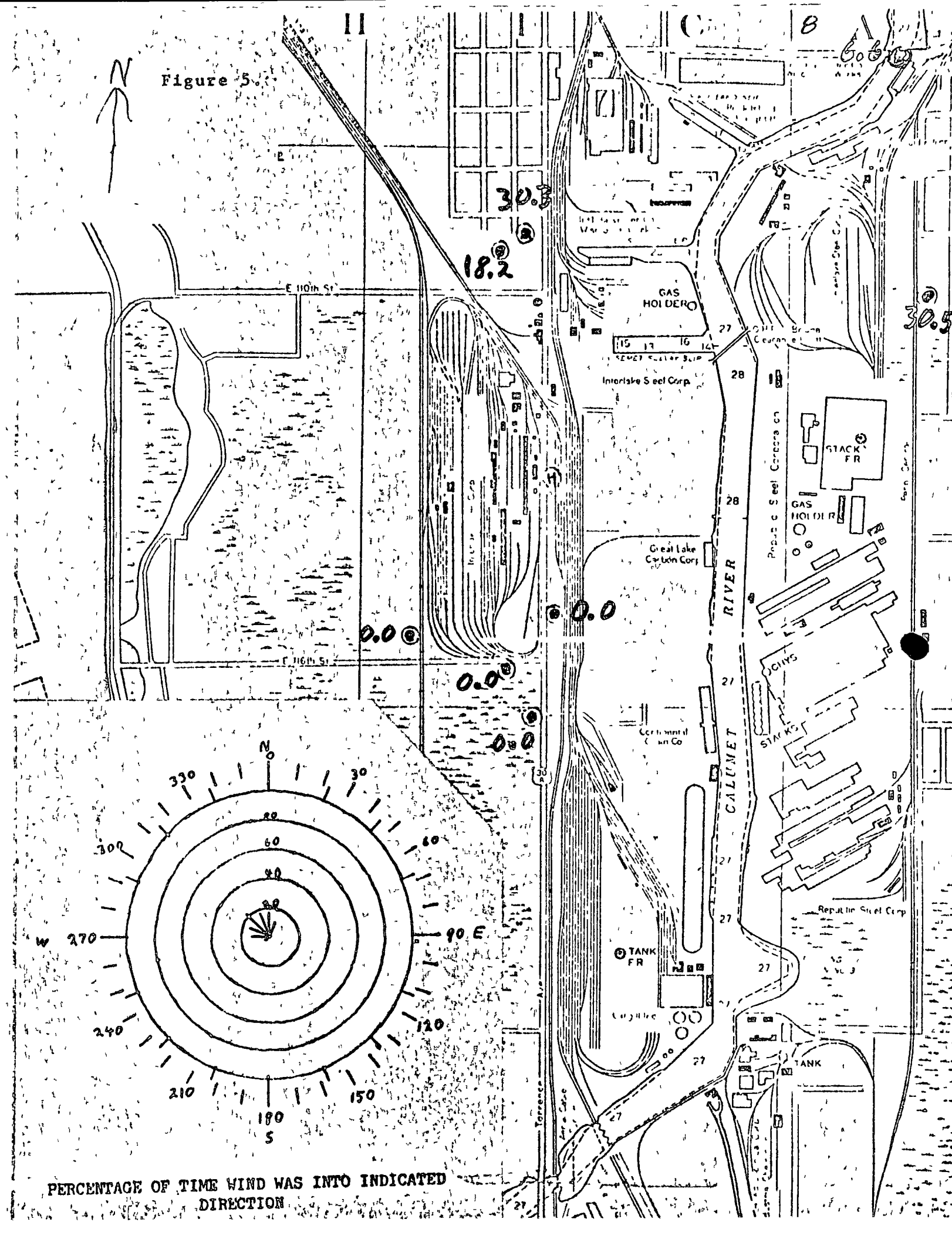


Figure 5.
N
E 110th St
GAS HOLDER
Interlake Steel Corp
Republic Steel Corporation
STACK FR
GAS HOLDER
Great Lake Carbon Corp
CALUMET RIVER
Continental Carbon Co
STACKS
Republic Steel Corp
TANK FR
TANK
Cargill Inc
Torrence Ave
30.8
18.2
30.5
0.0
0.0
0.0
0.0
N
30
60
90 E
120
150
180
S
210
240
270 W
300
330
PERCENTAGE OF TIME WIND WAS INTO INDICATED DIRECTION

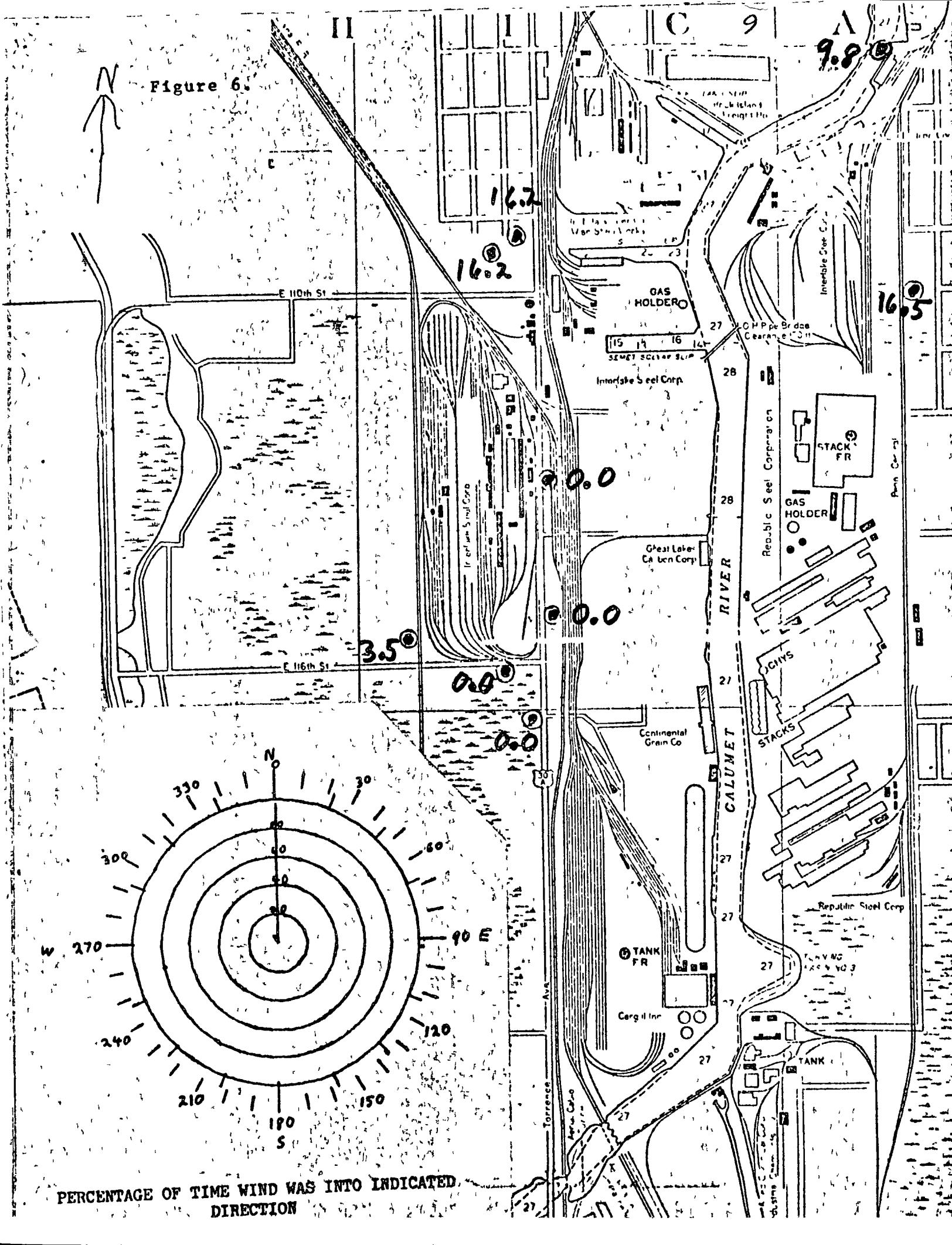
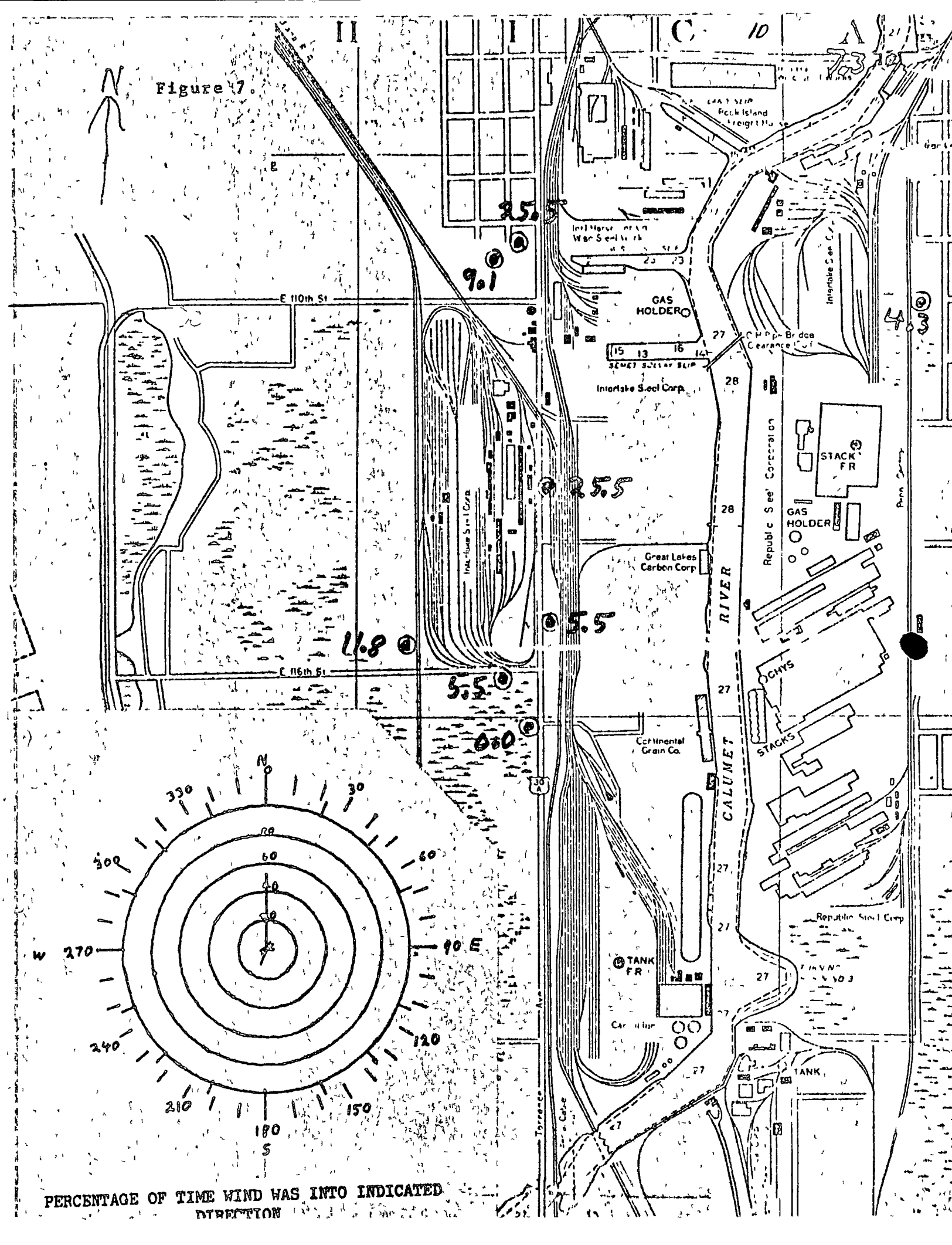
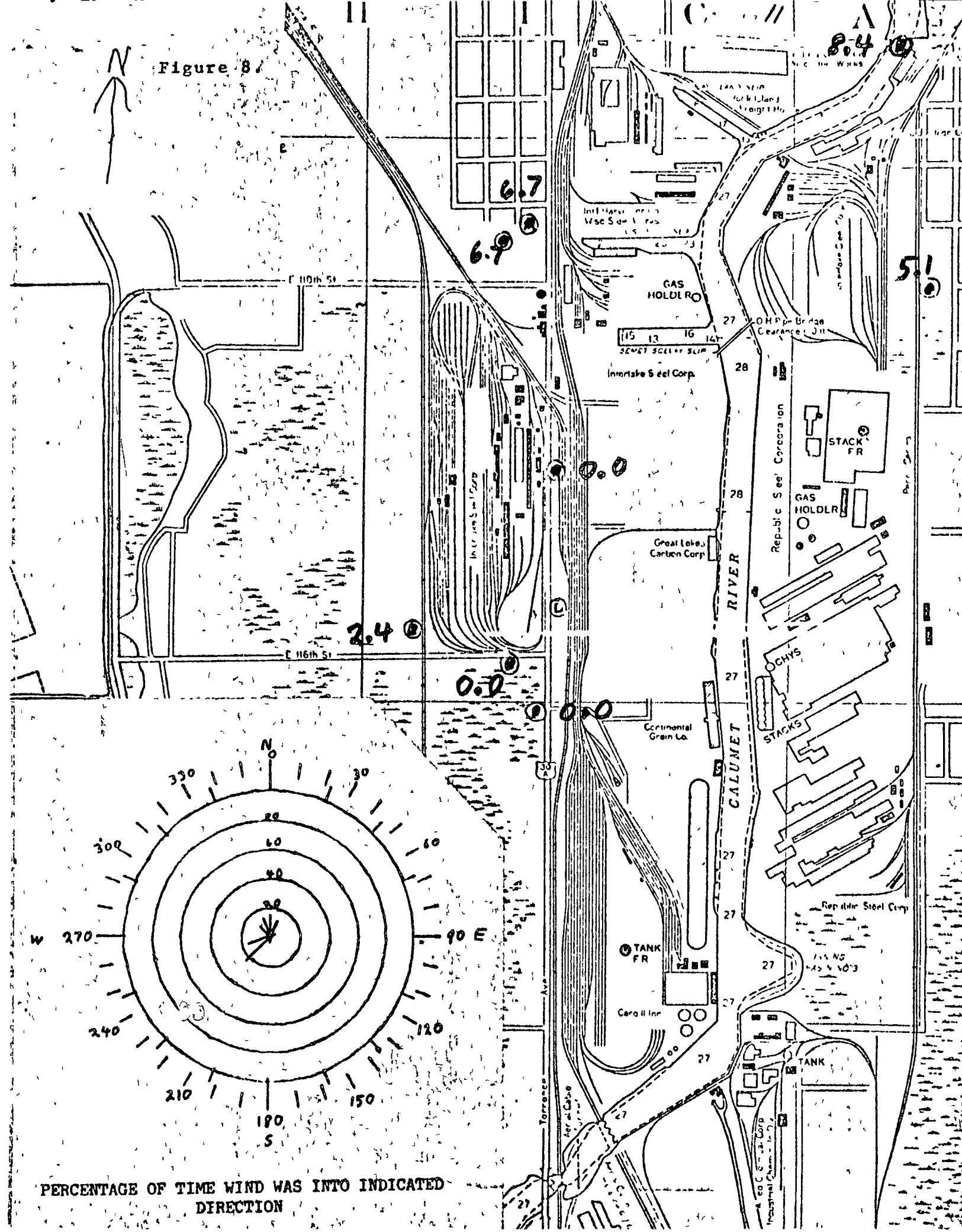


Figure 6.
II
I
C
9
A
N
16.2
16.2
9.8
16.5
E 110th St
GAS HOLDER
Interlake Steel Corp
Great Lakes Carbon Corp
0.0
0.0
3.5
0.0
0.0
E 116th St
RIVER
CALUMET
Republic Steel Corp
STACK FR
GAS HOLDER
CINS
STACKS
Continental Grain Co
TANK FR
Cargill Inc
TANK
Torrence Ave
N
30
60
90 E
120
150
180 S
210
240
270 W
300
330
PERCENTAGE OF TIME WIND WAS INTO INDICATED DIRECTION



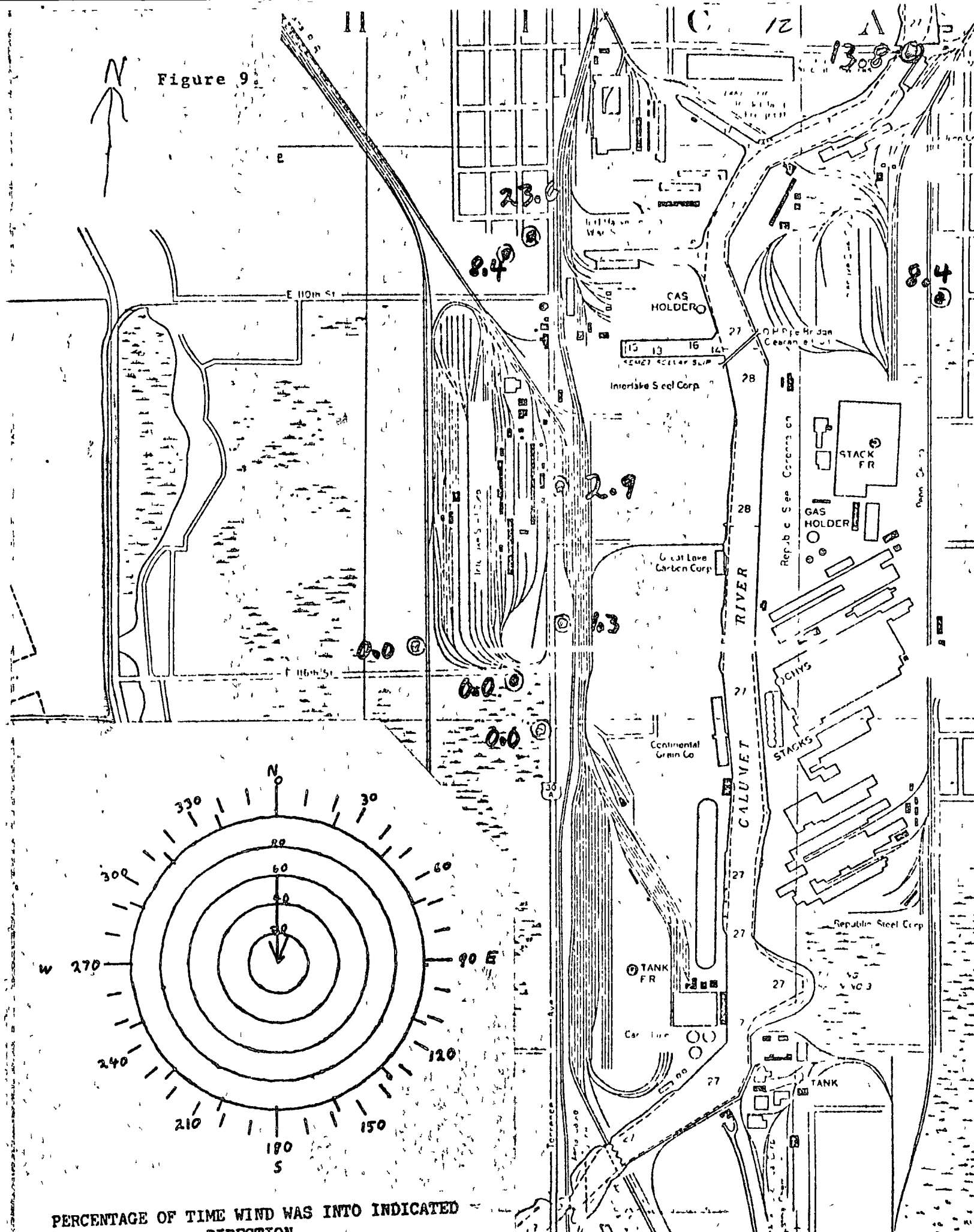
PERCENTAGE OF TIME WIND WAS INTO INDICATED DIRECTION

Figure 8



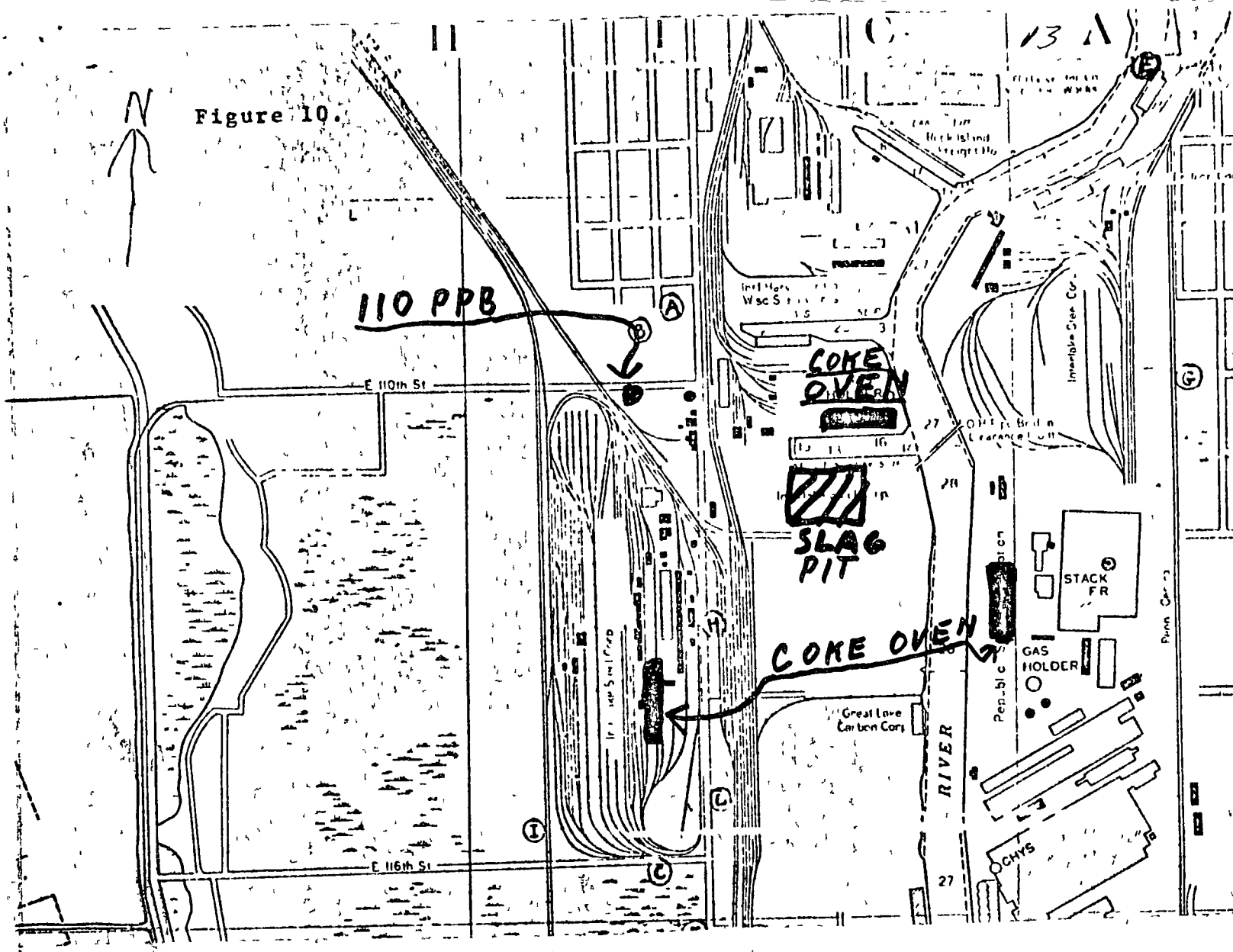
PERCENTAGE OF TIME WIND WAS INTO INDICATED DIRECTION

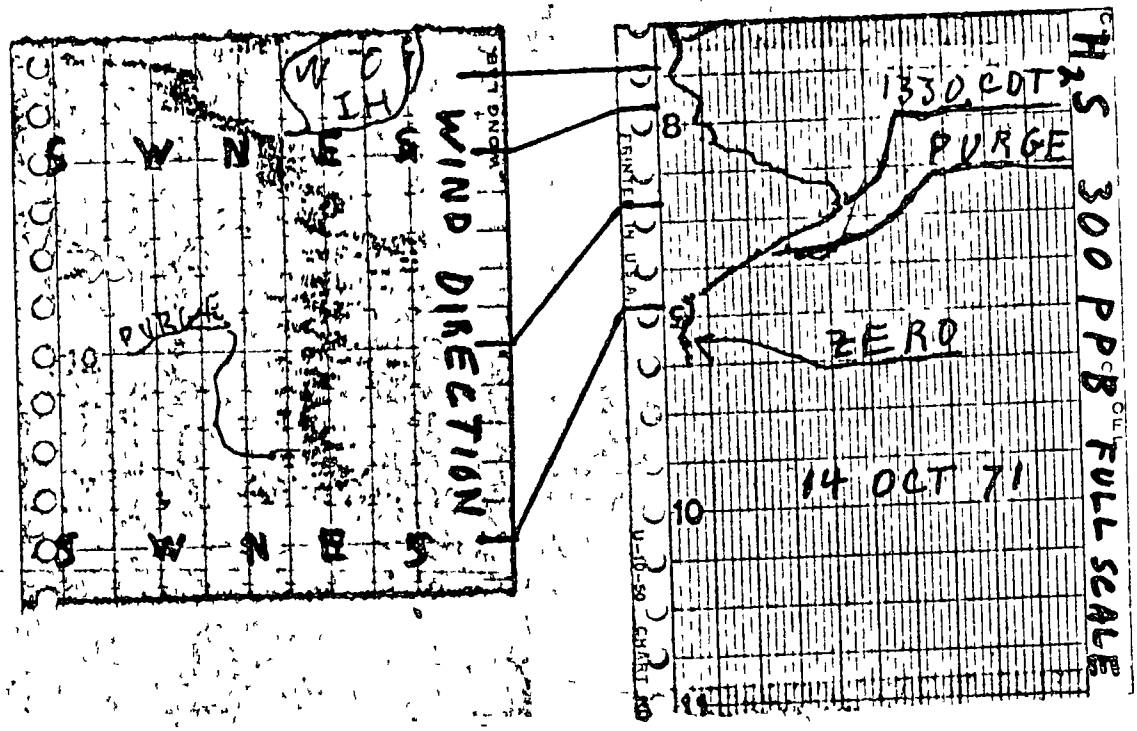
Figure 9.



PERCENTAGE OF TIME WIND WAS INTO INDICATED DIRECTION

Figure 10.


N
110 PPB
E 110th St
E 116th St
COKE OVEN
SLAG PIT
COKE OVEN
STACK
GAS HOLDER
RIVER
Great Lake Carbon Corp
CHYS


WIND DIRECTION
PURGE
1330 CDT
PURGE
ZERO
14 OCT 71
H2S 300 PPB FULL SCALE

II

TENTATIVE METHOD FOR DETERMINATION OF OXIDANTS IN THE ATMOSPHERE (NEUTRAL BUFFERED POTASSIUM IODIDE METHOD)

(Key Words: Oxidants, Ozone, Ambient Air, Potassium Iodide, Spectrophotometric)

1. Principle and Applicability

1.1 A sample of ambient air is drawn through a chromium trioxide scrubber to remove sulfur dioxide and then through two absorbers in series containing potassium iodide reagent to collect the oxidants.

1.2 Oxidants are defined by this method as those compounds capable of liberating iodine from a 1% potassium iodide solution buffered with disodium phosphate and potassium dihydrogen phosphate. The iodine produced in the absorbing reagent is measured spectrophotometrically as the triiodide ion.

1.3 This method is intended for the measurement of total oxidants as ozone in the atmosphere. However, the various oxidizing species, such as ozone, nitrogen dioxide, peroxyacetyl nitrate, and peroxides are present in widely varying concentrations and react with the reagent at different rates. Also, reducing compounds in the atmosphere have a negative effect on the oxidant reading. Thus the number obtained is a "net" oxidant value, which describes a condition of the atmosphere and is not the total concentration of the oxidizing species present.

2. Range and Sensitivity

2.1 Concentrations of oxidants in the range of about 20 to 20,000 $\mu g/m^3$ (0.01 to 10 ppm) as ozone can be determined.

2.2 At a sampling rate of 2 liters/min. for 15 min. using 10 ml absorbing reagent, 20 $\mu g/m^3$ (0.01 ppm) should produce an absorbance of approximately 0.025 measured in 1-cm cells. At concentrations below 100 $\mu g/m^3$ (0.05 ppm) readings may be quite imprecise because of the instability of oxidants or iodine at very low concentrations.

2.3 The above limits are based on a molar absorptivity of 24,200 liters/mole/cm.

3. Interferences

3.1 Reducing gases such as sulfur dioxide and hydrogen sulfide give very serious negative interferences. Sulfur dioxide gives a 100% negative interference of an equivalent molar concentration of ozone. The interference from sulfur dioxide, even when it is present at ambient concentrations, can be eliminated by a properly conditioned chromium trioxide scrubber (See 6.6, 7.1).

3.2 The oxidant reading contains a contribution of 10% of the molar concentration of NO_2. When a chromium trioxide scrubber is used, NO is converted to NO_2, thus contributing to the oxidant reading to the same extent as NO_2. If an oxidant value less NO_2 is desired, NO + NO_2 must be measured simultaneously and a correction factor of 10% of the NO_x concentration (as NO_2) must be subtracted.

3.3 Glassware should be cleaned with chromic acid, since dust or foriegn materials may interfere.

3.4 Direct sunlight will affect the iodine concentration.

Precision, Accuracy, and Stability

4.1 A ± 5% relative standard deviation can be obtained at a concentration of 000 $\mu g/m^3$ (0.5 ppm) of ozone.

4.2 Accuracy cannot be defined, since the sensitivity of the potassium iodine eagent varies widely with the different oxidizing species.

4.3 Analysis should be completed immediately after sampling to obtain consistent results. This is necessary because some oxidants release iodine slowly to hange color, while fading due to slow decomposition of iodine may occur.

Apparatus

5.1 Absorber - All-glass impingers as shown in Figure 1 are recommended. ese impingers may be purchased from major glassware suppliers. Two absorbers in eries are needed to insure complete collection of the sample.

5.2 Air Pump - Capable of drawing 2 liters/min. through the absorbers. The mp should be equipped with a needle valve at the inlet side to regulate flow. If critical orifice (5.7) is used, the pump must be capable of maintaining 0.7 atmohere vacuum.

5.3 U Tube - 140 ml, for the chromium trioxide scrubber.

5.4 Thermometer - Or other temperature-measuring device with an accuracy of ± C

5.5 Barometer - Atmospheric, accurate to the nearest mm Hg.

5.6 Wet Test Meter - 1 or 3 liters/revolution.

5.7 Flowmeter - Calibrated metering device for measuring flow of 2 liters/min. thin ± 2%. A 20-gauge hypodermic needle 1 in. long acting as a critical orifice n be used to give a flow of approximately 2 liters/min.

5.8 Drying Tube - Containing an indicating drying agent to protect flowmeter.

5.9 Prescrubber - Tube filled with granular MnO_2 and charcoal to remove oxints.

5.10 Volumetric Flasks - 25, 100, 500, 1000 ml.

5.11 Buret - 50 ml.

5.12 Pipets - 0.5, 1, 2, 3, 4, 10, 25, and 50 ml volumetric.

5.13 Erlenmeyer Flasks - 300 ml.

5.14 Oven - Capable of maintaining 105°C.

5.15 Spectrophotometer - Capable of measuring absorbance at 352 nm. Matched 1-cm cells should be used.

6. Reagents

6.1 Purified Water - Used for all reagents. To distilled or deionized water in an all-glass distillation apparatus, add a crystal of potassium permanganate and a crystal of barium hydroxide, and redistill.

6.2 Absorbing Reagent - Dissolve 13.6 g potassium dihydrogen phosphate (KH_2PO_4), 14.2 g anhydrous disodium hydrogen phosphate ($Na_2H\ PO_4$) (or 35.8 g dodecahydrate salt), and 10.0 g potassium iodide (KI) in purified water and dilute to 1000 ml. The pH should be 6.8 ± 0.2. The solution is stable for several weeks, if stored in a glass-stoppered amber bottle in a cool, dark place.

6.3 Standard Arsenous Oxide Solution (0.05 N) - Use primary standard grade arsenous oxide (As_2O_3). Dry 1 hour at 105°C immediately before using. Accurately weigh 2.4 g arsenous oxide from a small glass-stoppered bottle. Dissolve in 25 ml 1 N sodium hydroxide in a flask or beaker on a steam bath. Add 25 ml 1 N sulfuric acid. Cool, transfer quantitatively to a 1000-ml volumetric flask, and dilute to volume. NOTE: Solution must be neutral to litmus, not alkaline.

$$\text{Normality } As_2O_3 = \frac{\text{wt } As_2O_3 \text{ (g)}}{49.46}$$

6.4 Starch Indicator Solution (0.2%) - Triturate 0.4 g soluble starch and approximately 2 mg mercuric iodide (preservative) with a little water, add the paste slowly to 200 ml boiling water. Continue boiling until the solution is clear, allow to cool, and transfer to a glass-stoppered bottle.

6.5 Standard Iodine Solution (0.05 N)

6.5.1 Preparation - Dissolve 5.0 g potassium iodide (KI) and 3.2 g resublimed iodine (I_2) in 10 ml purified water. When the iodine dissolves, transfer the solution to a 500-ml glass-stoppered volumetric flask. Dilute to mark with purified water and mix thoroughly. Keep solution in a dark brown glass-stoppered bottle away from light, and re-standardize as necessary.

6.5.2 Standardization - Pipet accurately 50 ml standard arsenous oxide solution into a 300-ml Erlenmeyer flask. Acidify slightly with 1:10 sulfuric acid, neutralize with solid sodium bicarbonate, and add about 2 g excess. Titrate with the standard iodine solution using 5 ml starch solution as indicator. Saturate the solution with carbon dioxide by adding 1 ml of 1:10 sulfuric acid just before the end point is reached.

$$\text{Normality } I_2 = \frac{\text{ml } As_2O_3 \text{x Normality } As_2O_3}{\text{ml } I_2}$$

6.6 Chromium Trioxide Scrubber - Dissolve 125 g chromium trioxide (CrO_3) crystals in 35 ml concentrated sulfuric acid and add to 750 ml distilled water. Place a 15- by 25-cm sheet of a flash-fired glass-fiber filter in an oven rack equipped with glass rod attachments to prevent the filter from touching metal. Saturate the filter with 15 ml chromium trioxide solution. Place the filter in an oven set at

65-70°C for 1 hour. A freshly prepared filter is brownish pink. At the end of this time remove the filter and fold every 1-2 cm along the 15-cm dimension in an accordion fashion. While the sheet is folded, cut the 15-cm length into 10 equal widths. As each strip is cut, place it in the 140-ml U-tube. Place five cut strips in each tube, rotating alternate strips 90 degrees so that folds will not match. Before the scrubber is used for sampling, condition for several hours to ozone at a high concentration from an ozone source such as a UV photolysis lamp. As the filters absorb moisture, scrubbing efficiency is decreased. This condition is evident as a green color. CAUTION: When working with chromium trioxide and sulfuric acid, wear gloves to prevent irritation of the skin.

7. Procedure

7.1 Sampling - Assemble the apparatus as shown in Figure 1. Use ground-glass connections upstream from the impinger. Butt-to-butt connections with Tygon tubing may be used. Check assembled system for leaks. Pipet 10 ml absorbing reagent into first absorber and place MnO_2 prescrubber on the sample probe. Draw air through the prescrubber and the sampling train for 15 min. at 2 liter/min. If an absorbance reading at 352 nm is obtained, repeat until zero or constant absorbance is obtained. This system blank absorbance should be subtracted from the absorbance of the first absorber when analyzing for oxidants. Remove the prescrubber. Pipet 10 ml absorbing reagent into each absorber. Attach the chromium trioxide scrubber and draw ambient air through the sampling train at 2 liters/min. for 15 min.

7.2 Analysis- Immediately transfer the solutions from each absorber to separate clean 1-cm cells. Determine the absorbance of each at 352 nm against unexposed absorbing reagent as the reference. Add the absorbances of the two solutions to obtain total absorbance. Read total µg O_3 from the calibration curve (see 8.2).

8. Calibration, Standards, and Efficiencies

8.1 Sampling - The flowmeter must be calibrated with the sampling train assembled and solution in the absorbers. Connect the wet test meter to the sample probe and calibrate the flowmeter.

8.2 Analysis - Pipet 1 ml standard iodine solution into a 100-ml volumetric flask Dilute to mark with absorbing reagent. (Prepare fresh before use.) Into a series of 25-ml volumetric flasks, pipet 0.5, 1, 2, 3, and 4 ml of diluted standard iodine solution, and dilute each to the mark with absorbing reagent. Mix thoroughly, and immediately read the absorbance of each at 352 nm against unexposed absorbing reagent as the reference. Calculate the concentration of the solutions as total µg O_3 as follows:

$$\text{Total } \mu g\ O_3 = (N)(96)(V)$$

N = normality I_2 (see 6.5.2), meq/ml

V = volume of diluted standard I_2 added, ml (0.5, 1, 2, 3, 4)

Plot absorbance versus total µg O_3.

8.3 Sampling Efficiency - Sampling efficiency in the first absorber may be 90-95% depending upon the impinger orifice and the ozone concentration. When two absorbers are placed in series essentially all ozone is collected.

9. Calculations

9.1 Sampling - Correct the volume of air sampled to the volume at standard conditions of 25°C and 760 mm Hg.

$$V_s = V \times \frac{P}{760} \times \frac{298}{t + 273}$$

V_s = volume of air at standard conditions, liters
V = volume of air at sampling conditions, liters
P = barometric pressure, mm Hg
t = temperature of sample, °C

9.2 Calculate ozone concentration in $\mu g/m^3$ at standard conditions of 25°C and 760 mm Hg.

$$\mu g\ O_3/m^3 = \frac{(A)\ (10^3)}{V_s}$$

A = Total $\mu g\ O_3$ read from calibration curve
10^3 = conversion of liters to cubic meters
V_s = volume sampled at standard conditions, liters

9.2.1 If desired, concentration of oxidants may be calculated as ppm O_3 at standard conditions of 25°C and 760 mm Hg.

$$ppm\ O_3 = (\mu g\ O_3/m^3)\ (5.094 \times 10^{-4})$$

Derivation of equation for total $\mu g\ O_3$ (See 8.2)

(1) Total $\mu g\ O_3 = [N_D\ (meq/ml)] \times [10\ ml) \times [24{,}000\ \mu g/meq]$

(2) N_D = normality of diluted calibration standard

$$N_D = [\frac{1}{100}(1st\ dilution)] \times [\frac{V}{25}(2nd\ dilution)]$$

(3) therefore: Total $\mu g\ O_3 = (N)(96)(V)$

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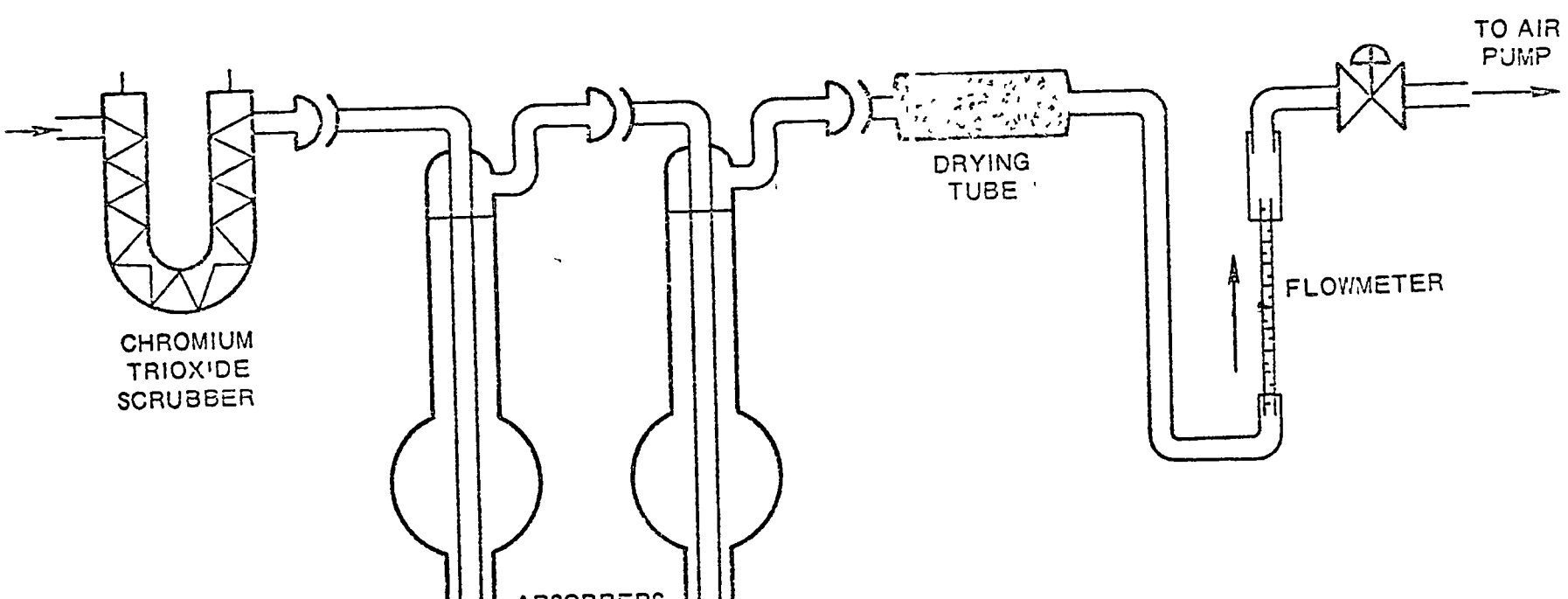

Figure 1. Sampling train.

IV

TENTATIVE METHODOD FOR DETERMINATION OF NITROGEN DIOXIDE IN THE ATMOSPHERE (GRIESS-SALTZMAN REACTION)

(Key Words: Nitrogen Dioxide, Ambient Air, Spectrophotometric)

1. Principle and Applicability

1.1 The air sample is drawn through a fritted glass bubbler containing an azo-dye-forming reagent in acid media.[1]

1.2 The nitrite ion formed reacts to produce an azo dye, which is measured spectrophotometrically.

1.3 The method is applicable to short-term sampling. Sampling periods should not exceed 1 hour because of possible color fading.

2. Range and Sensitivity

2.1 The method can determine 40 to 1500 μg NO_2^-/m^3 (0.02 to 0.75 ppm). For higher concentrations, sampling time may be less than 30 min.

2.2 At a sampling rate of 0.3 liter/min. for 30 min., 40 $\mu g/m^3$ (0.02 ppm) nitrogen dioxide will produce an absorbance of approximately 0.03 in a 1-cm cell.

3. Interferences

3.1 A 10-fold ratio of sulfur dioxide to nitrogen dioxide produces no effect. A 30-fold ratio slowly bleaches the color.

3.2 A 5-fold ratio of ozone to nitrogen dioxide causes some interference.

3.3 Peroxyacetyl nitrate (PAN) gives a response of approximately 15 to 24 percent of an equivalent molar concentration of nitrogen dioxide.[2] In ordinary ambient air the concentrations of PAN are too low to cause any significant error.

3.4 Interference from other nitrogen oxides and other gases that might be found in polluted air is negligible. For example, nitric oxide at concentrations above 120,000 $\mu g/m^3$ (100 ppm) will interfere; but these concentrations do not ordinarily occur.

4. Precision, Accuracy, and Stability

4.1 Under laboratory conditions, precision of ± 2% (expressed as relative standard deviation) can be achieved for sampling and analysis. The precision within an individual laboratory for concentrations of 0.20 μg/ml and 0.61 μg/ml are ± 2% and ± 1.3%, respectively.

4.2 No accuracy data for sampling are available; in analysis for nitrite ion, mean errors are -3.0% and -1.0% at 0.20 μg/ml and 0.61 μg/ml, respectively.

4.3 After collection, 15 min. is required for full color development. The colors must be measured within 1 hour to minimize loss from strong oxidizing or reducing agents. Colors produced by nitrite solution or pure nitrogen dioxide test atmospheres may be preserved with only 3 to 5 percent loss in absorbance per day if bottles are well stoppered.

5. Apparatus

5.1 Sampling

5.1.1 Absorber - The sample is absorbed in an all-glass bubbler with a 60 μm maximum pore diameter frit similar to that illustrated in Figure 1. The bubblers can be obtained from major glassware suppliers.

5.1.1.1 Perodically measure the porosity of an absorber. Clean the apparatus with dichromate-concentrated sulfuric acid solution and rinse thoroughly with distilled water and acetone. Assemble the bubbler, add distilled water to barely cover the fritted portion, and measure the vacuum required to draw the first perceptible stream of air bubbles through the frit. Calculate the maximum pore diameter.

$$\text{Maximum pore diameter, } \mu m = \frac{30s}{P}$$

s = surface tension of water at the test temperature, dynes/cm (73 at 18°C, 72 at 25°C, and 71 at 31°C)

P = measured vacuum, mm Hg.

5.1.2 Flowmeter - A glass flowmeter capable of measuring a flow of 0.3 liter/min. within ± 2%.

5.1.3 Air Metering Device - A 24-gauge hypodermic needle to maintain a flow of approximately 0.3 liter/min.

5.1.4 Trap - Containing glass wool and sodium hydroxide pellets or Ascarite^{R} to protect the flow metering device.

5.1.5 Sampling Probe - A glass or stainless steel tube 6 to 10 mm in diameter provided with a downward-facing intake (funnel or tip) is suitable. A small, loose fitting plug of glass wool may be inserted in the probe to exclude water droplets and particulate matter, but this may cause a loss of nitrogen dioxide. Keep the dead volume of the system to a minimum to avoid losses of nitrogen dioxide on the surfaces.

5.1.6 Air Pump - Capable of drawing air through the sampling system at 0.3 liter/min. for 30 min. If a hypodermic needle is used, the pump must be capable of maintaining 0.7 atmosphere vacuum.

5.2 Analysis

5.2.1 Volumetric flasks - 25, 1000 ml

5.2.2 Pipets - 1, 10, and 25 ml volumetric, 1 ml, graduated in 1/10 ml intervals.

5.2.3 Spectrophotometer or colorimeter - A laboratory instrument capable of measuring the pink color at 550 nm with stoppered tubes or cuvettes. The wavelength

6. Reagents

6.1 Nitrite-Free Water - All solutions are made in nitrite-free water. If the available distilled or deionized water contains nitrite impurities (produces a pink color when added to absorbing reagent), redistill from an all-glass still after adding a crystal each of potassium permanganate and barium hydroxide.

6.2 NEDA Solution - Dissolve 0.100 g N-1-naphthylethylenediamine dihydrochloride (NEDA) in 100 ml 1% aqueous acetic acid. Solution will be stable for several months if kept well-stoppered in a brown bottle.

6.3 Absorbing Reagent - Dissolve 5.00 g anhydrous sulfanilic acid (or 5.52 g $NH_2 \cdot C_6H_4SO_3H \cdot H_2O$) in 800 ml hot distilled water. Cool the mixture, add 140 ml glacial acetic acid and 20 ml NEDA stock solution and dilute to 1 liter. Avoid excessive exposure to air during preparation and use to prevent absorption of nitrogen dioxide. The solution will be stable for several months if kept well-stoppered in a brown bottle in the refrigerator. Allow absorbing reagent to equilibrate to room temperature before use.

6.4 Standard Nitrite Solution - Dissolve sufficient desiccated sodium nitrite ($NaNO_2$, assay of 97% or greater) and dilute with distilled water to 1000 ml so that a solution containing 1000 µg NO_2^-/ml is obtained. The amount of $NaNO_2$ to use is calculated as follows:

$$G = \frac{1.500}{A} \times 100$$

G = amount of $NaNO_2$, g
1.500 = gravimetric factor in converting NO_2 into $NaNO_2$
A = assay, %

7. Procedure

7.1 Sampling - Assemble the apparatus as shown in Figure 1. Use ground-glass connections upstream from the absorber. Pipet 10 ml absorbing reagent into the absorber. Shield the absorber from direct light. Connect calibrated flowmeter to probe and start sampling. Record flow and remove flowmeter. Sample for 30 min. at approximately 0.3 liter/min. and measure flow at end of sampling period.

7.1.1 If making routine measurements, the porosity of the frit should be checked after each 24 hr. of use.

7.2 Analysis - After collection of the sample, wait 15 min. for the color to develop. Read absorbance at 550 nm using unexposed reagent as a reference. Read the µg NO_2^-/ml from the calibration curve (8.2).

8. Calibration, Standards, and Efficiencies

8.1 Calibrate the flowmeter using a wet test meter.

8.2 Pipet 25 ml stock nitrite solution into a 1000-ml volumetric flask and dilute to mark with nitrite-free water. Add 0.2, 0.4, 0.6, 0.8, and 1.0 ml dilute solution to a series of 25-ml volumetric flasks and dilute to mark with absorbing reagent. The solutions contain 0.2, 0.4, 0.6, 0.8, and 1.0 µg NO_2^-/ml absorbing reagent. Mix, wait 15 min. and read the absorbances as in 7.2. Plot absorbance versus µg NO_2^-/ml.

8.3 Collection efficiency of over 95 percent can be expected with flow rates less than 0.4 liter/min. and a maximum pore diameter of 60 μm.

8.4 A stoichiometric factor must be introduced to account for the observation that 1 mole of nitrogen dioxide does not produce 1 mole of nitrite ion. Various values for this factor ranging from 0.5 to 1.0 have been reported. The best available data to date indicate a value of 0.76 which is in general agreement with the 0.72 factor in common usage.[3] Permeation tubes can be used to prepare the calibration curve and avoid the use of this empirical factor.[4,5]

9. Calculation

9.1 Sampling

9 1.1 Calculate sample volume at standard conditions of 25°C and 760 mm Hg.

$$V_s = AB \times \frac{P}{760} \times \frac{298}{t + 273}$$

V_s = sample volume at standard conditions, liters.
A = average sampling rate, liters/min.
B = sampling time, min.
P = barometric pressure, mm Hg.
t = temperature of sample air, °C.

Ordinarily, the correction for pressure is slight and may be neglected

9.2 Calculate the concentration of nitrogen dioxide in the air sample:

$$\mu g\ NO_2/m^3 = \frac{(\mu g\ NO_2^-/ml)(10)(10^3)}{V_s \times 0.76} = \frac{(\mu g\ NO_2^-/ml)(1.32 \times 10^4)}{V_s}$$

10 = volume of absorbing reagent, ml
10^3 = conversion, liters to cubic meters
V_s = volume of air sample at standard conditions, liters
0.76 = stoichiometric factor, $\mu g\ NO_2^-/\mu g\ NO_2$

9.2.1 If desired, concentration of nitrogen dioxide may be calculated as ppm NO_2 at standard conditions of 25°C and 760 mm.

$$ppm = (\mu g\ NO_2/m^3) \times 5.319 \times 10^{-4}$$

10. References

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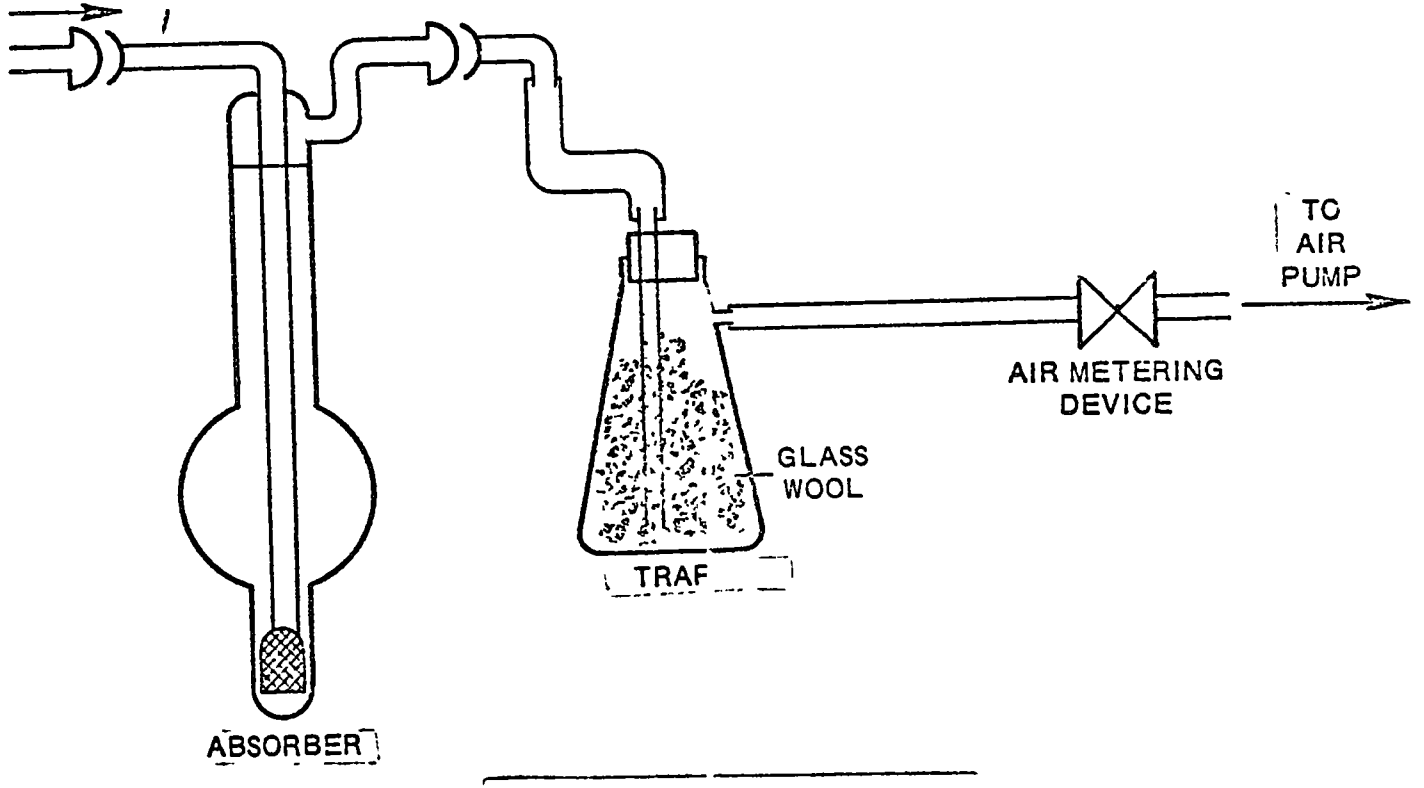


Figure 1. Sampling train.

REQUIREMENTS FOR IMPLEMENTATION PLAN
SAMPLING SITES

I. Fixed Stations

A Station Location

CO

- in a populated area

  downtown in area of heavy traffic

- near streets with high traffic flow - preferably near intersection

II. - 50 to 100 feet from curb

- 15 to 30 feet above street level

- down wind of traffic

Ox

- 4 to 8 miles down wind of downtown

- in a populated area

B. Instrument Location

- on outside wall in close proximity of sampling point

- distance from instrument to outside not to exceed 20 feet

- access to working space is necessary after regular working hours and on non-work days

C. Sample Probe Location

- sample probe to extend approximately 5 feet from building

D. Equipment Space Requirements

	CO	Ox
Bench space (min.)	3' x 4'	3' x 6'
Floor space for gas storage	3' x 6'	3' x 6'

E. Environment

- temperature controlled to + 5°F within the range of 70-85°F

F. Power Requirements

- 10-15 amps circuit with no other load on circuit

G. Manpower

- technician to be furnished by local agency, 4 man-hours per day. One week on-the-job training will be given on the operation of instruments and data reduction.

II. Mobile Sampling

A. Station Location

- variable, depending on complexity of mobile and stationary source emission pattern

- dependency on power availability

1. Stationary power - preferably less than 50 feet from service entrance, not to exceed 100 feet

2. Stationary power and mobile generator - not to exceed 100 feet from service entrance

3. Generator only - not to exceed 100 feet from generator.

- locations to be considered

1. Public property - schools, hospitals, health department, fire department, streets

2. Private property - service stations, bus stations, parking lots

Obtain written permission from appropriate authority. The site has to have protection from vandalism and be accessible at all times. It is recommended that one alternate site be designated for each selected site.

B. Instrument Location

- in mobile lab

C. Sample Probe Location

- nominal 5 feet from mobile trailer

D. Equipment Space Requirements

- mobile lab with towing vehicle (min): 50' x 15'
- mobile generator with towing vehicle (min): 10' x 15'

E. Environment

- temperature of mobile lab is controlled to ± 2°F

F. Power Requirement

- stationary power: access to 30 amps with no other load on circuit for temporary service. Conform with local codes. The service connections may have to be made by licensed electrician and/or power company.

- stationary power and mobile generators: 15 amps circuit with no other load for instrument operation. Generator for mobile lab (air conditioner, lights, etc.)

- generator only: instrument performance may be affected by load on generator

G. Manpower

- APCO personnel

H. Towing Requirements

- a station wagon each with towing hitch is adequate for mobile lab and generator towing. Provisions for electrical connections (lights, etc.) have to be made in accordance with city ordinances and state laws. Availability through GSA or commercial leasing companies such as U-Haul, Rider, etc. has to be ascertained.

Spitzer

Contaminants - Origen & Characteristics (Overview)

Four basic types of polluted atmosphere

1) Energy Production

Coal (oil or gas) burning for electrical power and domestic heating - Primary emissions SO_2, Particulate

Secondary " H_2SO_4, Trace Metals

Best Example: London, England

2) Mobile Sources

Automobile, Diesel Bus

Primary emissions: NO, CO, HC (Hydrocarbons)

Secondary pollutants: O_3, PAN, Aldehydes & other organics

Best Example: Los Angeles, California

3) Industrial Processes

Ferrous metals (Gary, Indiana) - Fe, Mn, Particulate, H_2S

Oil Processing (Houston, Texas) - H_2S, SO_2, RSH (Mercaptans)

Chemical Industry - widespread - great variety of organic

Mining & Smelting - SO_2, particulate

Paper pulp Industry - H_2S, SO_2, odors

Incineration of Refuse - odors, particulate, great variety of gases & metals

Sewage Disposal - odors

4) Natural Pollution (Little control Possible)

Volcanoes

Dust + Sand storms

NaCl (ocean spray)

Pollen

Tree emanations (e.g. pines etc.)

Mineral Deposits - wind + erosion

Detailed Discussion

1) Energy Production

Central problem not SO_2, but H_2SO_4

$SO_2 + O^* \Rightarrow SO_3 + H_2O \Rightarrow H_2SO_4$

H_2SO_4 adsorbs on particulate matter & is carried into lungs

High SO_2 with no particulate is not as serious as lower SO_2 + particulate.

Material Damage from H_2SO_4 → to building materials

MCO_3 (in limestone) + $SO_3 \Rightarrow MSO_4$
insoluble soluble

leather + $H_2SO_4 \Rightarrow$ corrosion & rotting

Health effects: must be interpreted with caution.

e.g. in Dublin, Ireland excess death in winter were attributed to SO_2 + particulate. But when coal substitute was used (1942-1946) burning low SO_2 + particulate emission, excess death continued as before!

2) Mobile Sources

Primary emissions CO, NO, HC, (NO_2), Pb

Photochemical Smog

a) $NO_2 + h\nu \Rightarrow NO + O$ fast

b) $O + O_2 + M \Rightarrow O_3 + M$ fast (M absorbs excess energy) N_2, O_2 etc.

c) $O_3 + NO \Rightarrow NO_2 + O_2$ fast

conclusion: O_3 + NO are in equal amounts

d) $O_3 = k_1 I \frac{(NO_2)}{(NO)}$ I = light intensity, k_1 = constant

experiment show $k_1 I \leq .02$ ppm ($26\ \mu g/m^3$)

Hence if $O_3 = .1$ ppm, NO_2/NO must equal 10

But O_3 has been measured above .3 ppm.

∴ some new element must disrupt equilibrium of a, b + c. This is reactive hydrocarbons. (OI)

e) $OI + O \Rightarrow OIO^*$ (free radical)

f) $OIO^* + O_2 \Rightarrow OIO_2^*$

g) $nIO^* \Rightarrow RCHO + RO^* + RCO^*$

h) $RCO^* + O_2 \rightarrow RCO_3^*$

i) $RCO_3^* + NO_2 \rightarrow RCO_3NO_2$ (PAN - peroxyacetyl nitrate if $R = CH_3$)

Cycle-O

j) $RO^* + O_2 + NO \rightarrow RO_2^* + NO_2$

k) $RO_2^* + NO \rightarrow RO^* + NO_2$

Hence NO can be converted to NO_2, and NO_2 to PAN without decreasing O_3 concentration.

Proof of reactive hydrocarbon hypothesis

Polluted air (HC, NO, NO_2, O_3) was irradiated with UV light for 24 hrs.

Hydrocarbon	at 0 hrs.	at 24 hrs	
ethane	.0385 ppm	.0384	inactive
3-me-pentane	.0348	.0088	active in 24 hrs.
ethylene	.134	.032	very reactive
propylene	.035	.001	"
2-butene	.006	.000	"
1-pentene	.005	.000	"
2-pentene	.005	.000	"
acetylene	.3105	.262	almost inactive

3) Industrial Processes

a) Particles (copy of p 10-8 from Handbook of Air Pollution - publ. National Air Pollution Control Assn. USA)

b) Measurement limitations

i) Specific particles - must be > 10 μ; but most atmospheric particles are < 5 μ. Therefore difficult to identify particle + source.

ii) General Properties

elemental analysis of mass of particle

determination of total mass

identification of anions in collected particulates

possible new tools - infra-red, [illegible], neutron activation, X-ray fluorescence

c) Gases
Will be discussed throughout seminar

SO_2 (H_2SO_4)
H_2S
CO
NO (NO_2)
HC
O_3
HCl
Cl_2
HF
F_2 etc.

units of measure - (conversion chart)

d) Smoke - will be discussed on Tuesday

e) Odors - everything is subjective because only the human nose detects specific odors as odors.

i) Intensity - many scales set up.

$I = k \ln C$ $\quad C$ = concentration of odor

ii) Threshold - minimum concentration which stimulates olfactory nerve.
Determined when 50% of test panel agree.

iii) Interaction of 2 odors

Independent
$I_{AB} = k \ln (C_A \text{ or } C_B)$

Counteracting
$I_{AB} < k \ln (C_A \text{ or } C_B)$

Additive
$I_{AB} = k \ln (C_A + C_B)$

Synergistic
$I_{AB} > k \ln (C_A + C_B)$

iv) Quality - many systems of classification

v) Acceptability - again variable - may depend on psychological factors, previous experience etc.

vi) Pervasiveness

ability of an odor to pervade a large volume of air & still be detectable.

measurement: odor units - number of volumes of clean air required to dilute one volume of odorous air to threshold value.

vii) Odor Theories

Wave - compound emits e.m. waves.

Contact - " must contact olfactory organ

Raman Shift - compound emits specific raman shift in energy spectrum

Stereochemical - stereochemistry of molecule affects olfactory organ.

viii) Odor Control Methods

Combustion at 1200°F

Water Soluble e.g. NH_3, SO_2 - creates water pollution problem

Absorption - active charcoal

Masking - perfume to mask body odor

Counteracting - wax + rubber

Dilution w. clean air

Oxidation - Cl_2, $KMnO_4$

Biological - Sewage treatment

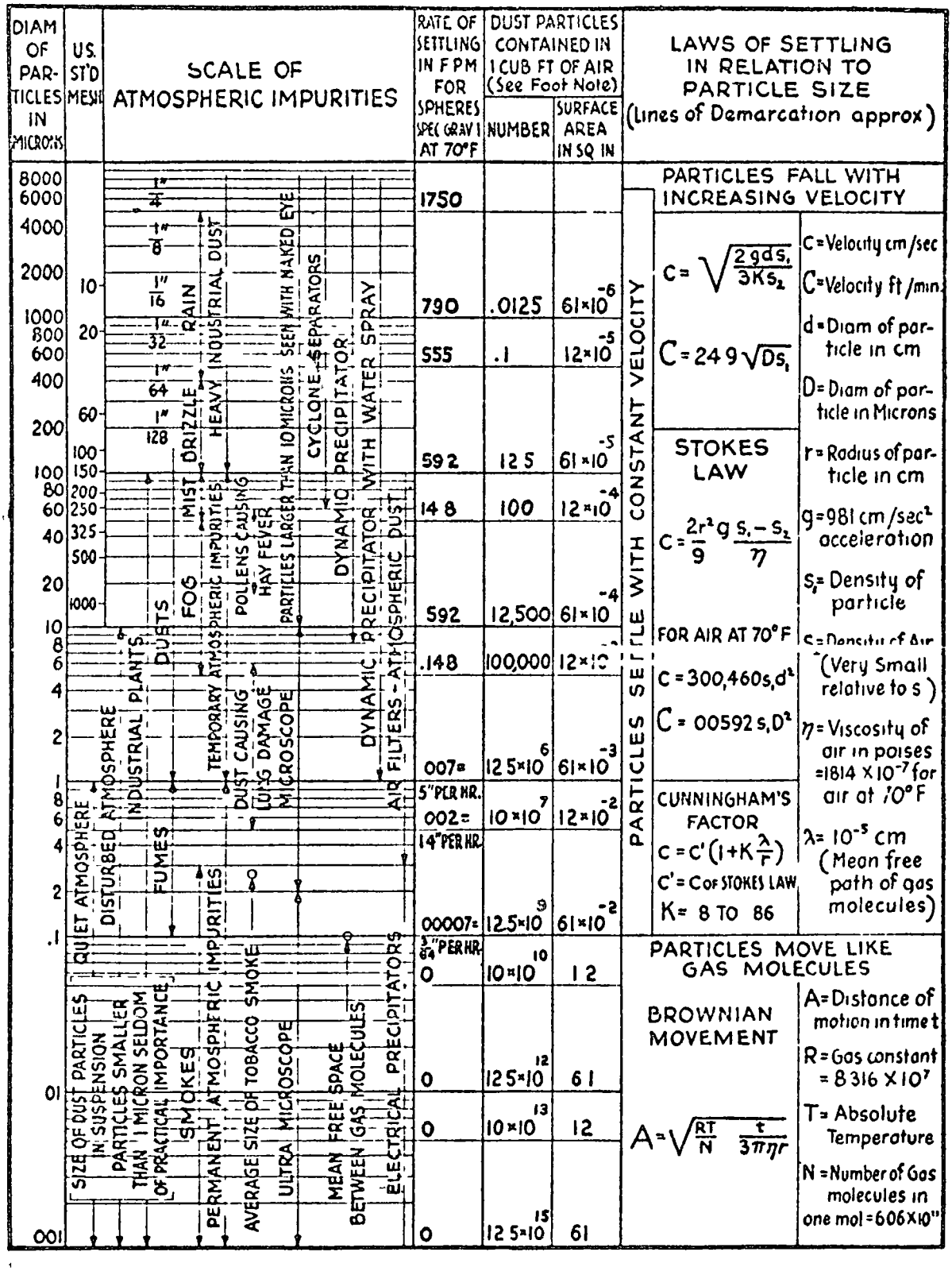
Containment - Covering + venting area

ix) Sampling

Gas chromatography - not sensitive enough

Human Nose still best means! [illegible]

SIZE AND CHARACTERISTICS OF AIR-BORNE SOLIDS (FRANK CHART)



IT IS ASSUMED THAT THE PARTICLES ARE OF UNIFORM SPHERICAL SHAPE HAVING SPECIFIC GRAVITY ONE AND THAT THE DUST CONCENTRATION IS 0 1 GRAINS PER 1000 CU FT OF AIR, THE AVERAGE OF METROPOLITAN DISTRICTS

See Reference No. 8

GASEOUS POLLUTANT CONVERSION CALCULATIONS

For use in interconverting ppm and ug/m^3 or mg/m^3

(Formula taken from AIR QUALITY CRITERIA DOCUMENTS - Appendix)

To convert ug/m^3 to ppm or vice versa, the following formula may be used:

$$ppm = \frac{w \times 10^6 ug/g}{V \times 10^{-3} m^3/l} \times \frac{8.21 \times 2.98}{M.W. \text{ of gas} \times 10^6}$$

To convert mg/m^3 to ppm etc., modify formula to:

$$ppm = \frac{w \times 10^3 mg/g}{\quad}$$

The following list of values is derivable from these formulas.

CO	1 mg/m^3 = .874 ppm	1 ppm = 1.15 mg/m^3
CH_4	1 ug/m^3 = .00153 ppm	1 ppm = 653 ug/m^3
NO	1 ug/m^3 = .000816 ppm	1 ppm = 1,260 ug/m^3
NO_2	1 ug/m^3 = .000532 ppm	1 ppm = 1,880 ug/m^3
O_3	1 ug/m^3 = .000510 ppm	1 ppm = 1,960 ug/m^3
SO_2	1 ug/m^3 = .000382 ppm	1 ppm = 2,620 ug/m^3

* M.W. = Moleculor Weight: CO,28, CH_4,16; NO,30, NO_2,46, O_3,48, SO_2,64.

To convert

x ug/m^3 to ppm multiply x by: .00153 ppm for CH_4
.000816 ppm for NO
.000532 ppm for NO_2
.000510 ppm for O_3
.000382 ppm for SO_2

x mg/m^3 to ppm multiply x by: .874 ppm for CO

To convert y ppm to ug/m^3

multiply y by: 653 ug/m^3 for CH_4
1,260 ug/m^3 for NO
1,880 ug/m^3 for NO_2
1,960 ug/m^3 for O_3
2,620 ug/m^3 for SO_2

To convert y ppm to mg/m^3 multiply y by: 1.15 mg/m^3 for CO

RINGELMANN SMOKE CHART

(Revision of IC 7718)

By Staff, Bureau of Mines

* * * * * * * * * * * * information circular 8333

UNITED STATES DEPARTMENT OF THE INTERIOR
Stewart L Udall, Secretary

BUREAU OF MINES
Walter R. Hibbard, Jr., Director

This publication has been cataloged as follows

U.S. Bureau of Mines

Ringelmann smoke chart. [Washington] U.S. Dept. of the Interior, Bureau of Mines [1967]

4 p. (U. S. Bureau of Mines. Information circular 8333)

Revision of I. C. 7718: Kudlich, Rudolf. Ringelmann smoke chart. 1955.

1. Smoke prevention. I. Ringelmann, Maximilian, 1861- . II. Kudlich, Rudolf. III. Title. (Series)

TN23.U71 no. 8333 622.06173

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RINGELMANN SMOKE CHART

(Revision of IC 7718)

by

Staff, Bureau of Mines[1]

ABSTRACT

The Ringelmann Smoke Chart fulfills an important need in smoke abatement work and in certain problems in the combustion of fuels. A knowledge of its history and method of preparation is, therefore, of interest to many. Since instructions on its use are not shown on the recent edition of the chart, those included in this revision of the previous Bureau of Mines publication now are a necessary complement to the chart. More detail regarding the use of the chart is included than was given in the earlier version.

INTRODUCTION

The Ringelmann Smoke Chart, giving shades of gray by which the density of columns of smoke rising from stacks may be compared, was developed by Professor Maximilian Ringelmann of Paris. Ringelmann, born in 1861, was professor of agricultural engineering at l'Institute National Agronomique and Director de la Station d'Essais de Machines in Paris in 1888, and held those positions for many years thereafter.

The chart apparently was introduced into the United States by William Kent in an article published in Engineering News of November 11, 1897, with a comment that he had learned of it in a private communication from a Bryan Donkin of London. It was said to have come into somewhat extensive use in Europe by that time. Kent proposed in 1899 that it be accepted as the standard measure of smoke density in the standard code for power-plant testing that was being formulated by the American Society of Mechanical Engineers.

The Ringelmann Chart was used by the engineers of the Technologic Branch of the U.S. Geological Survey (which later formed the nucleus of the present Bureau of Mines) in their studies of smokeless combustion beginning at St. Louis in 1904, and by 1910, it had been recognized officially in the smoke ordinance for Boston passed by the Massachusetts Legislature.

The chart is now used as a device for determining whether emissions of smoke are within limits or standards of permissibility (statutes and ordinances) established and expressed with reference to the chart. It is widely

[1]Office of the Director of Coal Research, Washington, D.C.

used by law-enforcement or compliance officers in jurisdictions that have adopted standards based upon the chart.

In 1908, copies of the chart were prepared by the Technologic Branch of the Geological Survey for use by its fuel engineers and for public distribution. Upon its organization in 1910, the Bureau of Mines assumed this service together with the other fuel-testing activities of the Technologic Branch.

DESCRIPTION AND METHOD OF PREPARING THE CHART

The Ringelmann system is virtually a scheme whereby graduated shades of gray, varying by five equal steps between white and black, may be accurately reproduced by means of a rectangular grill of black lines of definite width and spacing on a white background. The rule given by Professor Ringelmann by which the charts may be reproduced is as follows:

Card 0--All white.

Card 1--Black lines 1 mm thick, 10 mm apart, leaving white spaces 9 mm square.

Card 2--Lines 2.3 mm thick, spaces 7.7 mm square.

Card 3--Lines 3.7 mm thick, spaces 6.3 mm square.

Card 4--Lines 5.5 mm thick, spaces 4.5 mm square.

Card 5--All black.

The chart, as distributed by the Bureau of Mines, provides the shades of cards 1, 2, 3, and 4 on a single sheet, which are known as Ringelmann No. 1, 2, 3, and 4, respectively. Additional copies of the chart may be obtained free by applying to the Publications Distribution Branch, Bureau of Mines, 4800 Forbes Avenue, Pittsburgh, Pa. 15213.

USE OF CHART

Many municipal, state, and federal regulations prescribe smoke-density limits based on the Ringelmann Smoke Chart, as published by the Bureau of Mines. Although the chart was not originally designed for regulatory purposes, it is presently used for this purpose in many jurisdictions where the results obtained are accepted as legal evidence.

While the chart still serves a useful purpose, it should be remembered that the data obtained by its use is empirical in nature and has definite limitations. The apparent darkness or opacity of a stack plume depends upon the concentration of the particulate matter in the effluent, the size of the particulate, the depth of the smoke column being viewed, natural lighting conditions such as the direction of the sun relative to the observer, and the color of the particles. Since unburned carbon is a principal coloring material in a smoke column from a furnace using coal or oil, the relative shade is a function of the combustion efficiency.

While the Ringelmann Smoke Chart has many limitations, it gives good practical results in the hands of well-trained operators. However, it is questionable whether results should be expressed in fractional units because of variations in physical conditions and in the judgement of the observers.

To use the chart, it is supported on a level with the eye, at such a distance from the observer that the lines on the chart merge into shades of gray, and as nearly as possible in line with the stack. The observer glances from the smoke, as it issues from the stack, to the chart and notes the number of the chart most nearly corresponding with the shade of the smoke, then records this number with the time of observation. A clear stack is recorded as No. 0, and 100 percent black smoke as No. 5.

To determine average smoke emission over a relatively long period of time, such as an hour, observations are usually repeated at one-fourth or one-half minute intervals. The readings are then reduced to the total equivalent of No. 1 smoke as a standard. No. 1 smoke being considered as 20 percent dense, the percentage "density" of the smoke for the entire period of observation is obtained by the formula·

$$\frac{\text{Equivalent units of No. 1 smoke} \times 0.20 \times 100}{\text{Number of observations}} = \text{percentage smoke density.}$$

A convenient form for recording and computing the percentage of smoke density appears at the end of this report. This procedure is often used on acceptance tests of fuel-burning equipment.

The timing and extent of observations made for the purpose of determining compliance with a local smoke abatement ordinance depends upon the wording and smoke limitations of the ordinance.

RINGELMANN-CHART READING

Location.....

Hour 9:00-10:00 A.M. ..... Date.....

9

	0	1/4	1/2	3/4		0	1/4	1/2	3/4
0	-	-	-	-	30	1	1	1	1
1	-	-	-	-	31	1	1	1	1
2	-	-	-	-	32	-	-	-	-
3	1	1	1	1	33	-	-	-	-
4	1	1	1	1	34	-	-	-	-
5	2	2	2	2	35	1	1	1	1
6	2	3	3	3	36	1	1	1	1
7	3	3	3	3	37	1	1	1	1
8	2	2	1	1	38	1	1	-	-
9	1	1	-	-	39	-	-	-	-
10	-	-	-	-	40	-	-	-	-
11	-	-	-	-	41	-	-	-	-
12	-	-	-	-	42	-	-	-	-
13	-	-	-	-	43	-	-	-	-
14	-	-	-	-	44	1	1	2	2
15	-	-	-	-	45	2	2	3	3
16	-	-	-	-	46	3	3	3	3
17	-	-	-	-	47	3	3	4	3
18	-	-	-	-	48	2	2	2	2
19	2	2	2	2	49	2	2	2	2
20	2	2	2	2	50	2	1	1	1
21	2	2	2	2	51	1	1	1	1
22	3	3	3	3	52	1	1	1	-
23	3	4	4	4	53	-	-	-	-
24	4	5	5	5	54	-	-	-	-
25	5	5	5	5	55	-	-	-	-
26	4	4	3	3	56	-	-	-	-
27	3	3	3	3	57	-	-	-	-
28	2	2	1	1	58	-	-	-	-
29	1	1	1	1	59	-	-	-	-

Point of observation

.....

Distance to stack.....

Direction of stack.....

Direction of wind.....

Velocity of wind.....

Equiv. No. 1 Units

..7. Units No. 5.....35.....

..7. Units No. 4.....28.....

.27. Units No. 3.....81.....

.34. Units No. 2.....68.....

.52. Units No. 1.....52.....

113. Units No. 0.....0.....

240. Units .....264.....

$\frac{264}{240}$ X 20 pct =

.....22.pct.....Smoke density

Observer.....

Checked by.....

INT-BU OF MINES,PGH,PA 10992

2 EQUIVALENT TO 40 PERCENT BLACK

1 EQUIVALENT TO 20 PERCENT BLACK

Operations such as evaporation, drying, combustion and gas-scrubbing inherently emit water vapor that condenses in the colder atmosphere, forming opaque plumes Are such plumes really objectionable? Which design methods will serve to eliminate them, and what do these methods entail in terms of capital and operating costs?

Water Vapor in Effluent Gases: What to Do About Opacity Problems

BURTON B CROCKER, *Monsanto Co*

To the layman, the plume pictured on this page may appear to be a flagrant example of air pollution. Yet chemical analysis may show that 99 999% of the stack effluent is water vapor and air components. In that case, does the plant operator have anything to worry about? Under the equivalent opacity concept, perhaps he does. Let us quickly see how this concept came about

Slightly before the turn of the century in France, Prof. Max Ringelmann[1] published his now well-known method for qualitatively measuring the completeness of combustion of carbonaceous materials; he compared the darkness of the smoke emitted from a stack with the darkness of alternate black and white bands that were printed on areas of a poster and displayed a standard distance from the observer His darkness scale varied from 0 to 5, so that Ringelmann No 2 is equivalent to 40% black squares and 60% white squares (No 5 is 100% black, whereas No 0 is 100% white or colorless)

Although reasons have been set forth showing why the Ringelmann method is invalid,[2] the test has been incorporated as a control measure into practically all the pollution-control legislation in the country, and has generally been upheld by the courts as a valid and reasonable test for legal control purposes

More recently, in California, the concept of equivalent opacity[3] has been extended to the control of pollution from non-black plumes Equivalent opacity is generally defined as non-black smoke having an opacity such as to obscure an observer's view to a degree equal to that of black smoke of a particular Ringelmann shade The basic regulation in California State Law requires plumes of non-black smoke to have equivalent opacity of less than No 2 Ringelmann smoke, or essentially a plume that is less than 40% opaque.

Yocom,[4] Conner and Hodkinson[5] have pointed out problems in training smoke observers, and in ensuring that variations in lighting and background do not cause errors in determining equivalent opacity. For these reasons, it is preferable to determine effluent contaminants via chemical analysis of actual stack samples. Nevertheless, because of the ease of monitoring a control area by visual observation, the principle of equivalent opacity as applied to non-black plumes has remained attractive, and its legal application has generally been upheld by the courts

It is true that opacity observation of a non-black plume containing particulate solids in a comparatively dry gas is perhaps subject to some error due to lighting or background effects, and may be unfair

in neglecting the effect of stack diameter * However, this does not usually create much of a problem of interpretation for either the operator or the control official

But as for discharge of hot gases containing sizable quantities of water vapor, condensation will frequently start either in the stack or a short distance above it The quantity of water condensing may be sufficient to make the entire effluent plume essentially 100% opaque even though the quantity of other particulate matter is negligible Such a plume can raise serious questions for both the operator and for the control official unless the opacity regulations are carefully drafted when legislation and regulations are adopted

Within the last two years, there has been a growing tendency for other communities outside of California to adopt equivalent opacity requirements for non-black plumes, some of them further proposing requirement of opacity equivalent to Ringelmann No 1 for non-black plumes, while retaining a requirement of Ringelmann No 2 for black plumes. In many of these new or proposed requirements, only very limited attention has been paid to the effect of condensing water vapor in plumes This can lead to difficulties, as we shall see

Is Discharge of Water Vapor Objectionable?

While air is commonly considered to be composed primarily of oxygen and nitrogen, the atmosphere as we know it always contains appreciable quantities of water vapor (At 80 F and 60% relative humidity, air is approximately 2 3% water vapor by volume) In fact, very low levels of water vapor, as occur in winter in cold climates and on the desert, are objectionable A very low humidity contributes to the drying out of wood and production of cracks in floors and furniture A relative humidity of around 50% is considerably more healthful than either very dry or very humid conditions, for reasons that involve both the reproduction of microorganisms and the effects of humidity on the epithelial tissues of the respiratory tract

It would thus appear that, in many areas, particularly the western half of the U S , the discharge of water vapor should be beneficial, tending to increase the humidity and rainfall In areas with ample rainfall, the addition of a limited amount of water vapor to the atmosphere would have an insignificant effect on increasing the humidity, because the added H_2O would form a very small fraction of the total H_2O present.

In those few areas where condensing water vapor from a plume might obstruct visibility on a highway due to local topography or frequent ground fogs, water vapor might best be controlled by nuisance regulations rather than by opacity regulations

Elsewhere, the discharge of water vapor should be considered objectionable only if the sight of a plume is aesthetically objectionable While there are scenic recreational areas where any plume, and probably even the presence of a stack, might be intolerable, the presence of a condensing water-vapor plume per se in the usual industrialized area should not be objectionable

Is Discharge of Water Vapor Necessary?

There have been comments that industry adds steam or water vapor to effluents to mask the presence of other contaminants in the plume, and to make it difficult for control officials to exercise control of effluents by visual observation Perhaps this statement might be true of some small "fly by night" operation However, I am familiar with a great many installations that are of necessity emitting water vapor to the atmosphere, and no not know of a single operation in which water vapor is deliberately added to the effluent in order to conceal an emission.

The box on this page lists a number of operations that must ordinarily discharge gases containing high quantities of water vapor In many chemical, food and allied processes, water is used as a processing medium that must then be removed by evaporation in a drying operation Category (1) processes are typical This evaporated waste water is most economically disposed of to the atmosphere Category (2) operations produce water in the flue gas from combustion of hydrogen and hydrocarbons

Many operations evolve hot dusty gases—e g , from kilns, calciners, ovens, metallurgical processes and furnaces. The gases must be processed to remove particulates before release to the atmosphere While use of cyclone collectors would be the easiest and most economical way to handle hot gases, cyclones have too low a collection efficiency (85 to

* At constant particulate loading a high-velocity, small-diameter stack discharge will appear less opaque than will the same effluent discharging at low velocity through a large-diameter stack This is because one is looking through a thinner layer of smoke and, at any one instance, there are fewer particles to refract light in the small-diameter stack discharge

Typical Operations Discharging Water Vapor

1 Drying operations—e g , when rotary dryers, spray dryers, drum dryers, and tray and tunnel dryers are used on products such as powdered milk, chemicals, pharmaceuticals, instant coffee, detergents, ores, and paper
2 Combustion operations using hydrogenous fuels in which flue gases are discharged near the dewpoint
3. Air pollution control using water scrubbing on hot gases to remove solids or pollutant gases Equipment such as venturi scrubbers, packed towers, spray towers, etc , removing water-soluble dusts or toxic gases such as acids, fluorides, etc
4 Operations in which hot flue gases are cooled by direct water evaporation to protect pollution control equipment from high temperatures, or in which chemical heat of reaction is removed by water evaporation

95%) to meet modern requirements, particularly if the particles are below 10 microns in size Excellent collection efficiency can usually be obtained with bag filters, but it is often necessary to cool the effluent gases with cold air to obtain a suitable temperature for the bag cloth, the dilution greatly increases the volume of gas to be handled and also the cost of the installation, since cost is normally proportional to the quantity of gas cleaned

In such a situation, industry frequently turns to some type of wet scrubber, as shown in Category (3) There are many different kinds, involving cyclonic action of gas and water, venturi jet action, and impingement on packing and baffles of all types Efficiency can vary considerably, but if enough energy is used, efficiencies as high as 99% or better can be obtained If the flue gases also contain toxic gases such as fluorides, a properly designed water scrubber will remove them as well

So far, the choice is all in favor of both good economics and good clean air The only problem is that the wet collector cools the hot gas by saturating it with water vapor The end result is often the discharge of a gas saturated with water vapor at a temperature considerably above the atmospheric temperature This good, clean effluent then starts condensing water vapor and produces a very visible plume that is sometimes felt to be objectionable

A fourth category of operation involves the use of evaporating water to cool hot gases before they can enter some type of dry collector such as a cyclone or electrostatic precipitator This cooling may add enough water vapor to the gas so that condensation will occur in the effluent to the atmosphere.

Also in this category is the use of evaporating water to remove the heat resulting from chemical reaction Examples are the hydration of quicklime with water to produce hydrated lime, and the removal of the heat of combustion of phosphorus in the production of food-grade phosphoric acid. In the former, the heat of reaction of lime with water is so great that a portion of the reacting water is boiled off as steam In the latter, a portion of the reaction water to produce acid is also evaporated by the heat of combustion In both of these typical operations, scrubbers and mist eliminators will recover practically all of the product, but an opaque plume of air and steam is liberated to carry off the waste heat.

All four of these categories have one thing in common They normally emit gases saturated with water vapor at a comparatively high temperature, because the presence of the water vapor is an essential part of the process as it is operated.

The Control Regulation Problem

If one grants that the emission of water vapor into the atmosphere in most circumstances is not really objectionable, how can opacity regulations be written to permit this? The Health and Safety Act of the State of California, which originally set up opacity requirements, specifies that to be in violation a plume must exceed the equivalent of Ringelmann No 2 in opacity, and the opacity must be due to a contaminant In Section 24208, the Act defines a contaminant as including "smoke, charred paper, dust, soot, grime, carbon, noxious acids, fumes, gases, odors, or particulate matter, or any combination thereof"

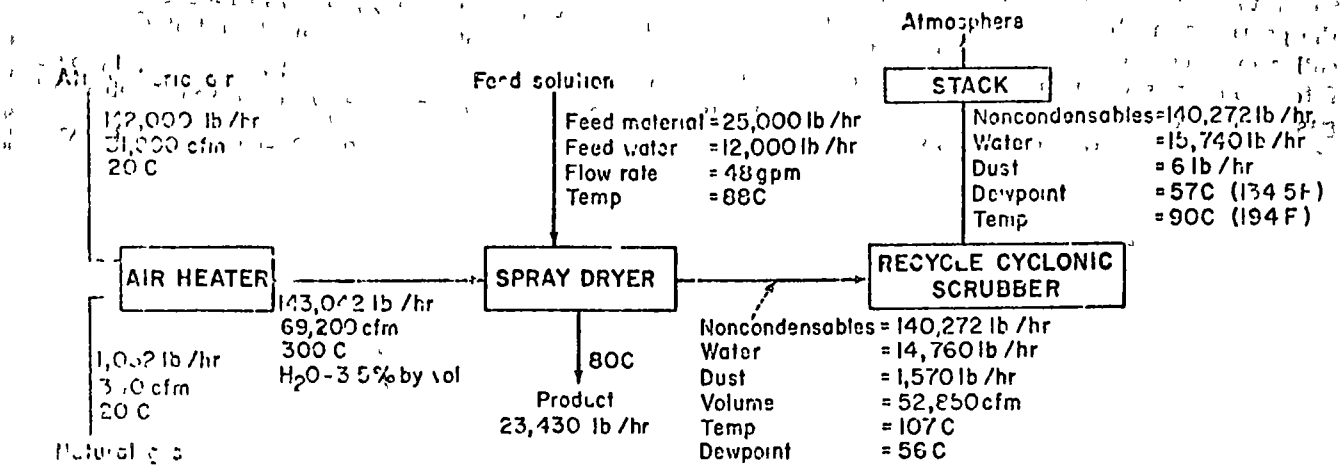
Hence, under this definition, water vapor per se is not a contaminant The control official must determine whether the quantity of contaminants present (exclusive of the condensing water vapor) would result in unlawful opacity It is my impression that one way in which this is being determined is to observe the opacity of any trail that remains after the water droplets have reevaporated into the atmosphere

As opacity regulations are proposed in other sections of the country, they are being fitted into frameworks of different definitions and regulations For instance, in some localities a contaminant is defined as the discharge of any material, other than oxygen or nitrogen, into the atmosphere Under such a definition, water vapor and carbon dioxide automatically become contaminants, even though generally harm-

What Can You Do About Proposed New Regulations in Your Community?

If you have a process that releases essentially pure steam to the atmosphere, what can you do about it?

1. First, sample your plume and analyze it Make sure that you are recovering essentially all objectionable contaminants and that the opacity from your plume is all due to condensing water vapor
2. Make sure that your employees understand that the visible plume is due to condensing steam and not to dusts or other objectionable material In their contacts in the community, they can help allay fears that the plume represents pollution
3. Acquaint all technical personnel with reasons why release of water vapor to the atmosphere is not detrimental in your locality Where applicable, point out the beneficial aspects of water release
4. Work toward securing local public support for release of water vapor to the atmosphere Encourage all technical employees to discuss pollution control with their acquaintances, and to speak on the subject before local civil groups Encourage them to participate in local activities of the Air Pollution Control Assn and of their professional technical societies Ask your technical employees to seek the support of others in regard to steam plume emissions
5. Become acquainted with local control officials, local and state public officials, and legislative representatives Explain to them your desire to be a good industrial neighbor Show them your operations and explain to them the problems involved in obtaining good pollution control involving steam plumes, and the need for a means of dissipating low grade waste heat



MATERIAL FLOW, and process flowsheet, for illustrative example involving plume from multipurpose spray dryer—Fig 1

less ones The word-for-word adoption of the California opacity standard in such a context of definitions immediately produces a problem with any condensing steam plume, no matter how pure—and results in the need to exempt plumes from the regulation wherever the opacity due to the presence of water vapor exceeds some arbitrary amount

Another possibility in such a case would be to direct that the plume opacity be observed beyond the point of dissipation of the condensing water droplets. Unfortunately, some of our newer proposed codes are specifying that the opacity must be observed "at the point of discharge" to the atmosphere. This phrase would appear to give the control officer no alternative but to include the opacity of the steam in his observations

Another proposal has been to exempt plumes from the opacity regulation where the opacity is due to the presence of "uncombined" water (which is not further defined in the regulation). This leaves every one concerned free to conjecture as to the meaning of "uncombined" until the courts finally rule on it: Does the word mean uncombined in the chemical sense to denote that there is no chemical reaction between the water and the other contaminants? What if there are water-soluble particulates present such as salt or sugar? If some of these particulates dissolve in the water, is the water still "uncombined"? What if the water is condensing from flue gas—the water will be saturated with CO_2; so does this in reality make the water very dilute carbonic acid and is the water now "combined"? What if the flue gas results from combustion of fuel oil so that the condensed water now contains traces of SO_2—is the water now combined in the form of very dilute sulfurous acid?

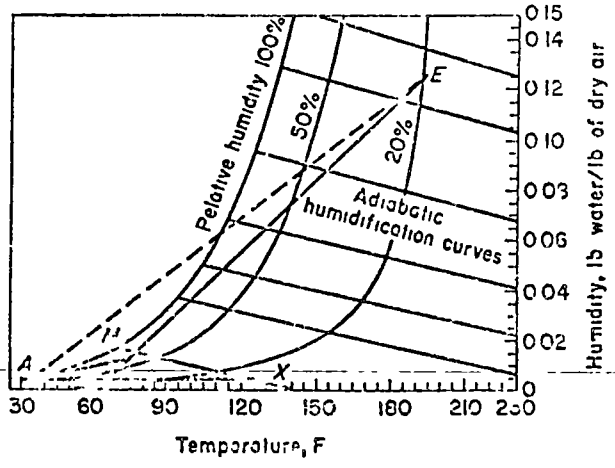
Or is "uncombined" used in the sense of "unmixed," and does the presence of water and other contaminants in the same turbulent plume render them "combined" in the sense that a housewife combines ingredients for a cake?

These may sound like petty questions, but they are ones that need to be considered when regulations are adopted, else they become questions that must be considered later in action before an appeal authority

Means of Eliminating the Visible Plume

We have already mentioned that it may be necessary to eliminate the condensing steam plume from a stack if, for instance, the plant is located beside a highway or near an airport (Atmospheric conditions may create extended periods where the steam from the plume increases the density of ground fogs, and greatly limits visibility) We have also noted that a steam plume may be aesthetically objectionable if a plant is located in a very scenic recreational area.

Various methods will serve to eliminate a visible plume in these situations; let us examine and com-



CASE 1: Operating lines for dilution with heated air are shown on this ordinary range psychrometric chart—Fig 2

pare their design principles and costs This detailed examination will give us a better insight into the limitations, as well as applications, of the various methods

As an example, let us consider a 20-ft-dia spray dryer fired with natural gas and evaporating 12,000 lb/hr of a heat-sensitive, water-soluble organic chemical Material flow and process flowsheet are shown in Fig 1 Note that the entrained particulates are removed from the dryer exhaust in a recirculating cyclonic scrubber operated slightly above the dewpoint of the dryer gases, so that the evaporated water will not condense in the scrubber This allows collection of the entrained product as a nearly saturated solution that can be reprocessed in the dryer

Various methods to eliminate the condensing water plume from this stack will be discussed, and their relative capital and operating costs presented It is assumed that the products handled are noncorrosive and that mild-steel construction materials can be used

▶**Case 1: Dilution With Heated Atmospheric Air**— One means of preventing condensation in the plume is to mix hot air with the moist effluent so as to reduce the dewpoint and thus prevent the effluent from becoming supersaturated as it mixes with cold gases in the atmosphere Unfortunately, many control regulations contain a clause labeled "circumvention," which in general prohibits the building and operation of equipment that does not reduce the total quantity of contaminants emitted, but instead tends to conceal the emission It would appear that dilution of a stack effluent to reduce opacity might be considered "circumvention" However, this approach is discussed for those areas where its use would be legally valid

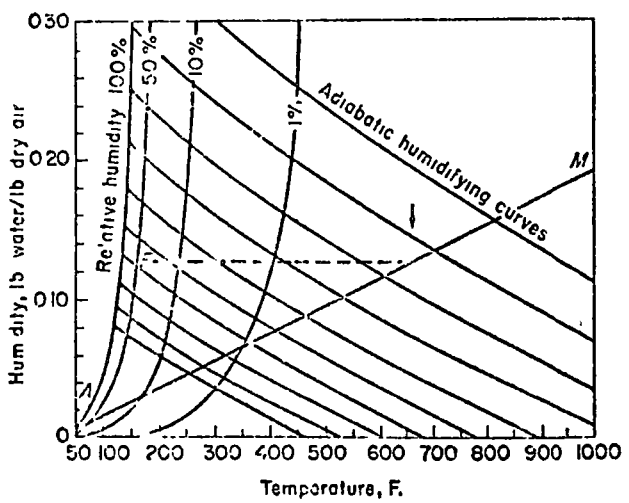
Let us assume that the atmospheric temperature is 35 F and saturated with water vapor A glance at the psychrometric chart of Fig 2 shows that a straight line connecting the effluent (Point *E*) and ambient air (Point *A*) crosses the saturation curve, which would result in fog generation when the two gases are mixed in the stack (This is the reason that the plume condenses in the atmosphere) It is necessary to preheat the atmospheric air (represented by the horizontal line *A-X* on the chart) to some temperature from which a straight line drawn to the effluent condition will not cross the saturation curve In this case, 65 F appears to be about the minimum safe temperature for preheating

It is also necessary to add sufficient heated air to cool the effluent down to some temperature such that a line drawn from the mixture temperature (*M*) to the ambient outside-air condition will not cross the saturation curve (represented by the line *A-M*) With air preheated to 65 F, it appears necessary to cool the effluent to 74 F (a higher value for the mixture temperature results in the line *A-M* crossing the saturation curve) An energy-balance calculation quickly indicates that the quantity of heated air required is 460,000 cfm at standard conditions, or almost a 10 to 1 dilution of the effluent

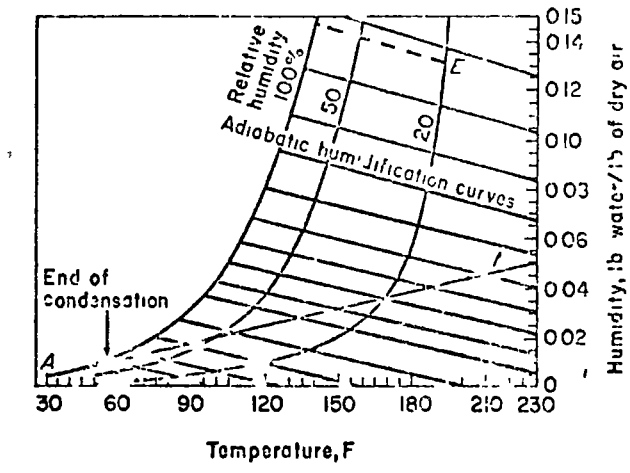
The equipment required would be a fuel-fired air heater or steam-coil heater for the air, a large-volume fan, and a much larger diameter stack

If natural-gas fuel is assumed, the gas requirement is about 16,700 cfh when the ambient air is no colder than 35 F

▶**Case 2: Superheating to Prevent Condensation**— Condensation can be prevented by superheating the plume to a sufficiently high temperature so that the effluent disperses in the atmosphere before it cools to the dewpoint Unfortunately, the relative magnitude of heat- and mass-transfer coefficients that occurs



CASE 2: Line A M on high range chart shows mixing path of superheated effluent envelope with ambient air—Fig 3



CASE 3: Operating lines are shown for the condensation of water vapor from effluent of spray dryer system—Fig 4

when an effluent mixes with the atmosphere has not received sufficient study to allow an engineering prediction of the minimum amount of superheat required The heat- and mass-transfer values are undoubtedly influenced by ejection velocity of the effluent, stack diameter and wind velocity, as well as the usual considerations of mass and thermal driving forces This subject would make a good research project for a graduate student

The exact amount of superheat required at present is best determined by experience However, one conservative design approach is available. Consider the mixing of the outside envelope of the plume with the ambient air To prevent condensation in the envelope, it is necessary to prevent the mixture in the envelope from crossing the saturation curve.

If one draws a line from the ambient air conditions tangent to the saturation curve, such as the line *A-M* of Fig 2, the coordinates of this line can then be located on a high-range psychrometric chart as has been done in Fig 3 The temperature at which this line crosses the absolute-humidity ordinate corresponding to the effluent gives a superheat temperature for the effluent that will prevent condensation as it physically mixes with ambient air (since the mixing operation is represented by all points on the line *A-M*) Fig 3 shows this as requiring superheating of the effluent of our example to approximately 680F.

Actually, it is not necessary to superheat this far because the combustion products that produce the superheat will provide some dilution and, in some cases, will lower the absolute humidity of the mixture along the mixing line of Fig. 3. Calculating the somewhat lower required temperature calls for solving complicated trial-and-error energy and mass balances. This may not be worth the effort, because a new superheat temperature is required every time atmospheric conditions change if one is trying to supply a minimum of superheat (The correct amount of superheat for each atmospheric condition can easily be determined experimentally in the plant by reducing the heat input until the plume just starts to condense)

For the condition considered—i e., of superheating the effluent to 680 F with the combustion of natural gas—the gas requirement is 24,400 cfh. If the effluent itself is used to supply the combustion air, the effluent is diluted less than 1% with combustion products of the superheating fuel.

Equipment requirements in this case are a combustion chamber and fuel-burning equipment in the stack, with a change in design of the stack to make it suitable for carrying a high-temperature effluent

Condensation of Water Vapor

So far, the cases considered do not reduce the emission of water vapor or any contaminant. In fact, they add additional thermal and CO_2 pollution to the atmosphere, and they waste valuable natural fuel resources—they merely conceal the visible appearance of the released water vapor. Let us now consider methods that will actually remove some of the water vapor from the effluent

▶ **Case 3a: Direct-Contact Condensation With Water** —The simplest and least expensive means of condensing the water vapor is to pass the effluent through a direct-contact water-cooled barometric condenser However, there may be problems associated with such an approach

First, a fairly large quantity of cooling water is required Unless the operation is located on a natural body of water that can be used for cooling purposes, it will be necessary to cool and recycle the water through a cooling tower This will not really eliminate the discharge of water vapor to the atmosphere but merely transfer the point of discharge to the cooling tower, where perhaps the visible appearance may be more acceptable to the community (If a cooling tower is not used, and once-through cooling water is returned to a body of surface water, discharge of water vapor to the atmosphere is still not really eliminated but is only removed further from the industrial operation Conclusions drawn by the Environmental Pollution Panel[6] of the President's Science Advisory Committee have indicated that about half of the heat added to surface waters is ultimately dissipated by evaporation into the atmosphere)

Second, the condensation will also remove some of the trace quantities, dust or other contaminants that would otherwise be released to the atmosphere These materials, on continued recirculation in a closed system, might foul or corrode a cooling tower or perhaps even produce foaming In that case, additional equipment might be required to purify the used cooling water Use of a surface condenser might therefore be preferable

Third, the heat resulting from the condensation of the water vapor ends up in the cooling water If the quantity of heat is large compared to the flow of a natural body of water, there may be complaints regarding thermal pollution of the water

Referring to the psychrometric chart of Fig 4, the dehumidification process of the effluent would follow an adiabatic humidification curve up to the saturation curve The mixture would then slide down along the saturation curve as water is condensed Here again, it is necessary to lower the temperature to a point where a straight line connecting the ambient conditions with the end conditions of the effluent will not cross the saturation curve into the supersaturated region The effluent must be cooled down to the point at which the line *A-M* ceases to be tangent to the saturation curve, or about 56 F This means that relatively cold cooling water will be required, and that a countercurrent condenser is preferable (An alternate combination process is to dehumify somewhat less and add back some superheat so that the effluent is not discharged completely saturated)

If 40 F. cooling water is available, and is heated in the barometric condenser to 65 F before discharge, approximately 1,670 gpm of cooling water is required. If it is important that the effluent be completely in-

visible, it is probably best to follow the condenser with an entrainment separator or mist eliminator.

▶ **Case 3b: Indirect-Contact Condensation With Water** — If contamination of the cooling water with dust or other contaminants creates a problem, it is possible to use a tubular surface condenser. However, this becomes very expensive, the heat-transfer coefficient on the effluent side of the tubes will be quite low due to the large amount of noncondensable gas present. In addition, if the contained solid particulates present are not readily water-soluble, they may adhere to the tubes and foul the heat-transfer surface further. The temperature to which the effluent must be cooled remains the same as in 3a.

In our example, the gases would enter the condenser at 191 F with a 124.5 F dewpoint. The condenser will be quite inefficient as a heat-transfer device until the gases cool to the dewpoint. The efficiency can be improved by spraying water into the inlet pipe to saturate the gases; 3.9 gpm is required in the proposed design. This reduces the inlet temperature to 137.5 F, saturated. If 40 F cooling water is available as before, and is heated to 65 F, an ordinary tubular exchanger would need about 76,000 sq ft of tube surface. This can be reduced considerably by use of an exchanger finned on the effluent side of the tubes. In the design considered, using a 0.4-in.-high fin, 0.20 in. wide and spaced 12 per in., the tube surface requirements dropped to 5,500 sq ft.

In this type of condensation, the water-vapor discharge to the atmosphere is merely transferred from the stack to the cooling tower or to the surface of a river or lake. If it were absolutely necessary to prevent release of water vapor to the atmosphere, one might consider circulating a brine or antifreeze solution through the surface condenser and, in turn, cooling it in a finned air-cooled exchanger, making maximum use of the cold weather temperature. Costs are presented for both types of cooling.

▶ **Case 4: Combination Processes**—The previous examples assume relatively mild winter conditions with ambient temperatures close to freezing. Although the same design methods apply as the ambient temperature decreases, the problem of preventing plume condensation becomes increasingly more difficult as the outdoor temperatures become progressively lower, because the slope of the moisture saturation curve becomes closer and closer to zero. A point is soon reached where any of the methods described becomes impractical.

The only practical approach then becomes a combination of methods—i.e., partial dehumidification to some reasonable humidity level with cold cooling water, followed by reheat with heated air or fuel. There is no rule for determining the optimum point in ceasing to dehumidify and starting to superheat, and an infinite number of solutions are possible. The procedure is to design a number of processes with the breakpoint at different temperature and humidity levels, and thus determine the most economical design. This tedious design process can be handled best on a computer.

Capital and Operating Costs

Table I presents the initial installed costs of the control equipment required to eliminate the plume opacity by the various methods discussed. These costs

First cost of opacity-control equipment (on installed basis)—Table I

Description	Case 1	Case 2	Case 3a			Case 3b		
	Dilution With Heated Air	Superheating With Fuel	Direct-Contact Condensation: Surface Water	Cooling Tower	Air-Fin Cooler	Condensation With Surface Condenser: Surface Water	Cooling Tower	Air-Fin Cooler
Equipment provided	Centrifugal blower, natural gas air heater, large dia stack, 100 ft tall	150 ft tall, high temperature stack with combustion chamber in base, gas burners	Direct-contact water condensers (barometric type), mist eliminator, ductwork			Finned surface condenser, desuper heating spray, mist eliminator, ductwork, sewer connection		
			Water supply and sewer disposal	Water circulating system	Water circulation system	Water supply and sewer disposal	Water circulation system	Water circulating system
Installed cost	$350,000	$175,000	$105,000	$105,000	$105,000	$205,000	$205,000	$205,000
Proportionate share of plant facilities								
Power distribution	80,000					40,000		
Surface water supply			40,000				90,000	
Cooling tower water				90,000				335,000
Air fin water cooler					335,000			
Power for air fin cooler					60,000			60,000
Other plant facilities	70,000	35,000	20,000	20,000	85,000	40,000	40,000	110,000
Total fixed investment	$500,000	$210,000	$165,000	$215,000	$585,000	$285,000	$335,000	$710,000

Note: These costs apply to the illustrative example of Fig. 1—an effluent containing 15,740 lb./hr. of water

Annual operating cost (in thousands of dollars) of opacity-control equipment—Table II

Description	Case 1	Case 2	Case 3a			Case 3b		
	Dilution With Heated Air	Superheating With Fuel	Direct Contact Condensation			Condensation With Surface Condenser		
			Surface Water	Cooling Tower	Air-Fin Cooler	Surface Water	Cooling Tower	Air-Fin Cooler
Utilities, $1,000/yr	164	117	41	81	173	41	81	173
Repairs and supplies	35	17	11	11	11	21	21	21
Depreciation	29	15	9	9	9	17	17	17
Taxes, insurance and overhead	74	47	19	31	56	27	39	60
Interest	30	13	10	13	35	17	20	43
Total operating cost, $1,000/yr	332	209	90	145	284	123	178	314

Note These costs are for the illustrative example of Fig 1

Operating Cost Assumptions

Utilities
- Electricity — $0.01 per kwh
- Natural gas — $0.60 per 1,000 cu ft (970 Btu/cu ft)
- River water — $0.05 per 1,000 gal
- Cooling tower water — $0.10 per 1,000 gal
- Air fin cooler water — $0.22 per 1,000 gal

Labor and Supervision—No labor or supervision cost is charged to the pollution control operation

Repairs and Supplies—10% annually of installed control equipment cost

Depreciation—12 y life for control equipment uniformly amortized

Taxes, Insurance, General Overhead—4% annually of installed control equipment cost, plus 30% of annual utility and repair cost

Interest Charges on Investment—6% of total investment

Onstream Time—90%

Note Utility costs include all expenses including distribution, maintenance, and depreciation, but not interest cost in utility investment

are developed for a condition where the atmospheric temperature is close to freezing or above. Table II presents the operating costs for each system (along with the cost-factor assumptions).

It can be readily seen that the most economical system is direct condensation with natural surface water, but this possibility will often not be available due to either lack of surface water or to thermal-pollution considerations. The next most economical case results in a choice between direct condensation with recirculated cooling water and surface condensation with natural cooling water. As has been pointed out, neither really eliminates the discharge of water vapor to the atmosphere but only moves the opaque plume to the cooling tower or to the body of water. The increased cost of surface condensation with once-through water is only beneficial if the surface water would otherwise be polluted with particulates in the effluent.

Third choice falls between surface condensing with circulated cooling-tower water and superheating, neither of which reduce the moisture released to the atmosphere. The only case that really minimizes air and water pollution (surface condenser and air-fin cooler) is esentially the most expensive.

What Conclusions Can Be Drawn?

In summary, we can conclude that means are available, where deemed necessary for aesthetic or safety reasons, to prevent opacity problems from a humid effluent. But use of these techniques for all humid effluents is not economical, may result in increased thermal and CO_2 pollution of the atmosphere, create water-pollution problems, and waste national resources. Because of all this—and because we have seen that complete elimination of condensing water vapor in stack plumes would serve no real purpose—care needs to be exercised in drafting control regulations so that provision is made for permitting the release of condensing water vapor from stacks in which the presence of other contaminants accounts for a very small portion of the total opacity.

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Meet The Author

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CARBON MONOXIDE CONCENTRATION
CITY OF CHICAGO
MOBILE MONITORING SURVEY

TEST PERSONNEL:
James Dowd
Hosie Thurmond
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John Watt
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DATES:
May, June
July, 1971

Department of Enviornmental Control
Technical Services
City of Chicago

September, 1971

CARBON MONOXIDE CONCENTRATION
CITY OF CHICAGO
MOBILE MONITORING SURVEY

1.0 Introduction

Carbon Monoxide (CO) concentrations at street level have been measured throughout the City of Chicago by the Department of Environmental Control (DEC) in order to determine the variations from the Telemetered Air Monitoring Network (TAMN) data which can be expected for different locations.

Air samples, collected in mylar bags, were analyzed on a non-dispensive infra-red (NDIR) carbon monoxide analyzer. Test results were averaged hourly and compared with the hourly averaged data from the TAMN. The results show that the CO concentrations at street level can be significantly different from the concentrations recorded by the TAMN, depending on traffic density, location, and, to a lesser extent, the wind speed.

2.0 Collection and Measurement of Samples

Ambient air samples were collected in 8" Dia. x 15" L Mylar bags, filled by means of a hand-operated air pump. The bags have valves at both ends so that they can be purged and filled in a single operation. Each bag is purged with twice its volume of ambient air before the ends are sealed, requiring about one minute for the entire operation. Sampling height and time, except when indicated otherwise, was normally three-feet above ground and one minute, respectively.

The samples were measured for CO concentrations on the Beckman Model 315A(L) non dispersive infra-red analyzer at the Cermak Pumping Station. This analyzer is one of the four CO analyzers operated by the Dept. of Environmental Control (DEC) as part of the eight station TAMN system. Wind data and CO concentrations are telemetered from the stations and printed out at Central locations every fifteen minutes. CO analyzers are located at stations #1, #3, #6, and #8 (Fig. I) and wind equipment is located at all eight stations.

3.0 Sampling Areas

The samples have been grouped into time periods, or sampling hours, corresponding to the time periods used in averaging the TAMN data. The sampling hours have been grouped into catagories dependent on location and purpose of sampling, namely:

Hour #	Location
1-15	Entire City
16-26	Central Business Area
27-33	Near North Industrial & Residential Areas
34-35	Residential Areas
36	Lower Wacker Drive
37	Hubbard's Cave (Expressway Tunnel)
38-53	Dan Ryan Expressway at Harrison Street
54-71	Intersection of State & Madison Streets

Each of the measurements is listed in Table 2, along with the computed wind vector, average wind speed, and average CO concentration as determined from the TAMN stations closest to the sampling sites for the sampling hour, plus the TAMN (City) average CO concentration for the time period. Locations of the sampling sites are shown on the maps referenced in the text.

3.0.1 Data Presentation

Figures III, V, VIII, X, & XIII show the high, low, and average CO concentrations for the survey samples and the TAMN, and the resultant wind vector and average wind speed in the vicinity of the sampling sites for each sampling period.

3.1 Main Streets City-Wide

Sampling during hours #1-15 was limited to non-rush hours outside of the central business district. Sampling sites (Fig. II) were approximately two miles apart and, except for 111th & Yates and 26th on the Lake, were on main streets throughout the City, three to five feet from the street. It was sunny with no precipitation during the sampling times; wind data and CO concentrations for this period are shown in Fig. III, and weather data is given in appendix A.

3.2 Central Business Area

Samples in the Central business district (hours #16-26 & Figs. IV & V) were normally taken from the curb side of a moving car, so as not to obstruct traffic, and to provide an average sample at the intersections. The effect of busses, cabs, and cars bunching up at intersections can be seen from the measurements along Michigan Ave. (particularly at hours 20-24). Hours 25 & 26 were measured near the end of an

inversion. Wind conditions preceeding and during these hours are given in Table I. The wind had little clearing effect on 3 & 4 JUN, resulting in a build up of the pollution levels by the time this survey began. At ground level, on 4 JUN, there was practically no wind until mid-afternoon. The effect of the wind reaching ground level in the afternoon can be seen in the clearing effect on the east-west streets. While the north-south streets maintained relatively high CO concentrations (except Michigan-Jackson).

TABLE I

Wind Direction and Speed
As Recorded at TAMN #3

Date	Time (CDT)	W. D.	W. S. (knots)
2 JUN	1100-1730	N-NW	10
	1730-1830	light & variable	
	1830-0130	SE	2-5
3 JUN	0130-0445	--	0-3
	0445-0630	SE	3-7
	0630-1030	SE	6-8
	1030-1715	E-SE	5
	1715-2300	SE	2-5
4 JUN	2300-0745	--	0-3
	0745-1630	E-SE	3-6

It was sunny with no precipitation during the sampling time (hours 16-26); wind data and CO concentrations for this period are shown in Fig. V, and weather data is contained in appendix A.

3.3 Industrial Residential Area

The industrial-residential area from 800 N to 2400 N and 200 W to 1000 W (Fig. VI) was monitored during hours #27-33. Sampling sites are about evenly split between main streets and side streets, although the entire area is busier than a normal residential area so that the side streets are not truly representative of side streets in other areas of the City. Samples were taken about five feet back from the street. It was sunny with no precipitation during hours 27-29; and cloudy with a trace of precipitation during sampling hours 30-33. Wind data and CO concentrations for this period are shown in Fig. VIII. Weather data is included in appendix A.

3.4 Residential Areas

Sampling hours 34 & 35 included samples taken in repre-

sentative residential areas along with an equal number of samples at main intersections in the outer portions of the City (Figs. VII & VIII). The samples were taken about five feet back from the street. It was sunny with no precipitation for sampling hour 34. For sampling hour 35 it was cloudy with no precipitation during the sampling time. Wind data and CO concentration for this period are shown in Fig. VIII, and weather data is included in appendix A.

3.5 Enclosed streets

Lower Wacker Drive and Hubbard's Cave (Fig. IX.) were monitored during sampling hours 36 & 37 (Fig. VIII.). The first three measurements in Lower Wacker were taken from a moving car in the North (East) bound lanes; the last measurement was taken from the pier dividing the East and West bound lanes. These samples were taken in mid-afternoon, before the evening rush hour. On the following day (1600 Hrs. which would coincide with sampling hour #22) in a traffic back-up (including busses and delivery trucks), which extended from Clark St. to the stoplight under Michigan AVenue, a single 30 second sample from Lower Wacker at Dearborn indicated a CO concentration of 192 parts per million. Since this was an isolated measurement without any other samples taken in similar locations under similar conditions, it has not been included in any of the data groups. Samples for sampling hour 37 were in the vicinity of Hubbard's Cave, as indicated on the right side of Fig. IX. The samples were taken while walking along the East emergency walk of the northbound lanes. The sites were in the following order:

1) entrance to the tunnel
2) center of the tunnel
3) exit of the tunnel
4) between the tunnel and the railroad bridge
5) under the railroad bridge, and
6) under Grand Avenue bridge.

It was mostly sunny with no precipitation both days; CO concentrations and wind data for this period are shown in Fig. VIII, and weather data is contained in appendix A.

3.6 Expressway

The Dan Rayn Expressway at Harrison Street was monitored during sampling hours 38-53 (Figs. IX, X, XI). Six sites were chosen, as shown in Fig. XI, in close proximity to Cermak Pumping Station (TAMN #3). Sites 1 and 6 were about three feet in from the roadway and three feet above the roadbed. Sites 2 and 5 were on the bridges centered over the lanes about twenty feet above the roadbed. Sites 3 and 4 were alongside the roadway about fifteen feet above the roadbed and one hundred feet south of Harrison Street. Measurements from sites 1, 2, and 3 were used to obtain an average

concentration (N) for the northbound lanes; sites 4, 5 and 6 (S) for the southbound lanes; and all six sites for the average concentration.

TAMN #3 sample intake is about forty feet above the expressway roadbed, so that some mixing can take place before the ambient air is monitored. Sampling hours 44-53 were on the same days and provide an independent survey of the rush hour pattern for the expressway. The averaged concentrations versus time for this day are plotted in Fig. XII. There was a light rain in the morning from 0700 to 1000 CST, with complete cloud cover for the entire day. For the sampling hours 38-43 it was sunny with no precipitation. Wind data and CO concentration for this period are shown in Fig. X, and weather data is included in appendix A.

3.7 Intersection of State and Madison Streets

The intersection of State and Madison Streets was sampled in conjunction with the University of Illinois during sampling hours 54-71. The sampling sites for this survey are shown in Figs. XIV & XV and the averaged data in Fig. XIII. A severe thunderstorm passed the intersection (0540 to 0610 CST, sample hour 54) and loop area with 60-70 knot gusts of wind recorded at both Meigs Field and TAMN #3 at approximately 0540 CST, and heavy rain lasting until 0610 CST at the intersection. Sampling hours 56-71 were cloudy with no precipitation. For sampling hours 54-62 the averaged values from sites #1, 2, 3, & 4 are plotted, along with the city average CO concentration versus time in Fig. XVI. Normally the volume of traffic increases rapidly from 0500 to 0700 CST (0600 to 0800 CDT) as in Fig. XVII; however it is not clear whether the apparent anomoly in CO concentrations from 0400 to 0700 CST (Fig. XVI) is due to the storm passing through the city, followed by a relatively calm wind, or a shift in the normal morning traffic pattern due to the storm. The averaged values for sites 1 through 7 (sampling hours 63-71) along with the hourly traffic count of all vehicles passing through the intersection versus time are plotted in Fig. XVII. At rooftop level, the wind was from the west for the sampling period, while at street level the wind was from the east. The discontinuity of the CO concentrations in this figure is probably due to a ground level shift in the wind. General weather conditions for both these days are given in appendix A.

4.0 Results

4.1 Effect of Wind Speed

In Figs. III, V, VIII, X, and XIII, the average CO concentration for samples is normally higher than the TAMN (or city) average. This is to be expected, since the intakes to the TAMN are at rooftop level while the survey samples were taken at ground level and therefore much closer to the source.

It is interesting to note that, when this data is regrouped and averaged and compared to the averaged wind speed over the same time period (Figs. XVIII & XIX), the two averages (sample and city) tend to converge at wind speeds greater than ten knots and diverge or become unpredictable, at wind speeds less than ten knots. This indicates that, except in the central business area, some significant mixing at street level can be excepted throughout the city for winds in excess of ten knots.

4.2 Analysis of Data

Histograms showing the frequency of measured concentrations for the different areas in the city (Figs. XX & XXI) have the type of distributions that can be expected, except for the loop area. The loop area has many tall buildings so that ground level meteorological conditions are not similar from one location to another. There are some open areas (e.g. Michigan Avenue), some deep "canyons" (e.g. Jackson and LaSalle) and some enclosed areas (e.g. under the elevated tracks along Wells, Lake, and Wabash). The effects of these areas is to distort normal wind patterns at ground level, so that even with a moderate wind (10 knots, Fig. V, sampling hour 22) the street level CO concentrations do not necessarily decrease.

The results of a statistical analysis for each of the groups are shown on the right side of Figs. XX & XXI, and the distribution within each group is tabulated in Table 6.

4.3 Continuous Air Monitoring Program (CAMP) Data

Data collected from the Chicago CAMP station, sponsored by the Federal Air Pollution Control Agency (APCA) has been published in Air Quality Cirteria for Carbon Monoxide (AP-62). Their tabulation of CO concentration by averaging time and frequency is reproduced in Table #7. The geometric average CO concentration for the Chicago CAMP is approximately 12 PPM CO, irrespective of sampling time. The Chicago CAMP station is located on the North-east corner of Congress Street and Dearborn. Since Congress Street leads directly into the Eisenhower Expressway, it has heavy traffic volume during rush hours and normal business hours; since it is fairly open between the CAMP station and the Lake, a significant number of low CO concentrations can be expected during night and weekend sampling hours. This indicates that the average CO concentrations recorded should be close to, although somewhat higher than, the true City average. The air intake at CAMP is about twenty feet above ground so that it is above the level at which the samples for this survey were taken but lower than the TAMN intakes.

4.4 Effect of Sampling Height

conjunction with the street level samples at State and Madison Streets (Figs XIV & XV). On July 8, single one-minute samples, with a short time interval between samples, were used to obtain the vertical profile. On July 22, two consecutive one-minute samples at each level, with simultaneous collection at all levels, were used to obtain the vertical profile. These profiles, and their averages, (Table 8) indicate that the CO concentrations are normally highest at ground level (where the samples for this report were collected) and decrease with height, depending on the mixing height.

4,5 Biasing of Data

Almost all of the samples in this survey were taken on main streets either during normal business hours or during rush hours. Without the benefit of a proportionate number of samples during non-business and non-rush hours, the resulting average, will be biased towards higher average concentrations than averages based on full twenty-four hour sampling, including non-business days such as weekends and holidays (i.e. the CAMP data). The difference in sampling heights between the survey samples and the CAMP and TAMN samples also biases the survey data towards higher average CO concentrations than the true average. Both of these forms of biasing the data have to be taken into account when comparing the geometric averages and distribution of concentrations in Tables 6 and 7.

Report submitted by
James Dowd

HOUR #	DATE	TAMN DATA						SURVEY DATA		
		WIND & CO AT TAMN					CITY AVG CO PPM			
		TAMN #	RESULTANT DIR.	RESULTANT MAG.	AVG WSP	AVG CO PPM		TIME CST	CO PPM	LOCATION
1	9 June	4,5,6	068	6.7	7.3	1.8	3	0915	8	115th & Halsted
								0925	8	100th & Halsted
								0935	7	85th & Halsted
								0945	20	70th & Halsted
								0955	8	56th & Halsted
2		2,3,4,5	047	8.2	9.0	9.7	4	1005	4	41st & Halsted
								1014	5	24th & Halsted
								1025	20	13th & Halsted
								1039	3	Chicago & Halsted
								1048	5	Fullerton & Halsted
3		1,2	051	8.5	8.5	2.7	3	1100	5	Grace & Halsted
								1111	6	Buena & (Halsted) Clarendon
								1120	3	Leland & Clarendon
4		1,2,7	072	9.5	10.3	2.5	3	1310	14	Devon & Western
								1315	10	Winnemac & Western
								1330	21	Addison & Western
5	15 June	6,8	0.70	7.7	7.7	1.0	6	1025	18	111th & Pulaski
								1030	8	95th & Pulaski
6		5,6,7,8	052	9.8	8.7	1.7	6	1118	5	79th & Pulaski

Table 2

HOUR #	DATE	TAMN DATA						SURVEY DATA		
		WIND & CO AT TAMN					CITY AVG CO PPM			
		TAMN #	RESULTANT DIR.	RESULTANT MAG.	AVG WSP	AVG CO PPM		TIME CST	CO PPM	LOCATION
								1125	9	63rd & Pulaski
								1135	9	47th & Pulaski
								1143	9	31st & Pulaski
								1150	10	22nd & Pulaski
								1158	7	Madison & Pulaski
7		1,2,7	055	9.7	9.8	4.1	6	1207	12	North & Pulaski
								1215	14	Belmont & Pulaski
								1224	45	Lawrence & Pulaski
								1232	11	Devon & Pulaski
								1240	6	Devon & Central
8	16 June	6	096	6.2	6.2	1.8	7	1026	11	79th & Yates
								1043	13	95th & Yates
								1100	7	111th & Yates
9		5,6,8	092	6.3	6.5	4.9	6	1113	11	130th & Torrence
								1140	11	111th & Western
								1148	9	95th & Western
								1156	16	79th & Western
10		5,7,8	080	9.1	9.3	1.3	4	1236	11	63rd & Western
								1243	8	47th Western

Table 2 continued

HOUR #	DATE	TAMN DATA						SURVEY DATA		
		WIND & CO AT TAMN					CITY AVG CO PPM			
		TAMN #	RESULTANT DIR.	RESULTANT MAG.	AVG WSP	AVG CO PPM		TIME CST	~~CO~~ PPM	LOCATION
								1252	6	31st & Western
								1300	9	12th & Western
11		2,3,5,7	081	7.3	8.3	7.7	4	1305	8	Madison & Western
								1314	58	North & Western
								1323	11	Fullerton & Western
12	18 June	4,6	227	9.4	9.4	1.4	6	0915	8	130th & Evans (Cottage)
								0935	10	111th & Cottage
								0945	9	95th & Cottage
								0956	9	79th & Cottage
13		3,4,5,6	228	8.1	8.5	4.8	6	1005	14	67th & Cottage
								1018	8	47th & Cottage
								1030	13	31st & King Drive
								1034	4	26th on Lake Michigan
14		1,7	156	16.7	16.8	12.0	6	1220	13	Roosevelt & Central
								1226	7	Madison & Central
								1237	7	North & Central
								1243	14	Fullerton & Central
								1248	16	Belmont & Central
								1258	9	Foster & Central

Table 2 continued

HOUR #	DATE	TAMN DATA						SURVEY DATA		
		WIND & CO AT TAMN					CITY AVG CO PPM			
		TAMN #	RESULTANT DIR.	RESULTANT MAG.	AVG WSP	AVG CO PPM		TIME CST	CO PPM	LOCATION
15		1,7	177	16.3	16.4	12.0	6	1310	10	Devon & Harlem
								1318	12	Lawrence & Harlem
								1328	13	Belmont & Harlem
								1343	22	North & Harlem
16	12 May	3	313	9.3	9.3	4.9	4	0915	16	State & Randolph
								0925	23	State & Madison
								0930	20	State & Adams
								0940	14	State & Congress
17		3	322	6.6	8.3	3.2	3	1105	30	Clark & Lake
								1108	9	Clark & Washington
								1110	12	Clark & Monroe
								1113	13	Clark & Jackson
18		3	074	4.2	5.3	3.6	3	1225	4	Lake & Canal
								1228	7	Lake & Wells
								1230	12	Lake & Dearborn
								1232	7	Lake & Wabash
19	13 May	3	288	6.8	6.9	3.9	5	0916	14	LaSalle & Quincy
								0921	14	LaSalle & Monroe
								0927	9	LaSalle & Washington

Table 2 continued

HOUR #	DATE	TAMN DATA						SURVEY DATA		
		*WIND & CO AT TAMN					CITY AVG CO PPM			
		TAMN #	RESULTANT DIR.	RESULTANT MAG.	AVG WSP	AVG CO PPM		TIME CST	CO PPM	LOCATION
								0930	16	LaSalle & Lake
20		3	275	6.3	6.3	1.7	5	1023	33	Michigan & Monroe
								1028	26	Michigan & Jackson
								1033	43	Michigan & Congress
								1040	20	Michigan & Balbo
21		3	262	8.1	8.1	6.1	6	1445	34	Michigan & Wacker
								1448	43	Michigan & Lake
								1450	15	Michigan & Randolph
								1452	21	Michigan & Washington
								1454	20	Michigan & Monroe
								1457	18	Michigan & Congress
								1459	24	Congress & State
								1500	37	Congress under Post Office
22		3	266	10.2	10.2	7.5	6	1608	35	Michigan & Wacker
								1611	33	Michigan & Lake
								1613	59	Michigan & Randolph
								1615	27	Michigan & Washington

Table 2 continued

HOUR #	DATE	TAMN DATA						SURVEY DATA		
		WIND & CO AT TAMN					CITY AVG CO PPM	TIME CST	CO PPM	LOCATION
		TAMN #	RESULTANT DIR.	RESULTANT MAG.	AVG WSP	AVG CO PPM				
								1618	45	Michigan & Monroe
								1620	51	Michigan & Jackson
								1623	21	Michigan & Congress
								1624	20	Congress & State
								1627	53	Congress under Post Office
								1635	27	N. Dan Ryan on Harrison
								1637	17	S. Dan Ryan on Harrison
23	14 May	3	096	5.8	5.8	3.6	6	0710	17	N. Dan Ryan on Harrison
								0715	13	S. Dan Ryan on Harrison
								0742	4	Michigan & Wacker
								0745	10	Michigan & Lake
								0747	8	Michigan & Randolph
								0748	19	Michigan & Monroe
								0752	8	Michigan & Washington
								0753	11	Michigan & Congress
								0754	26	Congress & State
								0757	21	Congress under Post Office
24		3	108	6.1	6.1	---	6	0845	14	S. Dan Ryan at Harrison
								0847	4	S. Dan Ryan on Harrison

Table 2 continued

HOUR #	DATE	TAMN DATA						SURVEY DATA		
		WIND & CO AT TAMN					CITY AVG CO PPM	TIME CST	CO PPM	LOCATION
		TAMN #	RESULTANT DIR.	RESULTANT MAG.	AVG WSP	AVG CO PPM				
								0851	10	S. Dan Ryan on Harrison
								0856	8	N. Dan Ryan on Harrison
								0850	8	Michigan & Wacker
								0853	6	Michigan & Lake
								0856	6	Michigan & Randolph
								0858	21	Michigan & Washington
								0900	4	Michigan & Monroe
								0903	4	Michigan & Congress
								0905	16	Congress & State
25	4 June	3	103	4.1	4.1	17.2	7	0957	46	Michigan-Wacker
								1000	29	Michigan-Lake
								1002	35	Michigan-Washington
								1004	35	Michigan-Monroe
								1007	45	Michigan-Jackson
								1013	79	LaSalle-Jackson
								1016	60	LaSalle-Monroe
								1018	51	LaSalle-Madison
								1020	31	LaSalle-Randolph
								1022	66	Lake-Clark

Table 2 continued

HOUR #	DATE	TAMN DATA						SURVEY DATA		
		WIND & CO AT TAMN					CITY AVG CO PPM	TIME CST	CO PPM	LOCATION
		TAMN #	RESULTANT DIR.	RESULTANT MAG.	AVG WSP	AVG CO PPM				
								1025	82	Lake-State
								1027	62	State-Madison
								1034	42	LaSalle-Adams-Monroe
								1040	27	LaSalle-Quincy-Adams
								1040	36	LaSalle-Madison-Washington
26		3	111	5.3	5.3	15.2	6	1300	66	Michigan-Wacker
								1303	48	Michigan-Lake
								1306	41	Michigan-Washington
								1309	87	Michigan-Monroe
								1311	19	Michigan-Jackson
								1317	48	LaSalle-Jackson
								1319	46	LaSalle-Monroe
								1322	50	LaSalle-Madison
								1324	41	LaSalle-Randolph
								1327	21	Lake-Clark
								1329	24	Lake-State
								1332	61	State-Madison
								1340	46	Dearborn-Adams
								1342	43	Dearborn-Madison
								1345	37	Dearborn-Randolph

Table 2 continued

HOUR #	DATE	TAMN DATA: WIND & CO AT TAMN: TAMN #	RESULTANT DIR.	RESULTANT MAG.	AVG WSP	AVG CO PPM	CITY AVG CO PPM	SURVEY DATA: TIME CST	CO PPM	LOCATION
27	6 July	2,3	109	6.8	6.8	6.1	4	1115	13	Halsted & Chicago
								1122	25	Halsted & North
								1130	19	Halsted & Fullerton
								1137	7	Sheffield & Fullerton
								1142	7	Sheffield & Armitage
								1147	13	Sheffield & North
								1155	5	Eastman & Kingsbury
28		2,3	107	7.4	7.7	7.0	4	1210	21	Ogden & Milwaukee
								1218	7	Hickory & Division
								1253	7	Geneva & Fullerton
								1258	10	Larrabee & Lincoln
29		2,3	096	6.7	6.7	6.4	4	1302	10	Larrabee & Armitage
								1308	24	Larrabee & North
								1312	7	Larrabee & Clybourn
								1320	7	Crosby & Hobbie
30	20 July	2,3	274	3.4	5.5	2.3	2	1045	16	Larrabee & Chicago
								1050	4	Larrabee & Oak
								1100	8	Larrabee & Division
31		2,3	097	6.5	6.6	1.8	2	1125	10	Larrabee & Clybourn

Table 2 continued

HOUR #	DATE	TAMN DATA: WIND & CO AT TAMN: TAMN #	RESULTANT DIR.	RESULTANT MAG.	AVG WSP	AVG CO PPM	CITY AVG CO PPM	TIME CST	CO PPM	LOCATION
								1130	6	Larrabee & Blackhawk
								1135	10	Larrabee & North
								1139	4	Larrabee & Willow
								1140	6	Larrabee & Armitage
								1145	7	Larrabee & Webster
								1150	12	Geneva & Fullerton
								1157	4	Sedgwick & Webster
32		2,3	102	5.9	5.9	3.4	2	1201	5	Sedgwick & Armitage
								1205	3	Sedgwick & Menomonee
								1215	4	Sedgwick & North
								1220	8	Sedgwick & Division
33		2,3	107	6.8	6.8	4.1	3	1330	8	Chicago & Orleans
								1333	6	Orleans & Oak
								1345	6	Chicago & Wells
								1348	4	Wells & Oak
								1350	16	Wells & Division
								1353	5	Wells & Schiller
								1355	20	Wells & North

Table 2 continued

HOUR #	DATE	TAMN DATA						SURVEY DATA		
		WIND & CO AT TAMN					CITY AVG CO PPM			
		TAMN #	RESULTANT DIR.	RESULTANT MAG.	AVG WSP	AVG CO PPM		TIME CST	CO PPM	LOCATION
34	21 June	3,5,8	037	15.3	15.3	2.5	3	1315	6	63rd & Central
								1323	5	63rd & Harlem
								1358	1	53rd & Nordica
								1412	2	Cullerton & Wolcott
35	23 June	1,2,6	222	6.2	7.0	4.9	4	0950	10	115th & Halsted
								1000	6	102nd & Union
								1120	9	Clarendon & Lawrence
								1130	4	Ainslie & Kenmore
								1220	7	Devon & Pulaski
								1225	4	Glenlake & Harding
36	12 May	3	080	7.0	7.4	4.0	9	1319	36	Lower Wacker & VanBuren
								1323	29	Lower Wacker & Madison
								1327	34	Lower Wacker & Post Place
								1330	13	Lower Wacker & Garvey Ct.
37	18 May	3	263	9.1	9.1	---	7	1040	24	Hubbard's Cave (Fig. IX) #1
								1043	30	" " " " #2
								1045	36	" " " " #3
								1050	22	" " " " #4
								1053	34	" " " " #5
								1055	34	" " " " #6

Table 2 continued

HOUR #	DATE	TAMN DATA						SURVEY DATA		
		WIND & CO AT TAMN					CITY AVG CO PPM	TIME CST	CO PPM	LOCATION
		TAMN #	RESULTANT DIR.	RESULTANT MAG.	AVG WSP	AVG CO PPM				
38	12 May	3	114	6.1	6.1	12.1	10	x	x	x See Table 3 & Fig. XI
39	13 "	3	262	7.9	7.9	13.0	8	x	x	"
40	17 "	3	189	17.5	17.5	---	10	x	x	"
41	18 "	3	218	11.6	11.6	3.5	7	x	x	"
42		3	212	14.2	14.2	2.9	7	x	x	"
43		3	238	10.2	10.2	1.9	6	x	x	"
44	26 May	3	305	10.6	10.6	3.5	4	x	x	"
45		3	295	11.4	11.4	2.3	2	x	x	"
46		3	289	10.8	10.8	2.4	2	x	x	"
47		3	298	10.0	10.1	3.3	2	x	x	"
48		3	304	9.3	9.3	3.2	2	x	x	"
49		3	313	7.0	7.1	6.5	3	x	x	"
50		3	311	9.3	9.3	4.8	3	x	x	"
51		3	297	9.3	9.3	---	3	x	x	"
52		3	312	8.9	9.0	8.0	4	x	x	"
53		4	332	7.0	7.0	---	2	x	x	"

Table 2 continued

HOUR #	DATE	TAMN DATA						SURVEY DATA		
		WIND & CO AT TAMN					CITY AVG CO PPM			
		TAMN #	RESULTANT DIR.	RESULTANT MAG.	AVG WSP	AVG CO PPM		TIME CST	CO PPM	LOCATION
54	8 July	3	265	11.2	13.1	6.0	4	y	y	y See Table 4 & Fig. XIII
55		3	266	3.1	4.6	10.2	8	y	y	"
56		3	125	10.7	10.8	10.6	7	y	y	"
57		3	165	12.1	12.1	12.7	7	y	y	"
58		3	175	14.1	14.1	9.8	6	y	y	"
59		3	199	11.1	11.2	7.3	5	y	y	"
60		3	223	9.5	9.5	6.4	4	y	y	"
61		3	266	6.5	6.6	7.2	5	y	y	"
62		3	156	1.7	2.9	16.8	7	y	y	"
63	22 July	3	234	11.2	11.2	2.2	4	z	z	z See Table 5 & Fig. XIV
64		3	247	11.8	11.8	2.3	3	z	z	"
65		3	246	12.9	12.9	2.1	3	z	z	"
66		3	225	12.4	12.4	2.0	3	z	z	"
67		3	229	10.2	10.7	2.1	4	z	z	"
68		3	219	12.3	12.3	2.7	4	z	z	"
69		3	219	11.7	11.7	2.8	4	z	z	"
70		3	221	10.2	10.2	2.4	4	z	z	"
71		3	223	10.0	10.1	1.6	4	z	z	"

Table 2 continued

TABLE 3

EXPRESSWAY

Hour #	Date	Time CST	Location 1	2	3	4	5	6
38	12 May	1425				20	5	11
39	13 May	1515			21	13		
40	17 May	1710			8	11		
		1720			6	12		
		1735			8	10		
41	18 May	0715	10	8	6	5	4	6
42		0805	9	10	6	10	5	6
43		0900	8	8	7	6	5	4
		0950	6	4	8	6	4	9
44	26 May	0715	13	21	7			
		0750	13	15	8	9	6	9
45		0830	5	6	4	8	5	8
46		0930	11	4	6	4	10	6
47		1000				6	11	8
		1045	5	3	4	10	20	19
48		1100	6	4	7			
49		1300	11	5	7	9	21	31
		1330	21	4	6	13	13	15
		1345	22	9	16			
50		1400	60	11	6	11	41	32
		1430	32	9	10	20	21	45
51		1500	13		10	20	43	21
		1530	41	14	11	13	15	20
52		1600	16	10	10	16	10	11
		1630	36	10	7	6	12	17
53		1700	15	.5	10	13	13	12
		1730	6	10	6	16	13	14

TABLE 4

STATE & MADISON

LOCATION (REF. FIG. XIII)

Hour #	Time CST	1	2	3	4	5	6	7	8
54	0500	9	6	7	6				
	0515	6	8	9	9				
	0530	11	9	7	12				
55,	0620	12	16	9	12				
	0635	21	12	15	12				
	0645	20	15	25	35				
56	0700					23	15		
	0715	20	16	18	30				
	0730	16	12				12		
57	0800	26	17	16	12				
	0815	12	11	17	27				
	0830	16		15					
	0845	22		11					
58	0900	24	15	16	20			14	43
	0915	31		16					
	0930		15	13					
	0945	12		19					
59	1000	16		17					
	1015	14		13					
	1030	15		18					
	1045	22		15					
60	1100	21		21					
	1115	15		15					
	1130	9		12					
	1145	10		20					
61	1200	18		12					
	1240	15	12	24	21			48	81
62	1300							21	46
	1303							30	18

TABLE 5

STATE & MADISON

LOCATION (REF. FIG. XIV)

Hour #	Time CST	1	2	3	4	5	6	7	x	x	x	x	8
63	1000	6	5	13	5	3	4	4					
		8	7	13	7	3	9	7					
	1025							5	4	5	5	--	4
								5	6	5	7	--	5
64	1100	8	6	11	6	4	3	4				--	
		5	6	7	7	4	4	4				--	
	1115							6	7	8	12	8	19
								7	9	8	10	15	40
65	1200	13	8	9	12	6	5	10					
		10	9	10	13	6	7	6					
	1220							5	4	4	5	5	21
								4	6	4	4	19	17
66	1300	14	4	7	6	3	4	5					
		12	3	6	5	4	3	6					
	1350							5	7	5	16	--	16
								5	5	4	22	--	22
67	1400	11	6	6	4	3	5	9					
		8	5	4	5	6	3	4					
68	1500	5	6	8	12	3	4	7					
		7	7	6	7	4	3	5					
	1525							5	5	6	8	--	6
								4	7	7	10	--	20
69	1600	14	12	27	30	10	9	9					
		6	18	59	33	11	6	15					
	1620							8	18	9	11	--	34
								18	11	12	7	--	19
70	1700	8	18	8	40	13	15	8					
		6	18	27	22	26	10	9					
	1720							8	7	8	--	--	26
								6	9	7	--	--	45
	1745							11	8	6	10	--	10
								4	5	8	7	--	22
71	1800	7	8	8	11	20	13	19					
		8	9	8	17	21	10	9					

TABLE 6

DISTRIBUTION OF CO CONCENTRATIONS

AREA	HOURS	PERCENTILE (%)										
		MIN.	10	20	30	40	50	60	70	80	90	MAX.
Loop	16-24	4	6	8	11	14	16	20	21	27	37	59
Loop	25-26	19	24	31	36	41	45	46	50	61	66	87
Loop	16-26	4	7	11	15	20	23	30	37	45	53	87
City + Near North	1-15 + 27-33	3	4	6	7	8	9	10	11	13	19	58
Near North	27-33	3	3	5	6	7	7	8	10	13	19	25
City	1-15	2	5	7	8	8	9	11	12	14	18	58
State and Madison	54-71	3	4	5	6	8	9	11	14	17	22	81
Expressway	38-53	3	5	6	6	8	10	11	13	16	21	60
City + Loop + Near North	1-33	3	5	7	8	10	13	16	21	30	45	87

Table 7

Table 6–4 CARBON MONOXIDE CONCENTRATION BY AVERAGING TIME AND FREQUENCY, FROM DECEMBER 1, 1961, TO DECEMBER 1, 1967, CHICAGO CAMP STATION

(ppm)

Averaging time	Annl arith mean	Max	Min	% data avail	% of time concentration is exceeded																
					0 001	0 01	0 1	1	10	20	30	40	50	60	70	80	90	99	99 9	99 99	99 999
5 min	12	78	0	53	69	58	45	34	22	13	16	13	11	10	8	6	4	0	0	0	0
10 min	12	75	0	54		57	43	33	22	13	16	14	12	10	8	6	4	0	0	0	
15 min	12	69	0	54		56	42	32	22	13	16	14	12	10	8	6	4	0	0	0	
30 min	12	63	0	54		55	41	32	22	15	16	14	12	10	8	6	4	0	0	0	
1 hr	12	59	0	54		54	41	31	22	18	16	14	12	10	8	6	4	1	0	0	
2 hr	12	52	0	53			38	30	22	18	16	14	12	10	8	6	4	1	0		
4 hr	12	51	0	54			36	29	21	18	16	14	12	10	8	6	4	1	0		
8 hr	*12*	*44*	*0*	*55*			*35*	*27*	*21*	*18*	*16*	*14*	*12*	*10*	*8*	*7*	*5*	*1*	*0*		
12 hr	12	39	0	55				26	21	18	15	14	12	10	8	7	5	1			
1 day	12	33	0	55				25	20	18	15	13	12	10	8	7	5	2			
2 day	12	30	2	52				24	20	17	15	14	12	10	9	7	6	3			
4 day	12	27	3	54					19	17	15	13	11	10	9	8	6				
7 day	12	24	3	56					19	17	15	13	11	10	9	8	6				
14 day	12	23	5	59					19	17	15	14	11	10	9	8	7				
1 mo	12	21	6	60					18	16	15	13	11	10	9	7	7				
2 mo	13	21	7	58						17	14	13	11	11	9	8					
3 mo	12	20	7	63						15	14	13	11	11	9	8					
6 mo	12	19	8	58						14	12	12	10	9	9	8					
1 yr	14	17	12	50									12								

Carbon Monoxide Concentration - Vertical Profile

Date	7-8	7-8	7-8	7-8	7-22	7-22	7-22
Time CST →	0830-0900	0943-0955	1205-1220	AVG	1430	1640	AVG
Height ↓ Feet							
270	8	9	10	9.0	4-5	6-7	5.5
130	10	10	13	11.0	5-4	7-9	6.2
82	11	8	9	9.3	5-5	5-7	5.5
34	12	9	16	12.3	4-5	5-5	4.8
3	24	10	15	16.3	4-5	6-11	6.5

Table 8

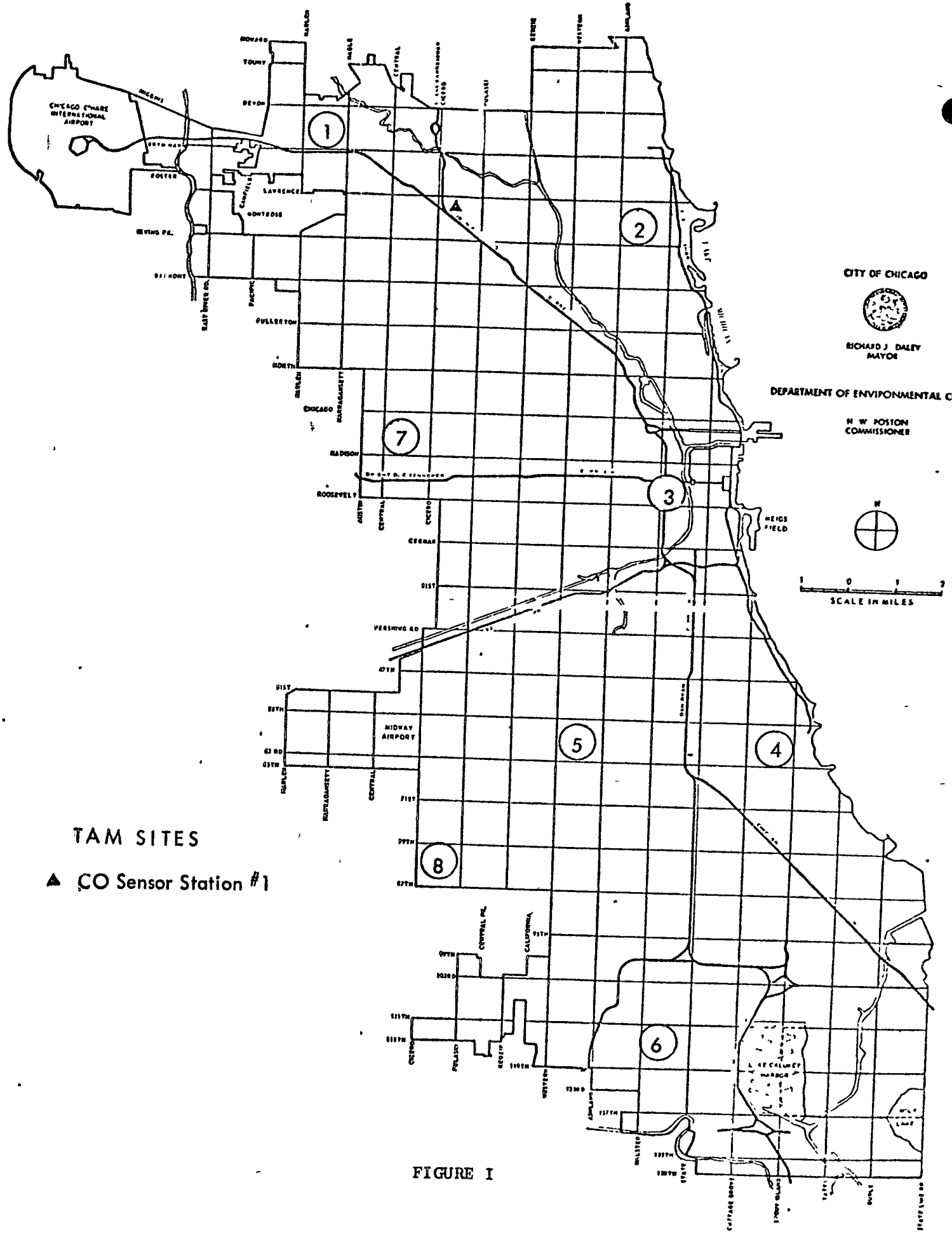
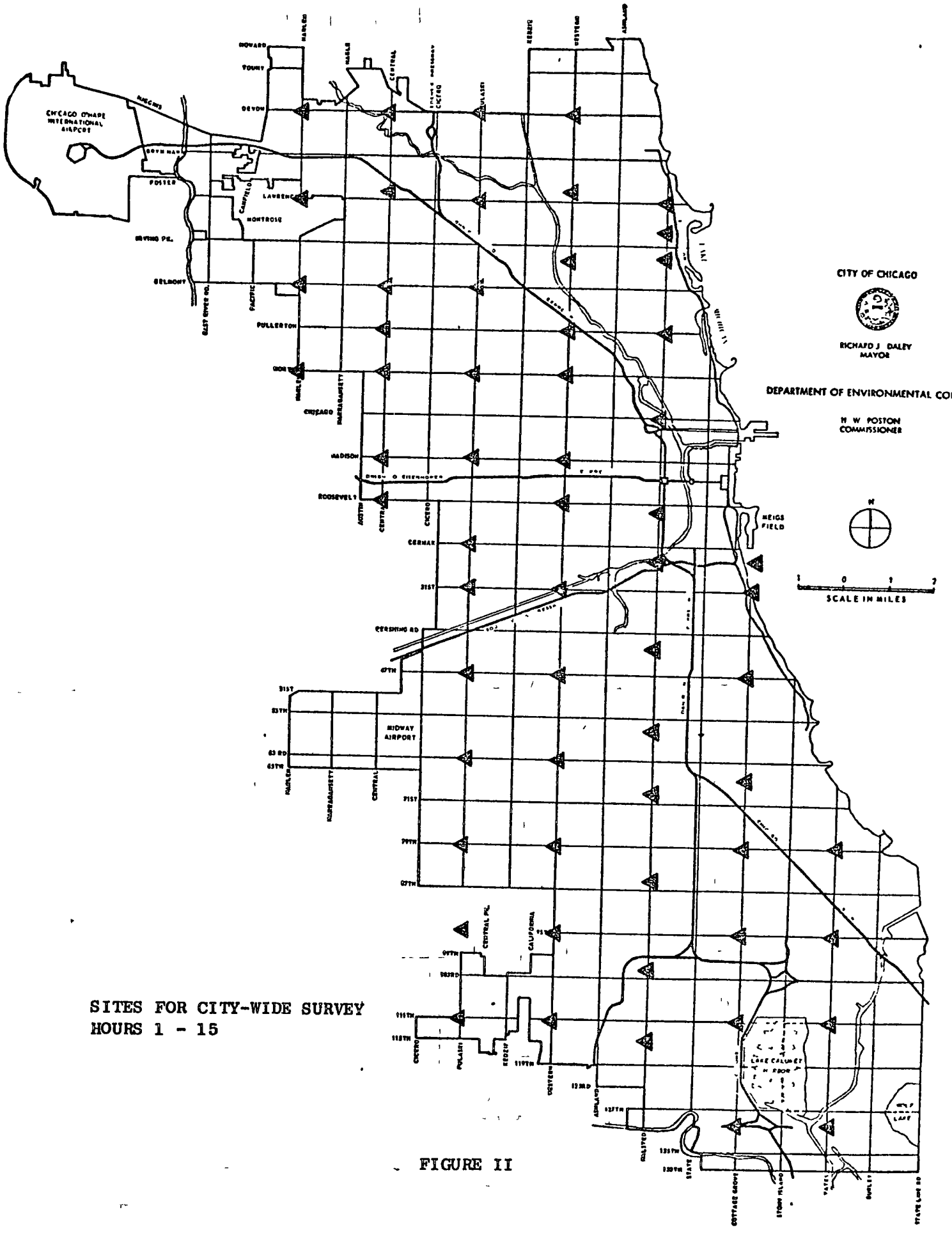

CITY OF CHICAGO
RICHARD J. DALEY
MAYOR
DEPARTMENT OF ENVIRONMENTAL CONTROL
H. W. POSTON
COMMISSIONER
SCALE IN MILES
1
0
1
2
CHICAGO O'HARE INTERNATIONAL AIRPORT
MIDWAY AIRPORT
MEIGS FIELD
1
2
3
4
5
6
7
8
TAM SITES
▲ CO Sensor Station #1

FIGURE I



SITES FOR CITY-WIDE SURVEY
HOURS 1 - 15

FIGURE II

K-E 10 X 10 TO THE INCH 46 0700
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO

▲ SAMPLE MAX. ⊛ TAMN MAX. ▬ AVERAGE ● MINIMUM

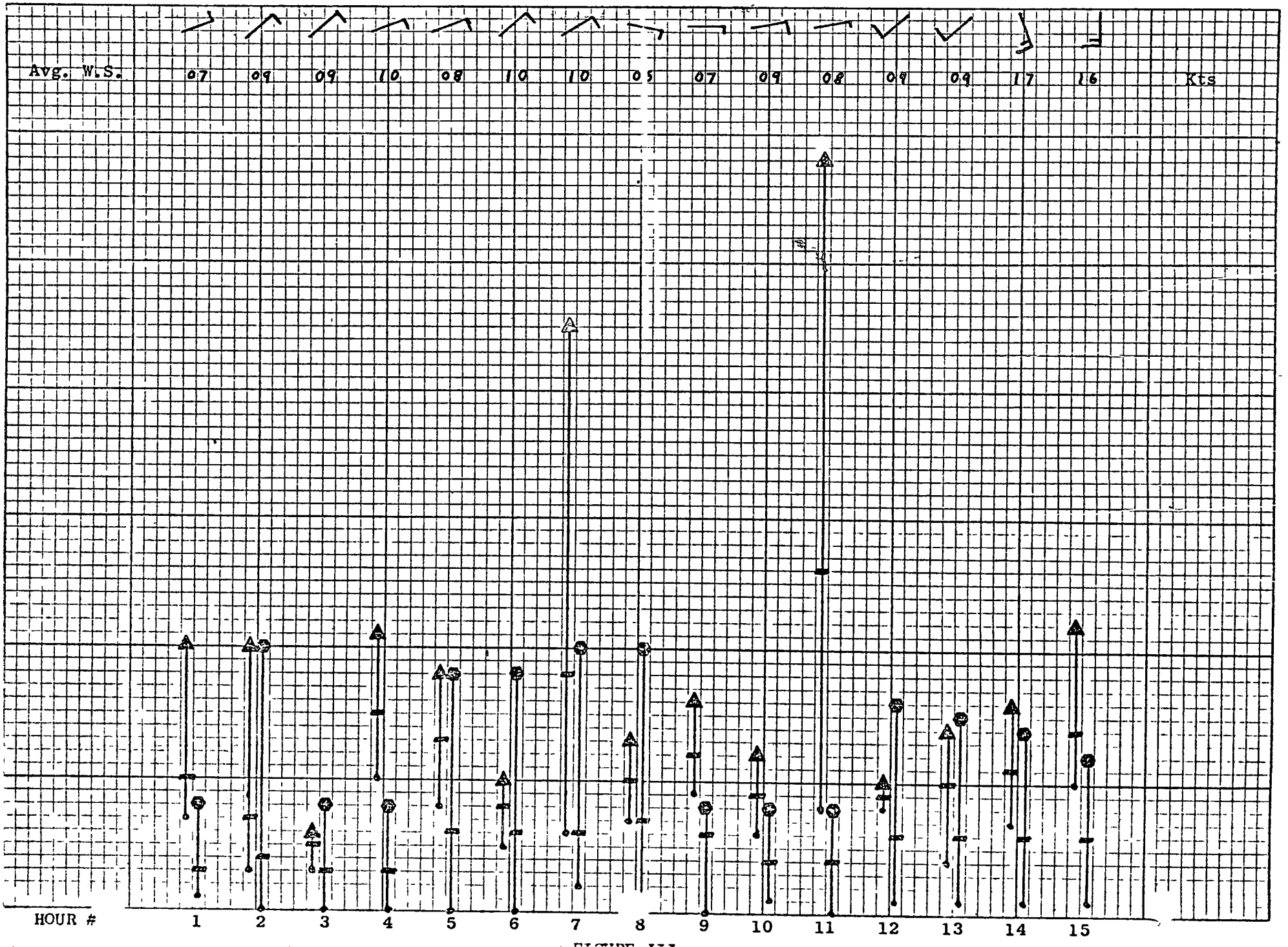


FIGURE VII

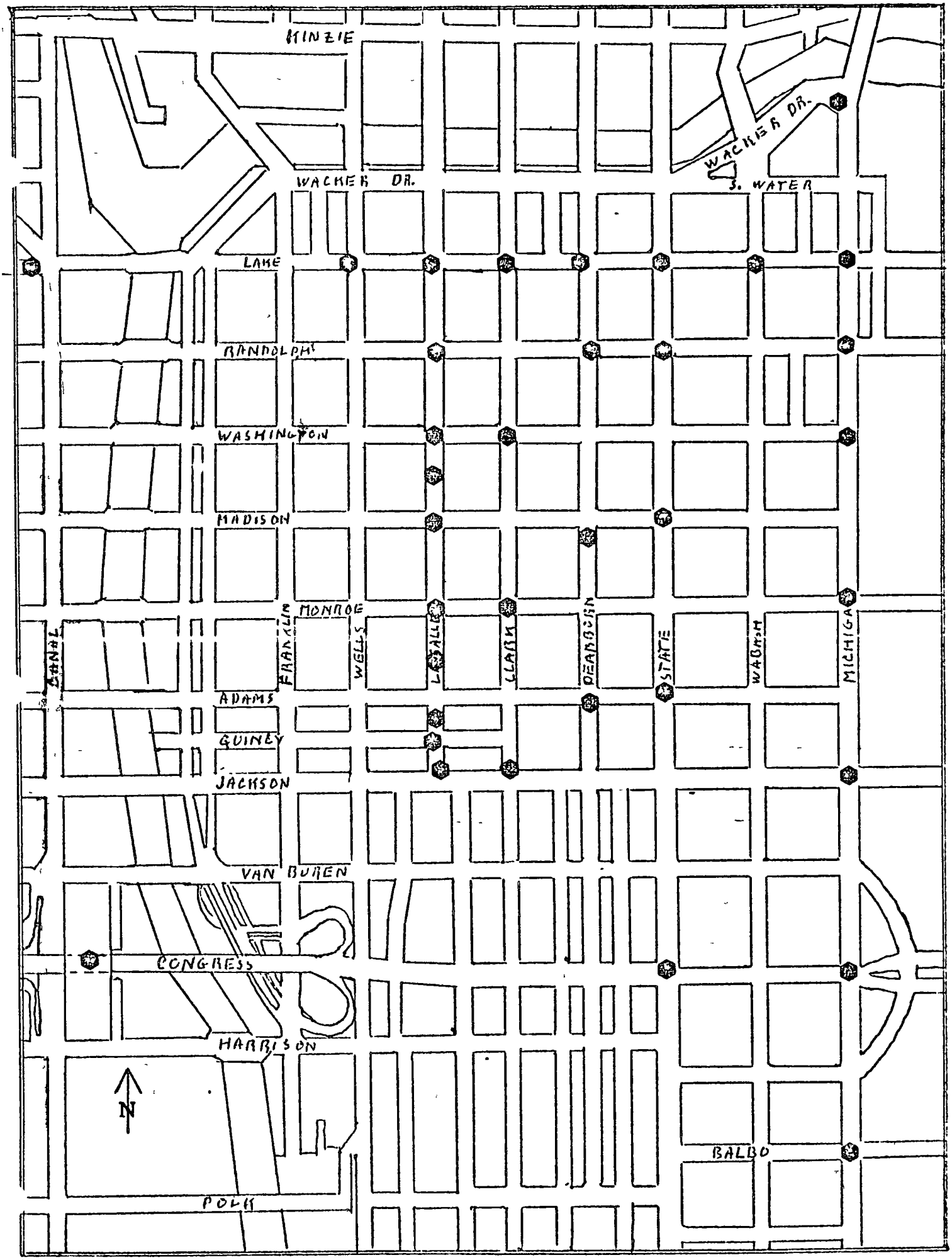
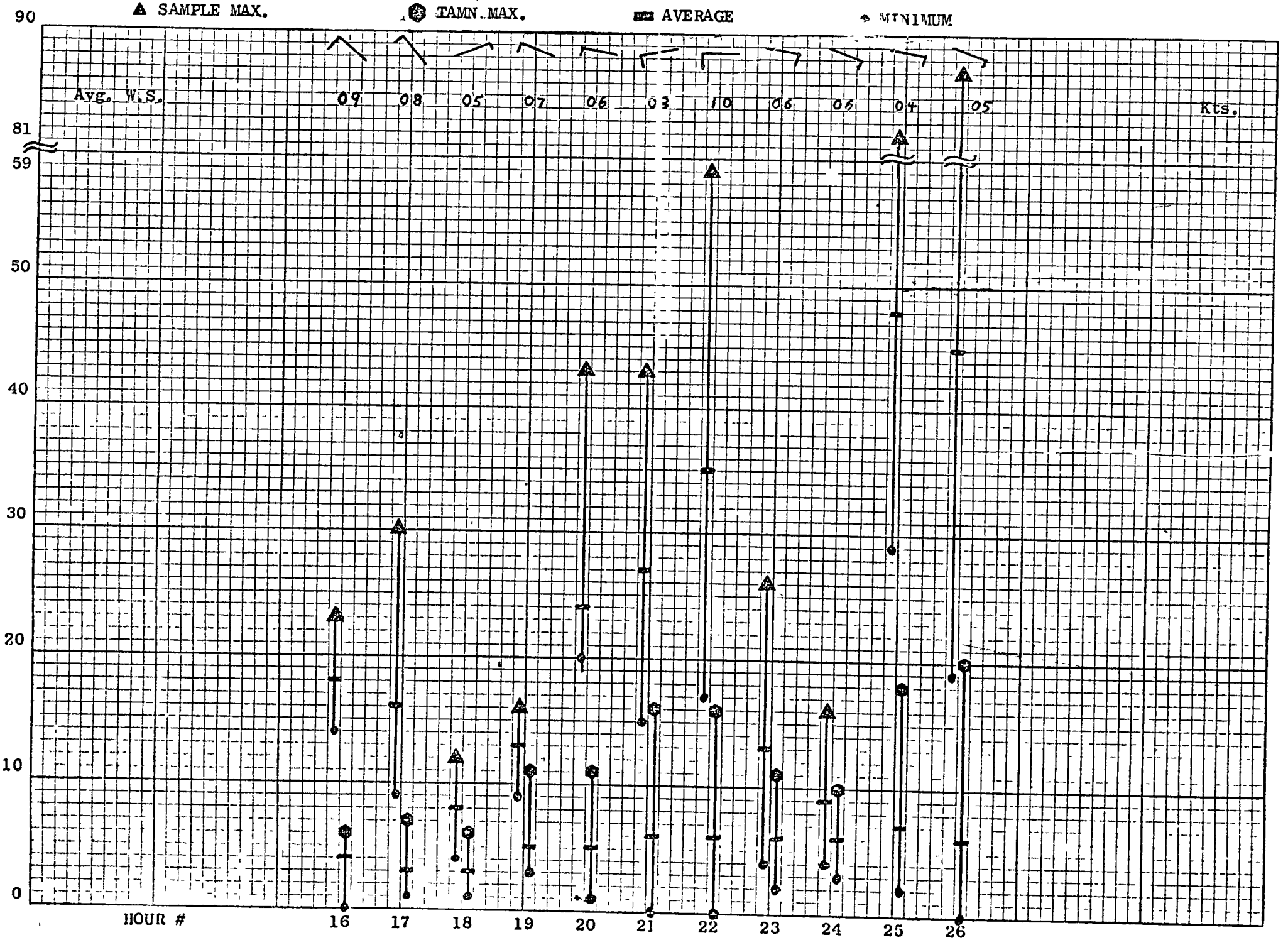


FIGURE IV

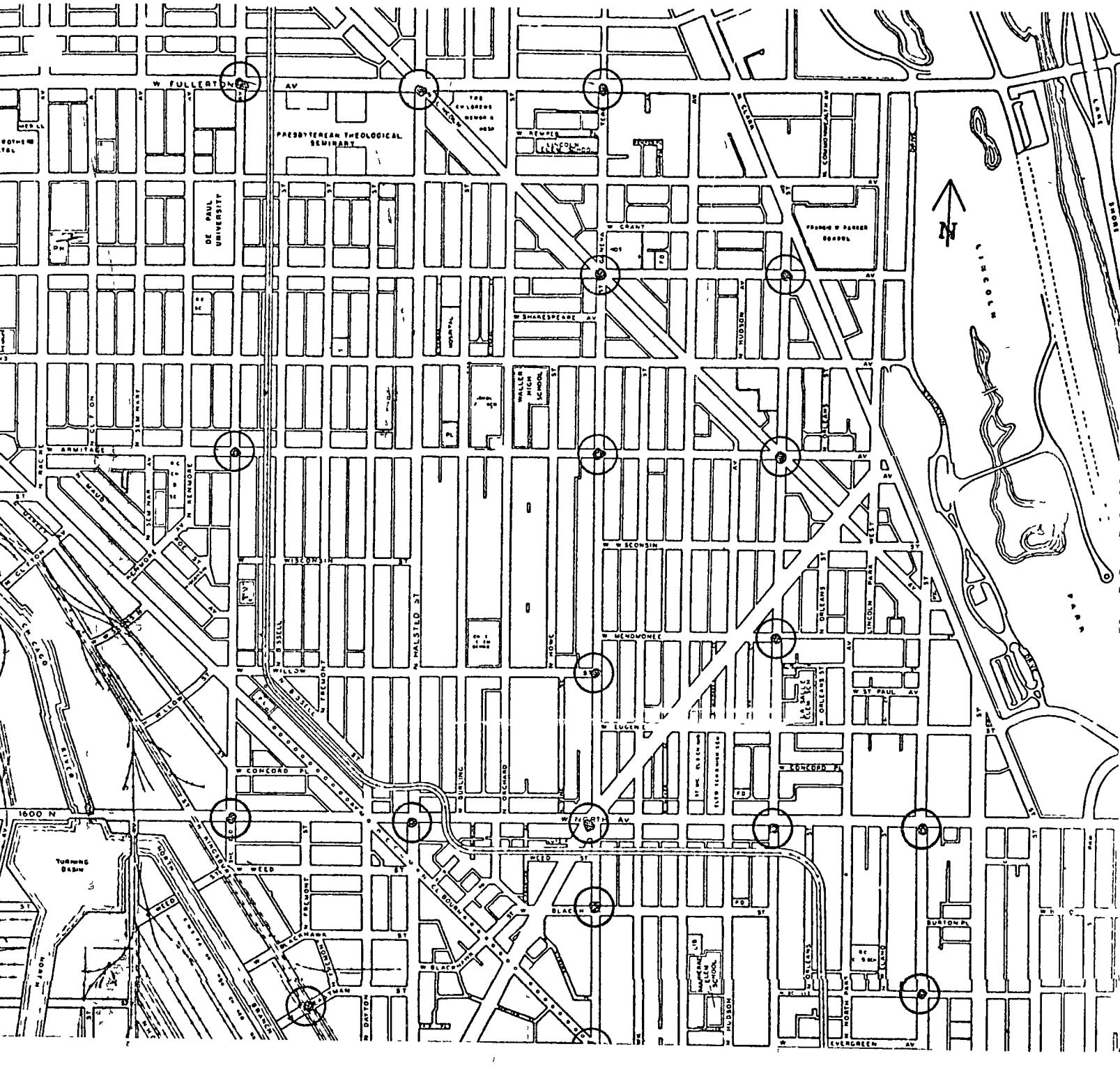
SITES FOR CENTRAL BUSINESS DISTRICT - HOURS #16 - 26

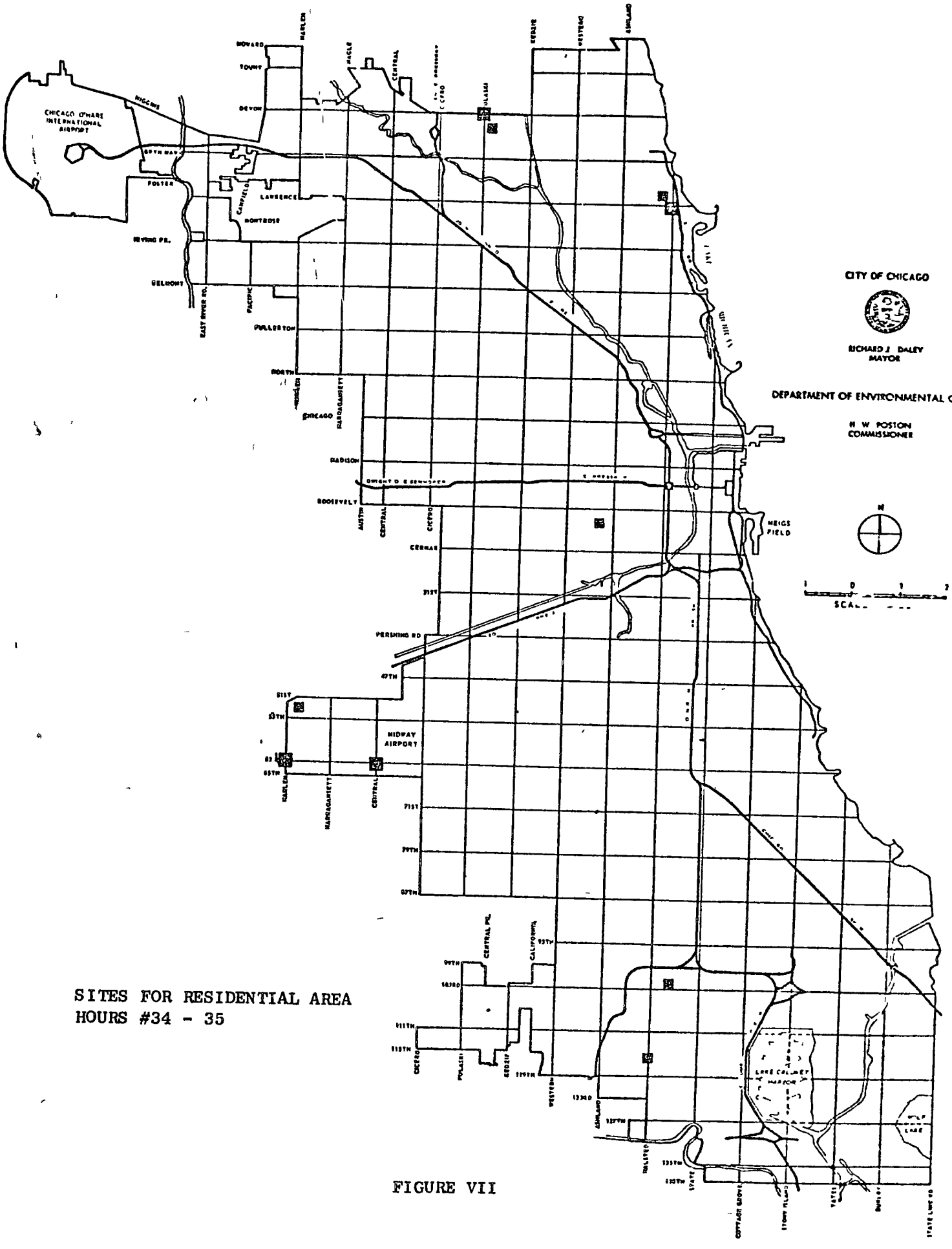
K&E 10 X 10 TO THE INCH 46 0708
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO



NEAR NORTH SIDE
SITES FOR INDUSTRIAL - RESIDENTIAL AREA
HOURS #27 - 33

FIGURE VI


W FULLERTON AV
PRESBYTERIAN THEOLOGICAL SEMINARY
DE PAUL UNIVERSITY
W ARMITAGE
W WISCONSIN
W WEBSTER
W CONCORD PL
W WEED
W BLACKHAWK
W EUGENIE
W ST PAUL AV
W MENDOMINEE
W SHAKESPEARE AV
W CRANT
W DIVERSEY PKWY
WALLER HIGH SCHOOL
LINCOLN PARK
LINCOLN
N
1600 N
TURNING BASIN
N CLIFTON
N SEMINARY
N RENMORE
N HALSTED ST
N DAYTON
N FREMONT
N ORLEANS
N HUDSON
N CLEVELAND
N CLARK
N DEARBORN
N ORCHARD
N SEDGWICK
N MOHAWK
N BURLING
N LARRABEE
N SEDGWICK
N WILLOW
N DEARBORN

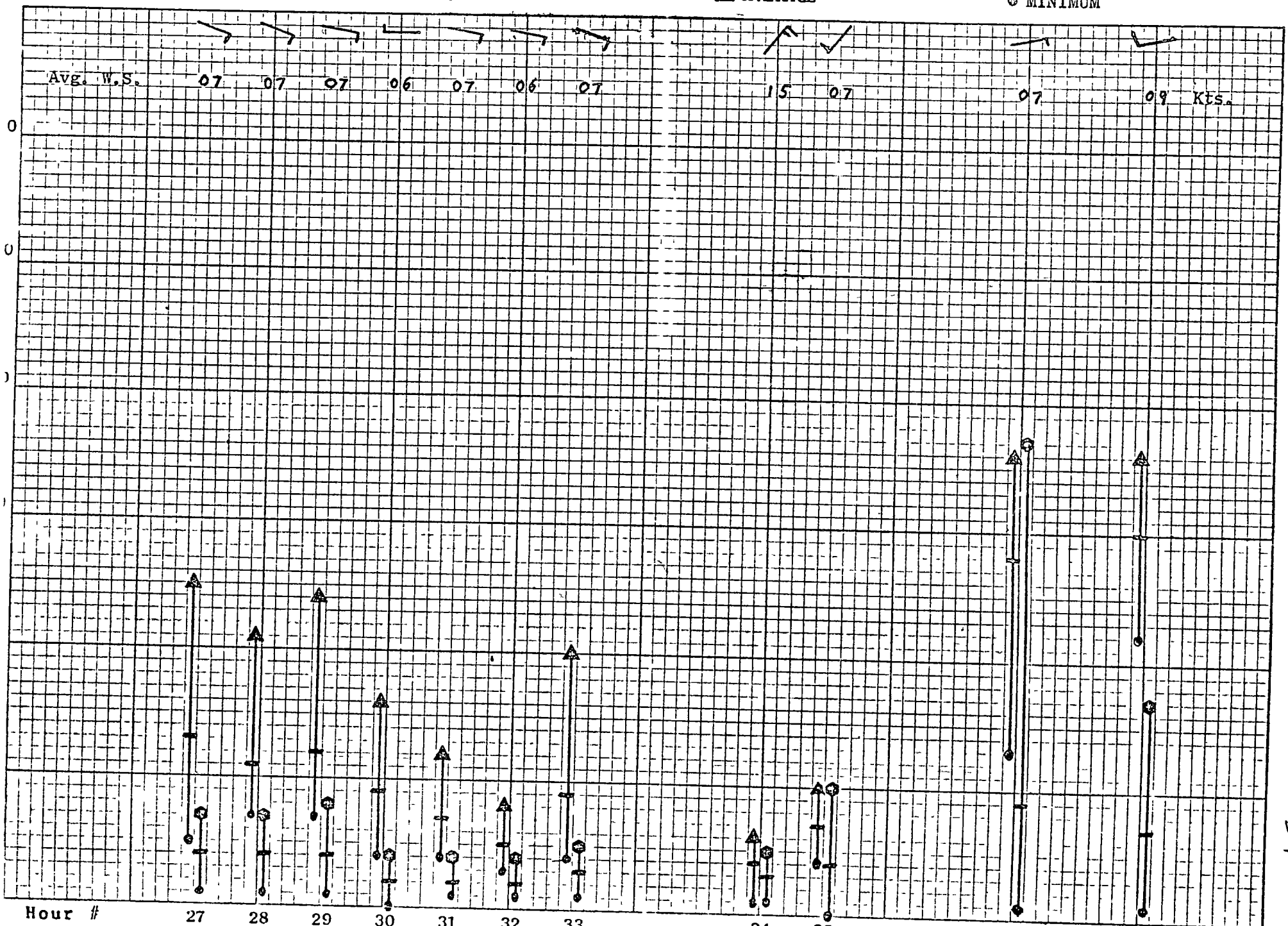


SITES FOR RESIDENTIAL AREA
HOURS #34 - 35

FIGURE VII

K·E 10 X 10 TO THE INCH 46 0700
7 X 10 INCHES MADE IN U S A
KEUFFEL & ESSER CO

▲ SAMPLE MAX. ⬢ TAMN MAX. AVERAGE ⊙ MINIMUM



SITES FOR
HUBBARD'S CAVE
AND EXPRESSWAY
HOURS #37, 38 - 53
FIGURE IX
1
2
3
4
5
6
1
2
3
4
5
6

K&E 10 X 10 TO THE INCH 46 0700
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO

▲ SAMPLE MAX. ⬢ TAMN MAX. AVERAGE ● MINIMUM

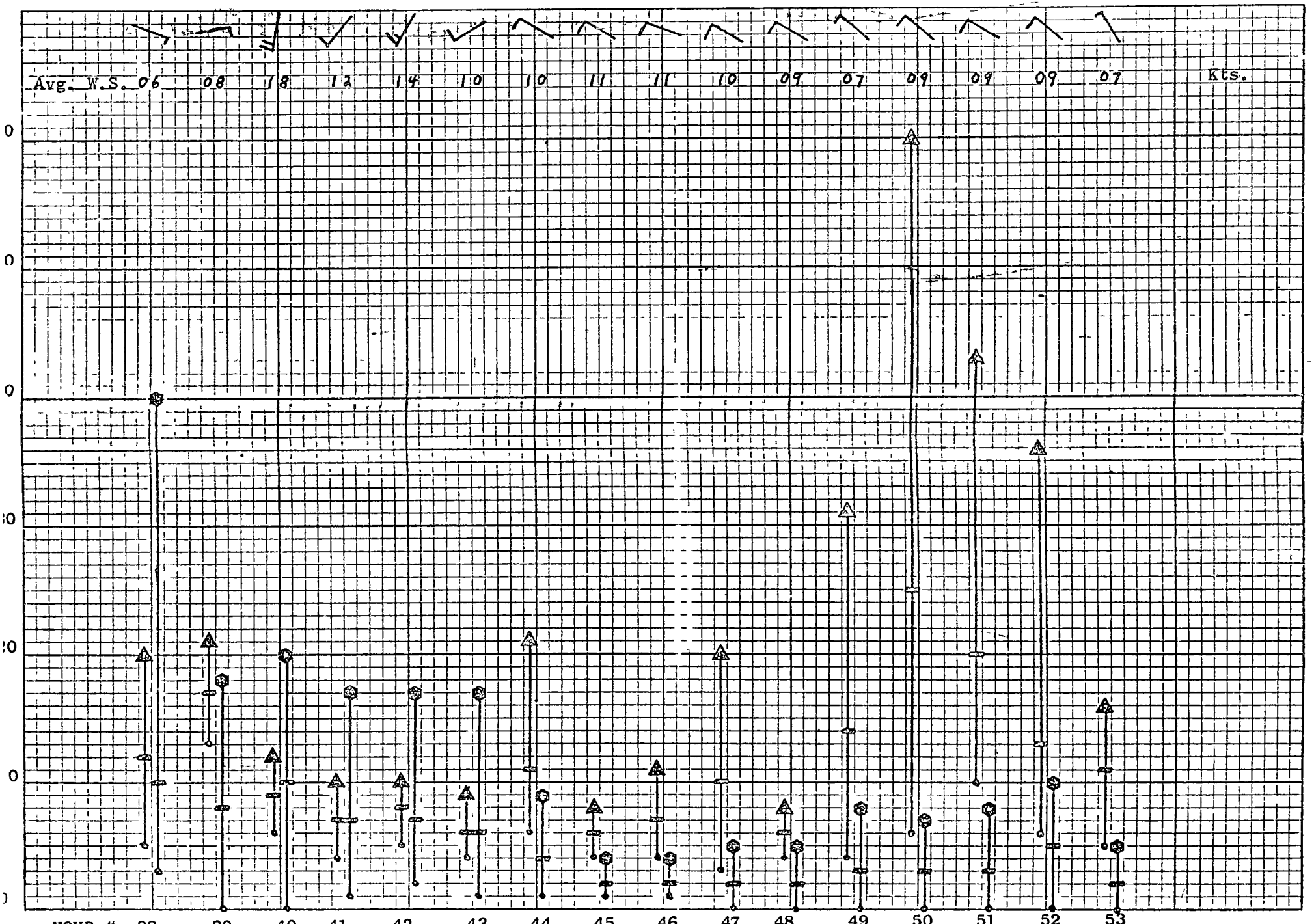
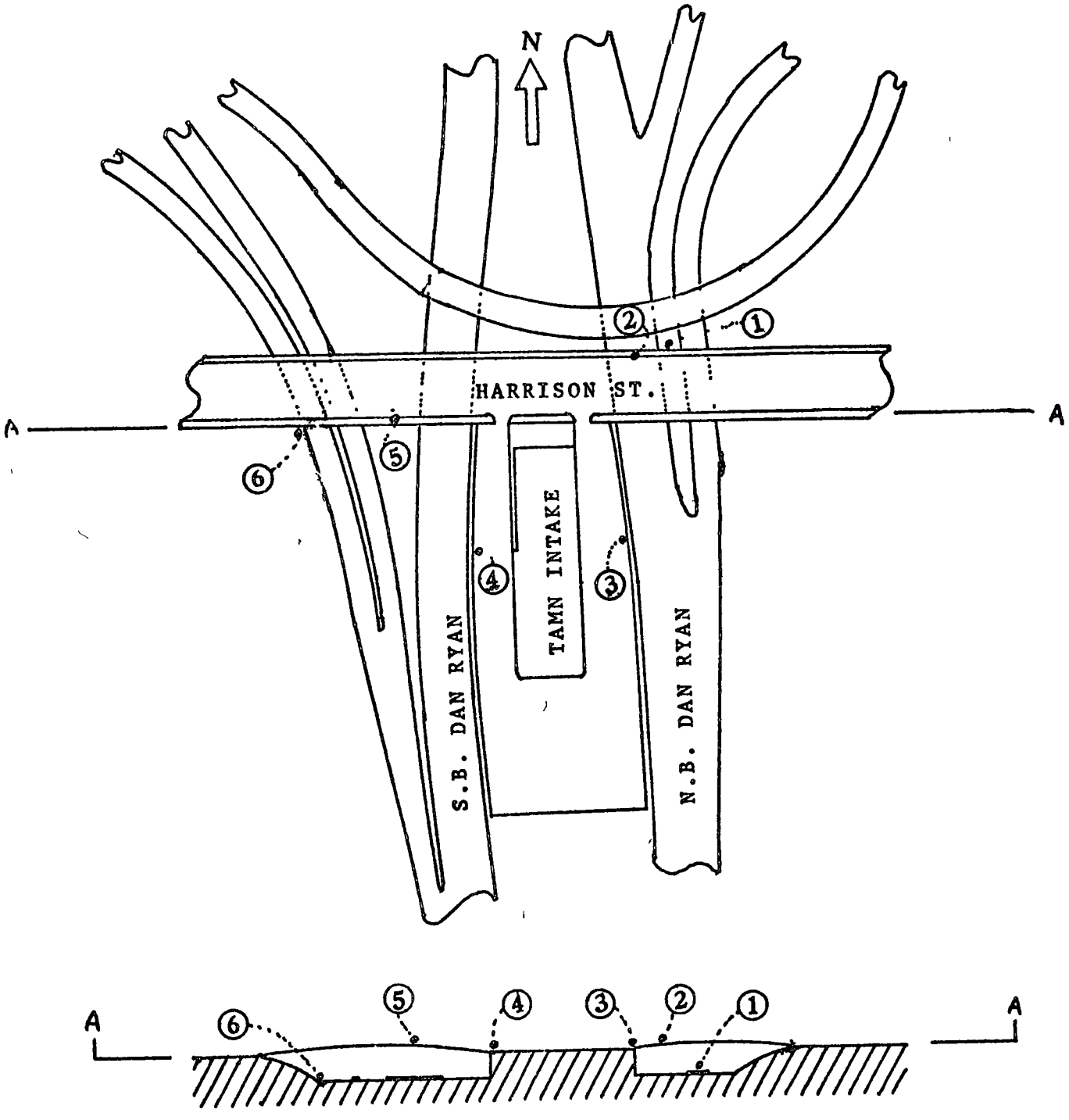


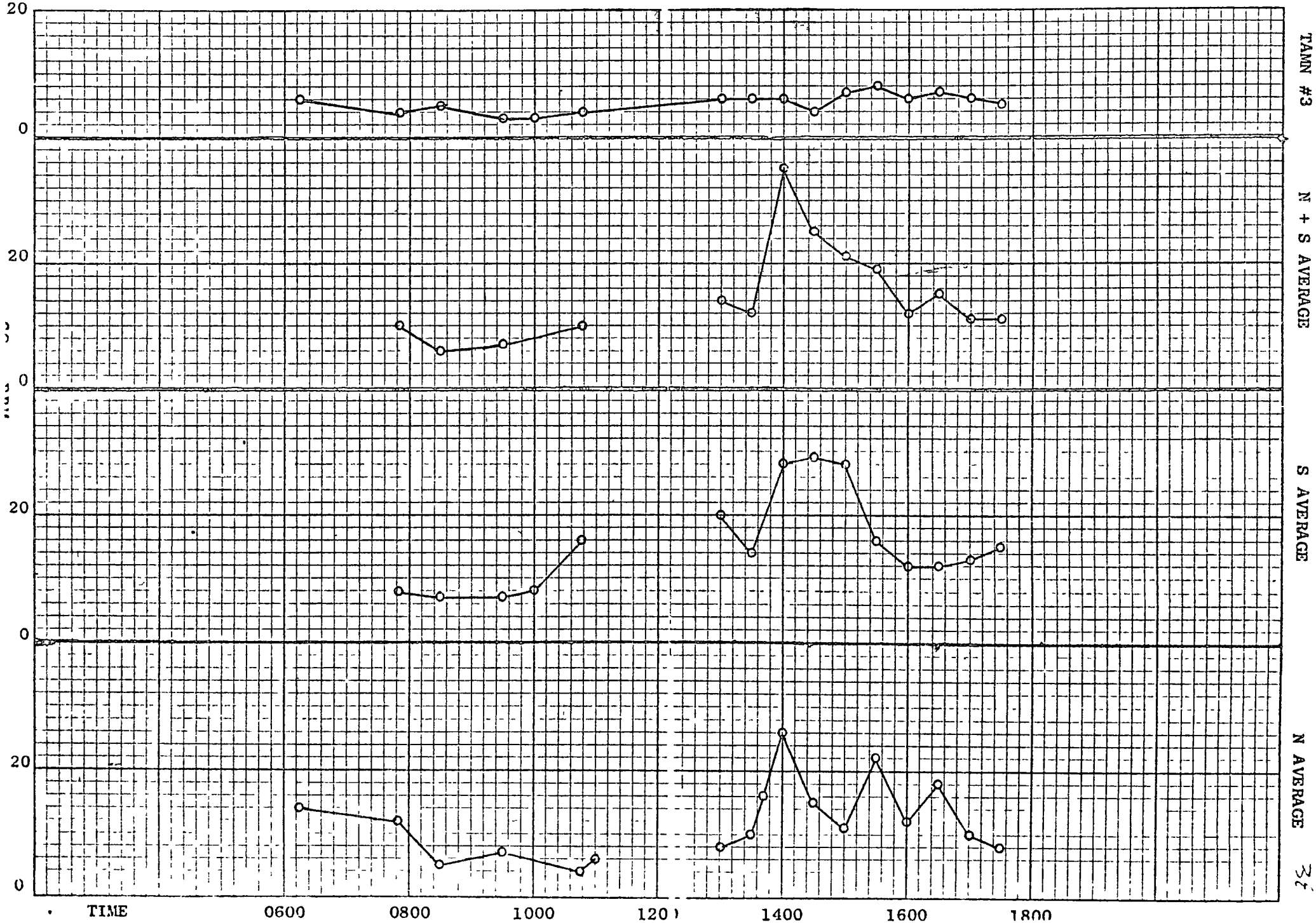
FIGURE X



DETAIL OF EXPRESSWAY SITES
HOURS #38 - 53

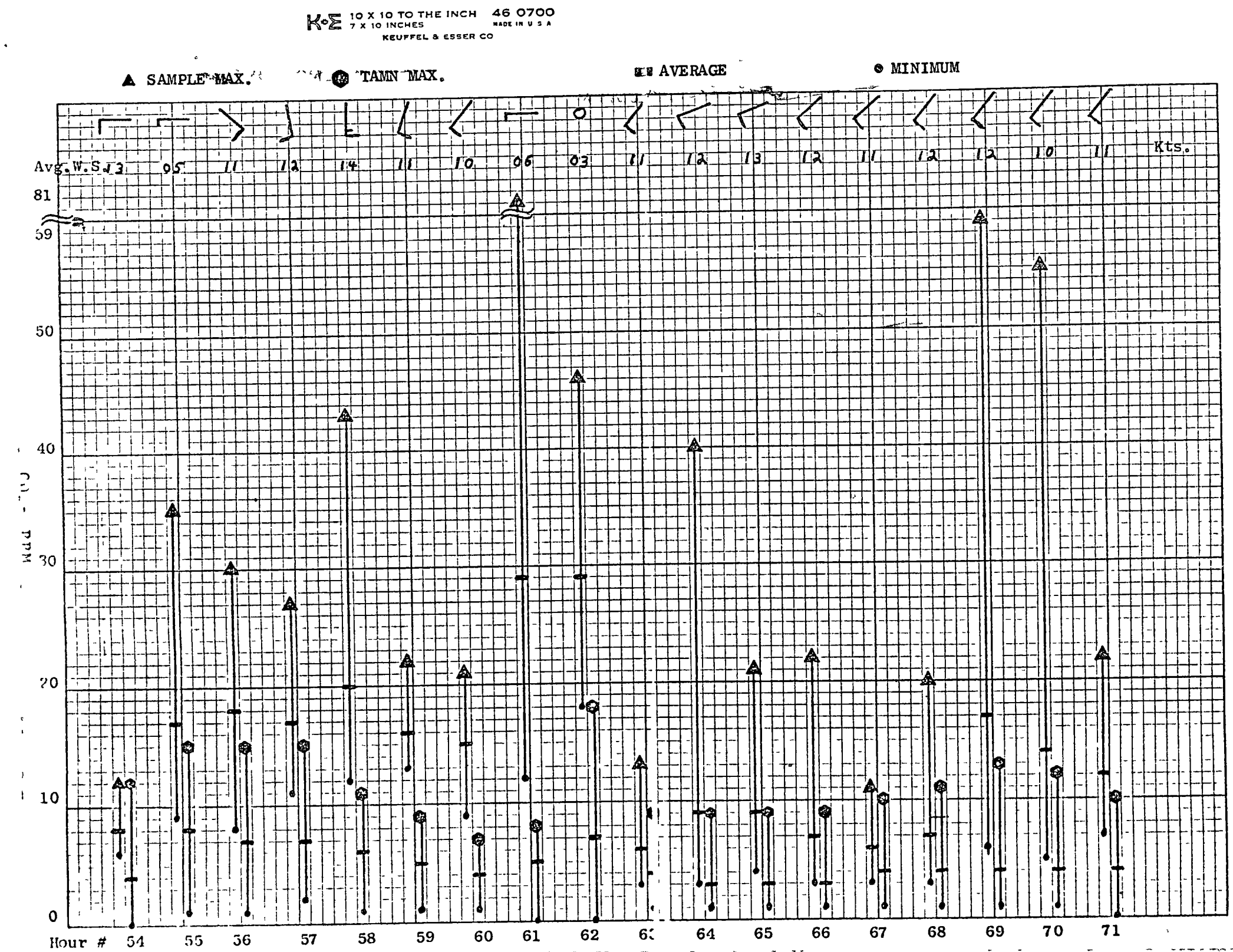
FIGURE XI

K&E 10 X 10 TO THE INCH 46 0700
7 X 10 INCHES MADE IN U S A
KEUFFEL & ESSER CO



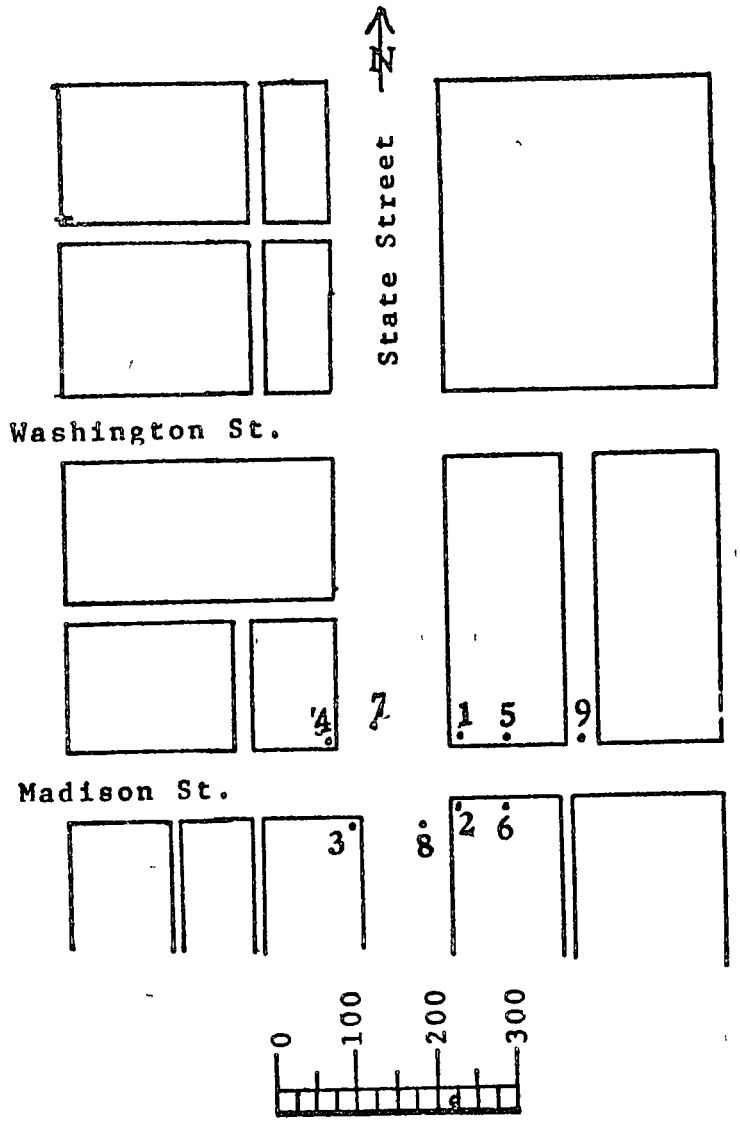
K&E 10 X 10 TO THE INCH 46 0700
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO

▲ SAMPLE MAX. ⊛ TAMN MAX. AVERAGE ⊛ MINIMUM



SAMPLING SITES: INTERSECTION OF STATE - MADISON STREETS

8 JULY '71



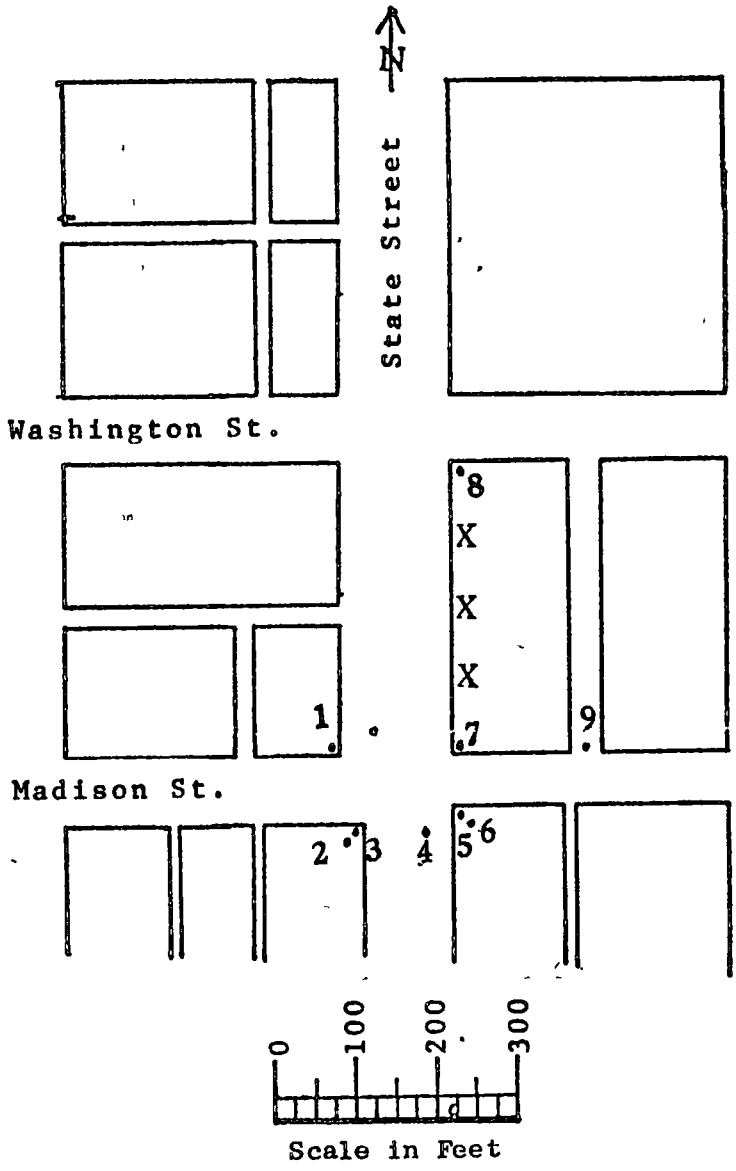
1) NE Corner
2) SE Corner
3) SW Corner
4) NW Corner
5) 60 Ft. East of State North Side of Madison
6) 60 Ft. East of State South Side of Madison
7) Safety Island North State
8) Safety Island South State
9) Vertical Profile

HOURS #54 - 62

FIGURE XIV

SAMPLING SITES: INTERSECTION OF STATE - MADISON STREETS

22 JULY '71



1) NW Corner
2) E Wall of bldg.
3) SW Corner
4) Safety Island
5) SE Corner
6) W Wall of Bldg.
7) NE Corner
8) SE Corner
X) Uniformly spaced between 7 & 8
9) Vertical Profile

HOURS # 63 - 71

FIGURE XV

K·E 10 X 10 TO THE INCH 46 0700
7 X 10 INCHES MADE IN U S A
KEUFFEL & ESSER CO

● 4 CORNER AVERAGE

o CITY AVERAGE

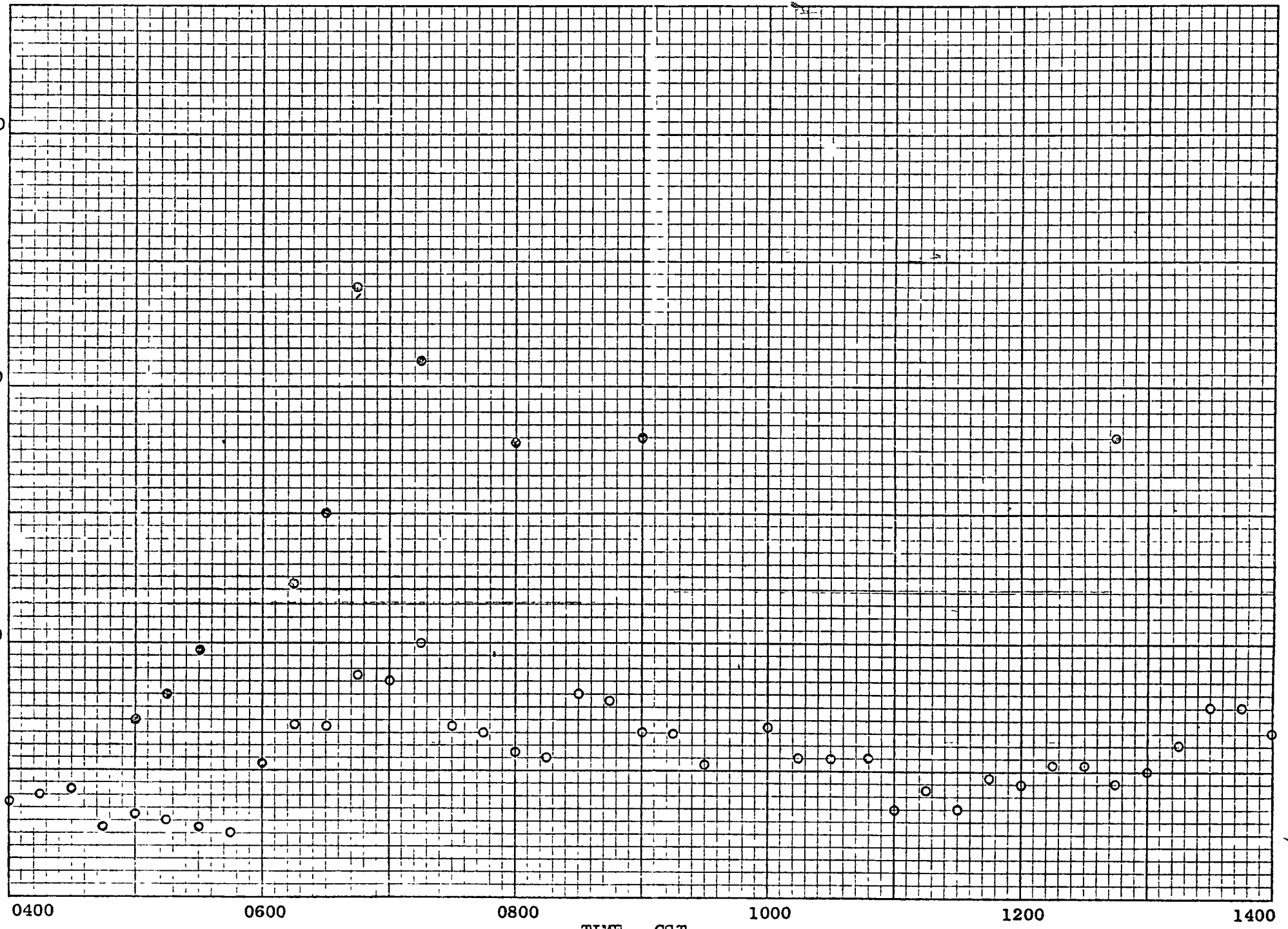
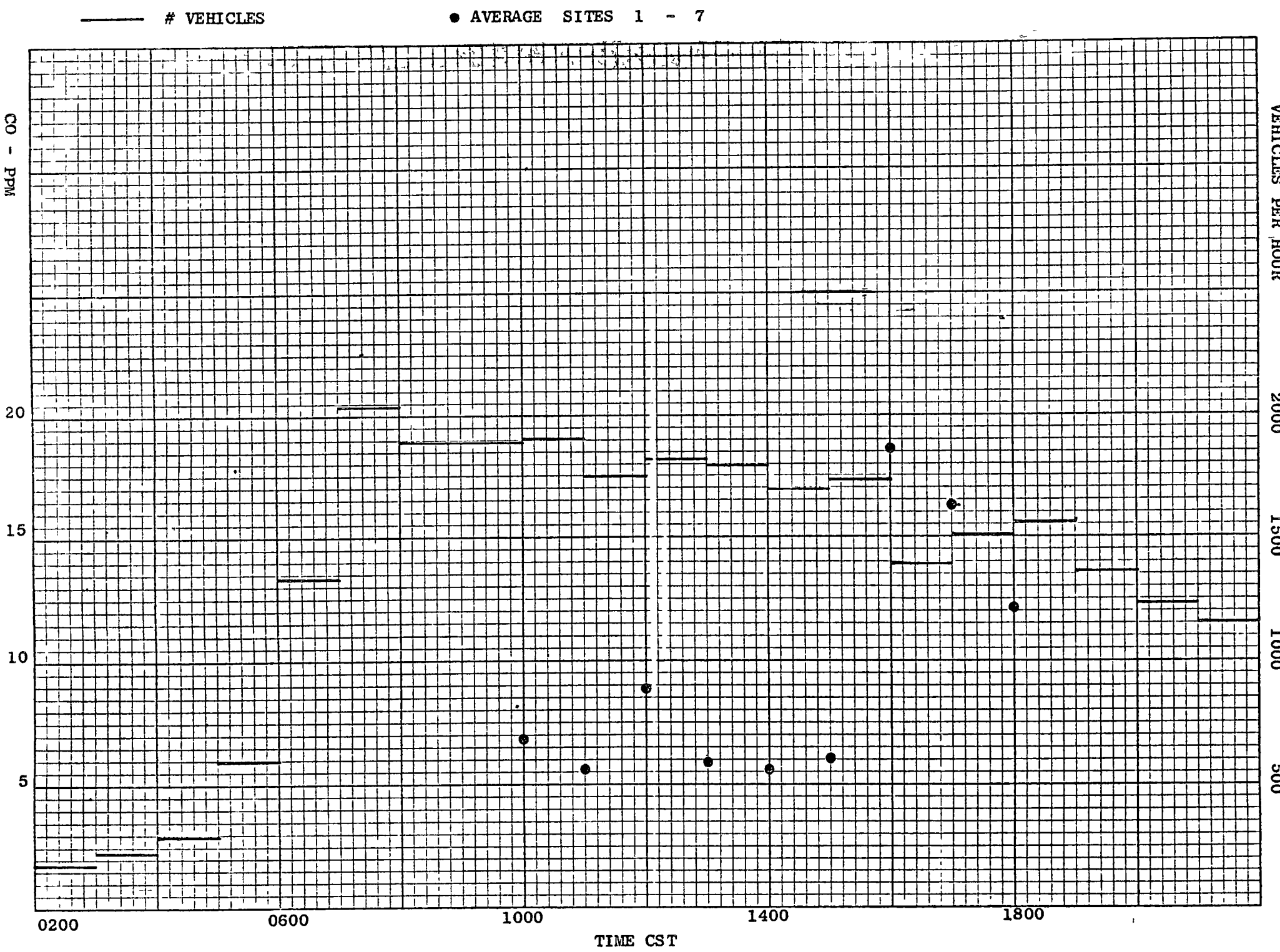


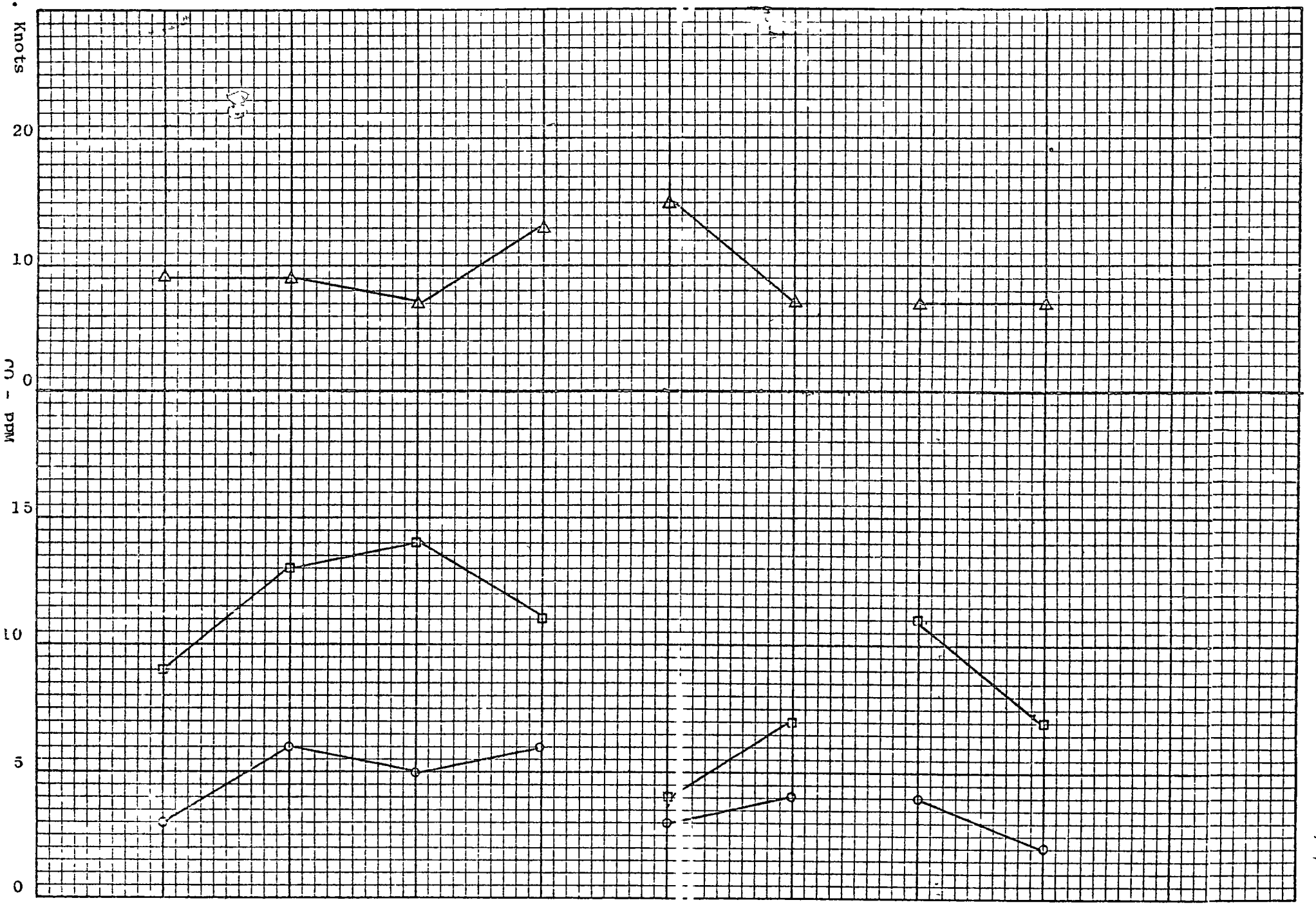
FIGURE XVI

K+E 10 X 10 TO THE INCH
7 X 10 INCHES
MADE IN U.S.A.
KEUFFEL & ESSER CO



K&E 10 X 10 TO THE ... 0702
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO

o CITY AVERAGE □ SAMPLE AVERAGE △ WIND SPEED



K&E 10 X 10 TO THE INCH 46 0702
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO

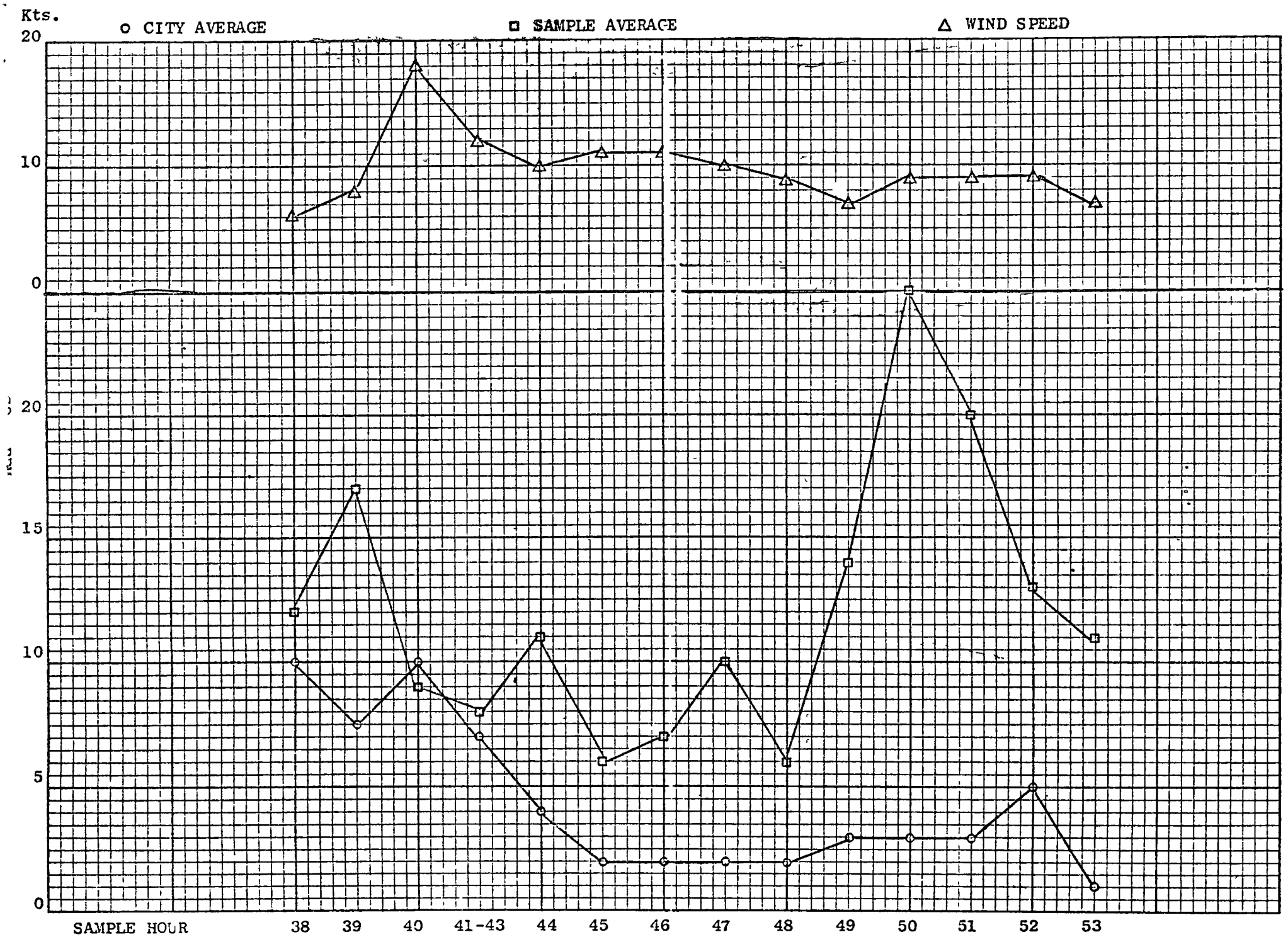
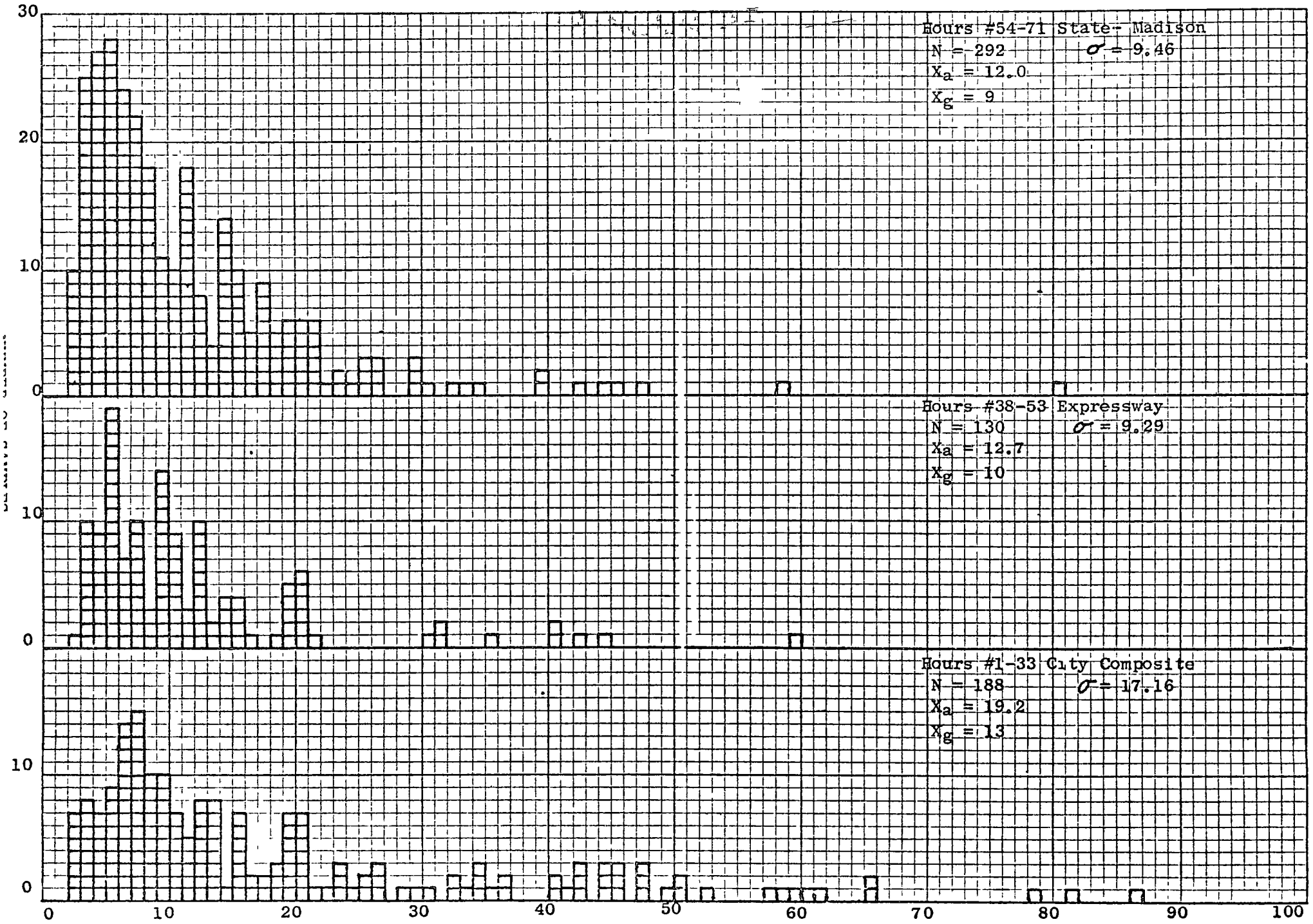


FIGURE XIX

K&E 10 X 10 TO THE INCH
7 X 10 INCHES
KEUFFEL & ESSER CO.

FIGURE XX

K&E 10 X 10 TO THE INCH 46 5755
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO



CO - PPM - FIGURE XXI

U S DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE

LOCAL CLIMATOLOGICAL DATA

SUMMARY

CHICAGO, ILL.
MIDWAY AIRPORT
MAY 1971

Latitude 41 ° 47 ' N Longitude 87° 45'W Elevation (ground) 607 foot Central Standard time used.

DATE	TEMPERATURE °F MAXIMUM	MINIMUM	AVERAGE	DEPARTURE FROM NORMAL	DEGREE DAYS	PRECIPITATION (inches) TOTAL (water equivalent)	SNOWFALL & SLEET	SNOW, SLEET & ICE ON GROUND AT 0700	WIND RESULTANT DIRECTION	AVERAGE SPEED (m.p.h.)	FASTEST (m.p.h.)	DIR	TIME (CST)	SUNSHINE TOTAL (hours and tenths)	PERCENT OF POSSIBLE	SKY COVER AVERAGE AMOUNT	AVERAGE OPACITY	PEAK WIND SPEED (m.p.h.)	DIR	TIME (CST)	VISIBILITY 1/4 MILE OR LESS (Number of times)	FASTEST MILE WIND (m.p.h.)	DIR	TIME (CST)	RELATIVE HUMIDITY (%) FROM HOURLY READINGS 4 AM	4 PM	PRESSURE (mb) 7 AM	1 PM	AVG.	DEGREE DAYS
1	64	50	57	+ 2	8	T	0	0	30	11.9	25	NW	32	11.24	84	4	6					46			80	19	62	47	55	10
2	50	35	43	-12	22	.20	T	0	36	12.3	25	NW	31	0 37	4	9	7					4			83	58	51	37	44	21
3	58	32	45	-11	20	0	0	0	35	9.9	17	NW	28	14 06	100	0	0					40			82	28	51	33	45	20
4	57	41	49	- 7	16	.10	0	0	23	10.0	20	S	30	0 52	6	9	6					47			69	38	57	47	52	13
5	63	46	55	- 1	10	.58	0	0	19	7.1	23	NE	25	1 25	10	10	9	T				40			96	58	58	47	53	12
6	60	45	53	- 4	12	.47	0	0	01	11.8	19	N	22	5 18	37	9	6	T				45			92	46	51	43	47	18
7	60	45	53	- 4	12	0	0	0	05	10.6	17	NE	23	0	0	10	9					46			83	34	55	47	51	14
8	73	41	57	0	8	T	0	0	32	8.1	19	E	30	13 10	92	4	6	T				45			80	19	61	49	55	10
9	65	41	53	- 5	12	0	0	0	05	9.7	17	NE	22	14 19	100	2	2					46			86	38	65	46	51	14
10	72	44	58	0	7	0	0	0	07	7.9	14	E	18	12 41	88	6	5					47			82	44	55	46	51	14
11	70	40	55	- 3	10	.40	0	0	19	10.2	32	N	43	1 29	10	10	10	T				47			97	61	63	41	52	13
12	55	33	44	-15	21	T	0	0	35	10.7	20	NW	28	14 17	99	4	4					48			97	39	52	39	45	20
13	70	38	54	- 5	11	0	0	0	24	9.7	17	SE	24	13 51	96	1	1					48			79	27	73	45	59	6
14	67	47	57	- 2	8	0	0	0	00	9.1	12	S	18	14 30	100	0	0					48			65	40	67	40	59	6
15	81	53	67	+ 7	0	.03	0	0	19	12.7	27	S	28	13 06	90	3	3	T				48			77	33	83	59	71	0
16	74	56	65	+ 5	0	0	0	0	05	9.3	17	NE	22	14 34	100	0	0					49			75	25	70	56	63	2
17	89	52	71	+11	0	0	0	0	18	16.6	26	S	37	13 43	94	6	4					49			55	26	80	58	71	0
18	85	67	76	+15	0	0	0	0	18	15.8	24	SE	36	10 18	70	7	6					50			65	37	86	68	77	0
19	72	51	62	+ 1	3	0	0	0	26	16.2	28	W	38	11 05	76	6	5					50			68	33	74	58	66	0
20	70	50	60	- 1	5	0	0	0	27	11.5	21	S	32	11 34	79	6	5					50			71	19	71	53	62	3
21	63	44	54	- 8	11	0	0	0	05	10.6	11	NE	23	14 43	100	2	2					50			68	39	62	46	54	11
22	69	43	56	- 6	9	0	0	0	07	10.7	16	NE	21	13 31	92	6	5					52			70	34	55	46	52	13
23	82	56	69	+ 7	0	T	0	0	16	16.4	25	S	36	5 41	38	10	9					52			68	26	76	53	65	0
24	79	59	69	+ 6	0	.14	0	0	19	17.9	31	SW	41	6 57	47	8	6	T				52			87	47	79	60	70	0
25	59	50	55	- 8	10	.06	0	0	24	18.0	25	W	37	0 11	1	10	10	DL				52			83	66	60	50	55	10
26	57	45	51	-13	14	T	0	0	31	11.3	17	W	23	1 18	9	10	9					50			77	51	55	50	53	12
27	64	40	52	-12	13	0	0	0	32	8.5	17	NE	21	14 53	100	1	1					52			79	21	56	46	51	14
28	70	42	56	- 9	9	0	0	0	04	8.2	14	NE	21	14 54	100	1	1					52			73	27	61	51	56	9
29	77	47	62	- 3	3	0	0	0	07	5.8	13	E	18	13 47	92	4	3					52			73	24	69	50	60	5
30	83	51	67	+ 2	0	0	0	0	05	6.1	12	E	18	14 39	93	6	5					53			63	24	76	54	65	0
31	74	50	62	- 4	3	T	0	0	06	7.2	14	NW	18	7 30	50	7	6					53			77	23	59	50	55	10
SUM	2132	1434	—	—	—	1.98	T	—	—	341.8	—	—	—	300.23	—	171	154	—	—	—	37	—	—	—	—	—	1992	1532	—	280
AV	68.8	46.3	—	—	—	—	—	—	18	11.0	fastest			possible	%	5.55.0	—	—	—	—	—	49	—	—	79	36	64.349	456	9	—
											NW	32	N	—	450.50	67														

TEMPERATURE DATA

AVERAGE MONTHLY 57.6
DEPARTURE FROM NORMAL - 2.4
HIGHEST 89 ON 17
LOWEST 32 ON 3
NUMBER OF DAYS WITH -
MAX 32 OR BELOW 0
MAX 90° OR ABOVE 0
MIN 32 OR BELOW 1
MIN 0° OR BELOW 0
DEGREE DAYS (BASE 65°F) -
TOTAL THIS MONTH 257
DEPARTURE FROM NORMAL +46
SEASONAL TOTAL 6209
DEPARTURE FROM NORMAL +102

WEATHER

NUMBER OF DAYS -
CLEAR (Scale 0-3) 9
PARTLY CLOUDY (Scale 4-7) 12
CLOUDY (Scale 8-10) 10
WITH .01 OR MORE PRECIP 8
WITH .10 OR MORE PRECIP 6
WITH .50 OR MORE PRECIP 1
WITH 1.00 OR MORE PRECIP 0
DATES OF -
HAIL NONE
SLEET NONE
GLAZE/RIME NONE

PRECIPITATION DATA

1 98
TOTAL FOR THE MONTH ___ IN
DEPARTURE FROM NORMAL -1.75 IN
GREATEST IN 24 HOURS 1.05 ON 5-6

SNOWFALL AND SLEET
TOTAL FOR THE MONTH T IN
GREATEST IN 24 HOURS T ON 2
GREATEST DEPTH ON GROUND T ON 2

623 Ft Elev BAROMETRIC PRESSURE
MONTHLY MEAN STATION 29.276 IN
HIGHEST SEA-LEVEL 30.30 IN ON 27
LOWEST SEA-LEVEL 29.42 IN ON 24

SYMBOLS USED
A Hail
BS Blowing Snow
DL Distant Lightning
D Dust
ES Sleet
F Fog
H Haze
K Smoke
L Drizzle
N Sand
R Rain
S Snow
T Thunderstorm
ZL Freezing Drizzle
ZR Freezing Rain

"T" under Precipitation indicates a trace, an amount too small to measure

Character and Duration of Each Precipitation Period

(Rain or Drizzle unless otherwise indicated a-A M ; p-P M.)

DATE:
1 Continued to 12 41a 10 11p-10 25p
2. 1 24a-5 10a, 7 05a-9 01a, S 8 45a-9 08a, 9 08a-11 20a, S 9 40a-10 25a; 1 13p-2 10p
4. 11 41a-2 40p, 5 40p-6 25p
5 10 01a-10 33a, 12 27p-2 14p, 5 27p-7 43p 8 20p-10 05p, 11 23p to past midnight
6. Continued to 3 04a
8 8 15p-10 30p, 11 04p-11 40p
11 2 33a-3 09a, 4 40a-7 13a, 7 01p-11 30p
12. 12 40a-1 15a.
15. 6 35p-8 05p
23. 5 37a-6 05a, 7 35p-8 05p
24. 12 08a-12 15a, 1 05a-4 02a, 1 46p-2 39p, 3 10p-4 05p, 5 35p-6 02p, 11 32p-11 40p.
25. 12 11a-1 25a, 2 38a-3 15a, 4 52a-5 22a, 7 41a-8 07a, 12 34p-2 13p, 4 10p-4 18p
26 7 24a-7 42a.
31. 11 24a-11 38a, 12 46p-1 13p.

HOURLY PRECIPITATION

DATE	AM 1	2	3	4	5	6	7	8	9	10	11	12	PM 1	2	3	4	5	6	7	8	9	10	11	12
4					02			08	05	06	01													
5													01	09					09	13	12		20	03
6	25	18	04																					
11																					50	03	01	02
15																					03			
24		01	02	02											09									
25	06																							

MEASURABLE AMOUNTS ONLY ARE DISPLAYED IN THIS TABLE

May was cool and dry A general frost occurred in suburbs away from Lake Michigan on the 27th and 28th. The low temperature for the month was 32 degrees on the 3rd This established a new record low for May 3, the old record was 34 set in 1940 Also a reading of 33 established a new record low for May 12, the old record was 35 set in 1960 Rainfall was variable in Chicago and suburbs during May with all reporting stations below normal Local heavy rains late on the 5th caused some flooding mostly on the South side During thunderstorms on the evening of the 11th minor wind damage was reported and electric power was temporarily interrupted in many sections One man was killed by lightning on the north side on the evening of the 15th. Thunderstorms and local heavy rains late on the 24th and early on the 25th resulted in wind damage and local flooding One man was killed by lightning and two golfing companions injured in south suburban Glenwood during the afternoon of the 24th.

Prevailing wind directions are indicated in tens of degrees from true North. For example 09 is East, 18 is South, 27 is West and 36 is North

I hereby certify that this is an official U S Government publication.

John J Sullivan

John J Sullivan, Meteorologist
National Weather Service
1819 W Pershing Rd
Chicago Ill 60609

Appendix A

U S DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE

LOCAL CLIMATOLOGICAL DATA

CHICAGO, ILLINOIS
O'HARE INTERNATIONAL AIRPORT
MAY 1971

Latitude 41 ° 59 ' N Longitude 87 ° 54 ' W Elevation (ground) 658 ' ft CENTRAL Standard time used

UNIVERSITY OF CHICAGO
5730 WOODLAWN AVE

Date	Temperature (°F) Maximum	Minimum	Average	Departure from normal	Degree days (base 65°)	Precipitation Total (Water equivalent) (In.)	Snow Sleet (In.)	Snow, Sleet, or Ice on ground at 6 A M. (In)	Wind Prevailing direction †	Average speed (m p h.)	Fastest mile Speed (m p h.) *	Direction †	Sunshine Total (hours and minutes)	Percent of possible	Sky cover Sunrise to sunset (tenths)	Midnight to midnight (tenths)	Thunderstorm or distant lightning	Weather restricting visibility to ¼ mile or less	TEMPERATURES °F MAX	MIN	AVG	DEGREE DAYS	Date
1	64	47	56	+ 3	9	T	0	0	29	11 4	20	34			5	7			63	48	56	9	1
2	50	35	43	-11	22	.11	T	0	35	12 4	25	35			9	7			49	37	43	22	2
3	59	31	45	- 9	20	0	0	0	31	9 0	17	36			0	0			55	38	47	18	3
4	56	41	49	- 5	16	20	0	0	23	9 7	21	25			10	7			57	44	51	14	4
5	62	42	52	- 3	13	.48	0	0	15	6 4	19	01			10	9	T		63	47	55	10	5
6	61	45	53	- 2	12	42	0	0	02	12.6	20	03			8	8	T		53	43	48	17	6
7	63	45	54	- 1	11	0	0	0	01	9 9	19	12			10	9			55	44	50	15	7
8	74	41	58	+ 2	7	04	0	0	29	8 5	17	35			4	6			67	45	56	9	8
9	65	44	55	- 1	10	0	0	0	03	9 1	20	03			2	2			57	44	51	14	9
10	73	42	58	+ 2	7	0	0	0	03	7.6	14	07			5	5			64	44	54	11	10
11	74	44	59	+ 3	6	.20	0	0	01	9 6	33	34			9	10	T		68	40	54	11	11
12	57	37	47	-10	18	T	0	0	32	11 1	21	35			3	3			50	38	44	21	12
13	73	37	55	- 2	10	0	0	0	25	10.7	18	24			1	1			72	41	57	8	13
14	70	45	58	+ 1	7	0	0	0	07	10 3	18	05			0	0			64	48	56	9	14
15	83	58	71	+14	0	01	0	0	19	12.9	20	18			3	3	T		83	57	70	0	15
16	77	52	65	+ 7	0	0	0	0	06	10.2	16	06			0	0			69	54	62	3	16
17	88	48	68	+10	0	0	0	0	19	13 7	26	19			6	4			89	55	72	0	17
18	85	69	77	+19	0	0	0	0	19	15 8	28	19			8	7			87	66	77	0	18
19	73	51	62	+ 3	3	T	0	0	24	16.4	32	24			7	5			72	56	64	1	19
20	72	48	60	+ 1	5	0	0	0	27	11 6	28	26			7	5			71	51	61	4	20
21	65	41	53	- 6	12	0	0	0	04	9.7	19	04			2	2			59	45	52	13	21
22	69	41	55	- 5	10	0	0	0	06	10 3	17	07			6	5			64	45	55	10	22
23	79	53	66	+ 6	0	0	0	0	16	10 5	28	16			10	9			79	56	68	0	23
24	79	60	70	+10	0	56	0	0	19	16 2	35	22			8	8	T		80	58	69	0	24
25	60	50	55	- 6	10	21	0	0	26	16.5	29	24			10	10	T		58	48	53	12	25
26	54	43	49	-12	16	0	0	0	29	11 2	18	27			10	9			54	47	51	14	26
27	64	38	51	-11	14	0	0	0	29	7 7	22	04			0	0			61	41	51	14	27
28	68	38	53	- 9	12	0	0	0	04	7 7	18	07			1	1			64	45	55	10	28
29	75	41	58	- 4	7	0	0	0	26	6 1	16	13			3	3			72	45	59	6	29
30	82	45	64	+ 2	1	0	0	0	25	8 1	18	08			6	6			79	52	66	0	30
31	79	52	66	+ 4	0	0	0	0	02	8 2	16	05			8	7			61	49	55	10	31
Sum	2146	1399				2 23	T			325 1					171	157			2039	1471		285	Sum
Avg	69 2	45 1								10 6	Fastest	Dir	Possible	%	5 5	5 1			65 8	47 5	56 7		Avg
										Misc.	35	22											Mis

T in columns 7 8 9 and in the Hourly Precipitation table indicates an amount too small to measure

TEMPERATURE (°F)

Average monthly	57 2
Departure from normal	- 0 6
Highest 88 on	17
Lowest 31 on	3
Number of days with —	
Max 32° or below	0
Max 90° or above	0
Min 32° or below	1
Min 0° or below	0

HEATING DEGREE DAYS (base 65°)

Total this month	262
Departure from normal	+ 2
Seasonal total (since July 1)	6286
Seasonal departure from normal	- 281

BAROMETRIC PRESSURE (In)

Avg station (elev 674 feet, m s l)	29.226
Highest sea level 30.30 on	27
Lowest sea level 29 40 on	24

PRECIPITATION (In)

Total for the month	2 23
Departure from normal	- 1 53
Greatest in 24 hours 0 90 on	5-6
Snow, Sleet—	
Total for the month	T
Greatest in 24 hours	T on 2
Greatest depth on ground	T on 2
Dates of — Hail	NONE
Sleet NONE Glaze/Rime	NONE

Symbols used in columns 18 19

A = Hail
BS = Blowing snow
DL = Distant lightning
D = Dust
E = Sleet
F = Fog
H = Haze
K = Smoke
L = Drizzle
N = Sand
R = Rain
S = Snow
T = Thunderstorm
ZL = Freezing drizzle
ZR = Freezing rain

Character and Duration of Each Precipitation Period

(Rain or Drizzle unless otherwise indicated a-A M ; p-P M)

DATE

1. 8 25p-8 35p, 9 45p-10 22p
2. 12 17a-4 20a, 7 13a-8 45a, 8 8 15a-9 30a, 9 18a-10:10a; 12 35p-1 42p, 2 40p-3 10p
4. 11.41a-2 15p
5. 8 35a-9 35a, 10 01a-10:12a, 12 45p-3 42p, 5 50p-9 46p; 10 16p to past midnight
6. Continued to 3 20a
8. 8;42p-11 45p
11. 3 04a-3 46a, 6 01p-6 06p, 6 28p-10.13p; 10 45p to past midnight
12. Continued to 12 14a
15. 7.01p-7 15p
19. 7;10a-7 25a
24. 12;10a-12 40a, 2 01a-4 10a, 1 45p-3 13p; 7 20p-7:25p; 10;45p to past midnight
25. Continued to 2 05a, 4 05a-4 15a; 12:02p-3:20p; 4.40p-5:45p.
31. 11;05a-11 40a, 12 01p-12 35p

HOURLY PRECIPITATION

DATE	A M. HOUR ENDING 1	2	3	4	5	6	7	8	9	10	11	12	P M HOUR ENDING 1	2	3	4	5	6	7	8	9	10	11	12
2									01	-6	02													
4												02	02	15	01									
5									-		01		02	10					03	07	05	12	02	1
6	20	15	05	02																				
8																						01	03	
11									-										07	10	02	01		
15									-											01				
24	01		02	04																				
25	15	05			01																		02	4

MEASURABLE AMOUNTS 5 OR MORE ARE DISPLAYED IN THIS TABLE

+ Also on earlier dates
*Fastest observed one minute wind speed
† Figures in columns 10 and 13 indicate directions in tens of degrees from true North. For example 09 is East, 18 is South, 27 is West and 36 is North

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MAY 1971

Comparative DAILY PRECIPITATION Chicago Area

Station	Day of Month																													Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
Highland Park, Ill Ve Plant	02	25		08	33	16	T	01			19	T						T	T					49	1 00	T					04	2 48
ev, Ill U > Naval Air Station	T	26		16	30	30		T			19													07	39	T						1 67
Sanitary District of Chicago Howard & McCormick, Skokie	01	23		18	36	31					21													07	25							1 62
National Weather Service O'Hare International Airport	T	11		20	48	42		04			20	T				01			T					56	21						T	2 23
Sanitary District of Chicago Lawrence & Francisco		19		19	50	36					04	01				04								16	19							1 67
City of Chicago 4950 Wilson		16		23	63	36					19					04								12	18	01			01			1 93
City of Chicago 1747 N Springfield		16		13	1 10	46		05			58					15								23	02							2 88
Sanitary District of Chicago 100 E Erie St	01	15		19	64	38			01		51					09								07	05							2 10
City of Chicago 1000 E Ohio St		14		24	68	42		04			48					10								06	06							2 22
Berwyn, Ill 1644 S Gunderson Paul Kubecka		18		14	85	48		01			56					04			T					17	05						T	2 48
§ 2419 S Christiana Ave Raymond Beeryl	01	15		15	08	1 35			01			40					08							05	05	T					T	2 33
Sanitary District of Chicago 3838 S Racine Ave.		12		08	63	72					30													05	02							1 92
Sanitary District of Chicago 40th & Lorenzo Stickney		16		15	88	42					35					28								11	04							2 49
§ LaGrange Park, 845 N Spring Charles Flag		11		14	17	1 33			01		38	24				07			T					17	22						T	2 84
University of Chicago 5730 S Woodlawn Ave	T	15		17	76	46		T	T		27	T				20							02	85	05	T					T	2 93
National Weather Service 6200 S Cicero Ave.	T	20		10	58	47		T			[illegible]	T				[illegible]							T	14	[illegible]						T	1 99
Oak Lawn, Ill 8501 S Mobile Frank Wachowski	T	18		09	66	46		T			42	T				04							T	29	04						T	2 09
/ Chicago ?> & Lake Michigan		20		13	52	43					30					25								30	07							2 20
City of Chicago 551 W 104th St,		26		10	63	49		02			38	01				04								64	03							2 60
Sanitary District of Chicago 126th & St Lawrence		24		05	96	45					20					04								44								2 38

AMOUNTS ARE FOR MIDNIGHT TO MIDNIGHT", EXCEPT AS NOTED, § 7 P M ; "T" INDICATES AN AMOUNT TOO SMALL TO MEASURE INC MEANS INCOMPLETE M MEANS MISSING

GPO 832-18

US GPO CHICAGO 6/4/71-2000

MAY 1971 HOURLY TEMPERATURES-MIDWAY AIRPORT

DATE	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	53	52	52	52	52	51	50	51	51	54	56	58	60	62	63	64	64	61	60	58	58	57	57	51
2	50	49	47	46	46	45	44	43	39	38	35	38	42	43	43	47	47	46	45	43	40	38	38	36
3	36	35	35	34	33	32	35	42	46	49	51	53	56	58	57	57	57	55	53	49	48	45	44	42
4	43	42	42	41	41	41	44	46	50	51	52	54	56	51	47	46	55	56	52	51	49	47	47	47
5	47	50	47	49	48	46	49	54	55	56	57	59	62	62	58	58	57	58	56	53	53	53	54	50
6	51	48	46	46	46	45	45	46	47	49	51	52	53	57	58	58	58	56	54	52	51	49	47	46
7	46	47	46	47	47	52	54	54	55	57	56	57	59	58	59	59	59	55	53	52	52	49	49	49
8	48	47	45	43	43	41	43	51	60	64	66	68	69	70	71	71	71	73	71	69	69	48	49	54
9	51	51	49	45	44	42	45	50	53	55	57	59	60	62	62	64	60	60	58	54	50	48	48	45
10	45	46	44	44	45	44	48	55	58	62	65	68	69	71	70	68	66	65	63	60	54	54	53	52
11	52	54	55	57	58	59	59	62	60	60	63	65	67	69	68	69	69	69	69	67	57	46	44	43
12	40	40	40	38	34	33	36	40	44	44	48	50	50	52	53	52	53	52	50	48	48	49	43	43
13	44	40	39	38	39	38	42	47	55	60	61	63	65	66	67	69	70	69	68	66	63	63	62	61
14	60	59	50	48	48	48	51	54	57	60	62	62	63	65	66	66	66	65	62	60	58	57	62	64
15	61	60	58	56	55	53	56	62	67	70	73	76	78	79	80	80	80	79	77	74	68	69	68	67
16	65	64	64	60	60	59	63	66	70	72	71	72	74	72	72	71	69	68	67	64	62	59	58	57
17	56	55	56	55	52	53	59	67	70	74	78	81	85*	85	87	88	88	85	83	81	79	76	74	73
18	72	70	69	68	69	67	67	69	70	74	76	77	76	77	82	85	85	84	82	82	80	78	75	74
19	72	71	70	69	68	67	67	69	71	69	68	68	68	68	68	70	69	63	61	60	57	56	54	54
20	51	52	53	52	51	51	51	54	59	62	64	66	67	69	70	70	69	68	67	66	63	61	55	58
21	55	53	51	52	50	49	53	58	60	62	62	61	60	60	59	54	54	50	49	48	46	45	45	44
22	45	46	47	43	45	44	47	50	55	58	61	63	64	65	66	68	67	65	60	56	53	54	54	54
23	56	58	57	57	58	58	59	58	58	59	62	66	69	69	73	76	81	77	75	73	71	69	67	65
24	64	65	64	63	62	62	62	64	66	67	75	76	77	78	75	65	63	74	73	69	68	68	66	63
25	59	57	55	54	53	53	53	53	52	52	53	53	54	53	53	54	53	53	53	52	51	51	51	50
26	50	50	50	49	49	49	50	49	50	52	54	54	54	53	56	56	55	54	53	52	51	48	46	
27	45	45	44	43	42	41	45	52	56	58	61	62	62	62	63	64	64	60	56	54	50	50	50	48
28	47	46	47	45	43	42	47	54	59	62	64	65	66	66	67	68	69	68	65	63	58	57	55	53
29	52	51	50	50	49	47	52	59	65	68	70	70	73	73	73	75	76	74	67	65	64	62	63	61
30	61	60	59	59	58	57	63	69	74	76	78	79	81	79	83	80	80	76	72	71	69	67	66	65
31	61	56	53	51	51	51	54	57	62	68	69	69	70	71	71	73	78	63	62	61	62	58	61	61

U S DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE

LOCAL CLIMATOLOGICAL DATA

SUMMARY

CHICAGO, ILL.
MIDWAY AIRPORT
JUNE 1971

Latitude 41 ° 47 ' N Longitude 87 ° 45' W Elevation (ground) 607 feet Central Standard time used.

DATE	TEMPERATURE °F MAXIMUM	MINIMUM	AVERAGE	DEPARTURE FROM NORMAL	DEGREE DAYS	PRECIPITATION (Inches) TOTAL (Water Equivalent)	SNOWFALL & SLEET	SNOW ICE ON GROUND AT 6:30 P.M.	WIND PREVAILING DIRECTION	AVERAGE SPEED (M.P.H.)	FASTEST MILE SPEED	FASTEST MILE DIR	PEAK GUST VELOCITY	SUNSHINE TOTAL (hours and tenths)	PERCENT OF POSSIBLE	SKY COVER (tenths) JONAL-ASKET	SKY COVER (tenths) MIDNIGHT-MIDNIGHT	RAIN OR DRIZZLE	FOG	VISIBILITY 1/4 MILE OR LESS CAUSED BY	COOLING DEGREE DAYS	AVG PITCH WATER TEMP	RELATIVE HUMIDITY FROM HOURLY OBSERVATIONS 1 AM	RELATIVE HUMIDITY FROM HOURLY OBSERVATIONS 7 PM	TEMPERATURE °F MAX	TEMPERATURE °F MIN	TEMPERATURE °F AVG	HEATING DEGREE DAYS
1	71	59	65	- 1	0	.7	0	0	06	7.4	17	SE	22	3.03	20	10	9	T			4	55	91	55	63	55	60	5
2	75	59	67	0	0	.07	0	0	28	10.0	17	W	21	11.35	77	7	7	T			6	56	90	58	72	56	64	0
3	86	60	73	+ 6	0	0	0	0	07	4.8	12	NE	16	1.0	04	2	2				10	55	81	45	70	58	64	1
4	93	65	79	+12	0	0	0	0	06	4.7	11	NE	16	12.5	85	6	5				13	55	78	33			68	0
5	97	72	85	+17	0	0	0	0	24	10.5	17	SW	25	12.7	81	6	5				18	55	82	34			82	0
6	97	70	84	+16	0	.29	0	0	22	9.2	31	SW	39	6.3	43	8	6	T			14	55	79	42			75	0
7	89	69	79	+11	0	0	0	0	18	16.0	26	W	38	13.10	88	4	3				12	58	81	32			77	0
8	69	50	60	- 9	5	0	0	0	01	13.3	19	NE	25	12.4	84	5	4				0	55	84	40			59	6
9	71	49	60	- 9	5	0	0	0	04	9.1	17	NE	22	10.60	72	6	5				1	54	83	47			58	7
10	80	53	67	- 4	0	0	0	0	13	10.3	17	NE	28	12.19	81	8	6				6	55	91	41	65	55	60	5
11	87	69	78	+ 9	0	.24	0	0	19	10.0	31	SW	43	5.16	35	9	9	T			10	58	84	57	78	64	71	0
12	89	68	79	+ 9	0	0	0	0	21	9.5	15	SW	22	10.49	71	6	6				15	57	87	55	90	68	79	0
13	90	64	77	+ 7	0	.05	0	0	32	9.1	24	N	29	9.18	61	8	7	T			10	56	81	43	81	60	71	0
14	77	62	70	0	0	0	0	0	02	8.5	14	N	18	13.50	91	4	5				7	59	81	58	66	59	63	2
15	83	61	72	+ 1	0	0	0	0	04	8.2	14	NE	21	14.00	92	2	3				8	60	78	51	71	58	65	0
16	69	61	75	+ 4	0	0	0	0	05	6.5	12	NE	18	14.27	95	0	0				10	60	75	29	78	61	70	0
17	93	68	81	+10	0	0	0	0	18	9.7	14	SE	23	12.05	78	3	3				12	60	59	27	83	69	76	0
18	94	67	81	+10	0	.50	0	0	18	11.7	34	NE	39	11.45	77	7	7	T			14	60	88	32	92	66	79	0
19	91	71	81	+ 9	0	0	0	0	10	8.2	17	NE	16	12.47	84	3	5	DU			14	60	79	49	80	65	73	0
20	95	66	81	+ 9	0	.34	0	0	24	10.5	32	W	51	5.18	34	9	9	T			12	61	88	45	92	62	77	0
21	74	61	68	- 4	0	0	0	0	03	13.0	22	N	28	13.58	92	3	3				4	62	78	34	71	60	66	0
22	84	58	71	- 1	0	0	0	0	22	7.0	18	NW	28	9.33	63	6	6				9	62	69	43	84	61	73	0
23	83	68	76	+ 3	0	.07	0	0	18	6.6	18	SE	25	6.03	40	8	7	T			11	63	80	54	82	66	74	0
24	93	67	80	+ 7	0	.07	0	0	17	7.6	25	NW	40	13.18	88	7	7	T			13	63	84	35	85	66	76	0
25	83	59	71	- 2	0	.07	0	0	01	11.0	21	SE	29	6.00	39	8	8	T			8	62	84	53	74	60	67	0
26	85	60	73	0	0	0	0	0	02	7.3	12	E	18	11.27	75	3	3				10	62	81	46	72	61	67	0
27	101	73	87	+13	0	0	0	0	24	10.6	17	SW	25	14.56	98	2	2				19	63	82	29	96	69	83	0
28	101	76	89	+15	0	0	0	0	22	9.3	15	SE	22	15.00	100	0	0	DU			19	64	74	35	97	80	89	0
29	96	75	86	+12	0	0	0	0	18	10.3	16	SE	23	15.11	100	0	0				18	62	72	36	92	76	84	0
30	96	75	86	+12	0	.01	0	0	19	11.6	21	SW	31	8.56	59	8	6	DU			16	64	74	40	92	77	85	0
SU	2612	1935	—	—	—	2.18	0	—	—	2820	—	—	—	333.43	—	158	148	—	—	—	323	—	—	—	2397	1899	—	26
AV	87.1	64.5	—	—	—	—	—	—	18	9.4	Fastest MISC	—	—	possible	%	5.34.9	—	—	—	—	—	59	81	43	79.9	63.3	71.6	—

TEMPERATURE DATA

AVERAGE MONTHLY 75 8
DEPARTURE FROM NORMAL + 5 3
HIGHEST 101 ON 27,28
LOWEST 49 ON 9
NUMBER OF DAYS WITH —
MAX 32 OR BELOW 0
MAX 90° OR ABOVE 13
MIN 32 OR BELOW 0
MIN 0° OR BELOW 0
DEGREE DAYS (BASE 65°) —
TOTAL THIS MONTH 10
DEPARTURE FROM NORMAL -38
SEASONAL TOTAL 6219
DEPARTURE FROM NORMAL + 64

WEATHER

NUMBER OF DAYS —
CLEAR (Sky 0 3) 10
PARTLY CLOUDY (Sky 4 7) 11
CLOUDY (Sky 8 10) 9
WITH 0.01 OR MORE PRECIP 11
WITH 0.10 OR MORE PRECIP 5
WITH 0.50 OR MORE PRECIP 1
WITH 1.00 OR MORE PRECIP 0
DATES OF —
HAIL 18,20
SLEET NONE
GLAZE/RIME NONE

PRECIPITATION DATA

TOTAL FOR THE MONTH 2.18 IN
DEPARTURE FROM NORMAL + 1.89 IN
GREATEST IN 24 HOURS 0.54 ON 1-2

SNOW, ICE
TOTAL FOR THE MONTH 0 IN
GREATEST IN 24 HOURS 0 ON
GREATEST DEPTH ON GROUND 0 ON

623 Ft Elev BAROMETRIC PRESSURE
MONTHLY MEAN STATION 29.286 IN
HIGHEST SEA-LEVEL 30.20 IN ON 4
LOWEST SEA-LEVEL 29.67 IN ON 13

SYMBOLS USED

A Hail
BS Blowing Snow
BL Distant Lightning
D Dust
E Sleet
F Fog
H Haze
K Smoke
L Drizzle
M Sand
R Rain
S Snow
T Thunderstorm
ZL Freezing Drizzle
ZR Freezing Rain

"T" under Precipitation indicates a trace, an amount too small to measure

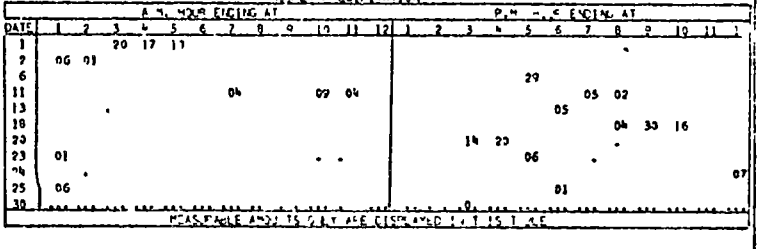
Character and Duration of Each Precipitation Period

(Rain or Drizzle unless otherwise indicated a-A M ; p-P M.)

DATE

1 1 5 [illegible] 4 a, 6 [illegible]-11 30a, 12 02p-12.28p.
6. 1 43p-3 30p, 4 08p-5 10p, 7 45p-8 02p
11. 5 43a-7 02a, 9 01a-10 25a, 5 36p-8 36p.
13. 5 20p-6 02p
18. 7 35p-10 01p, A 9 01p-9 03p.
20 6 42a-7 09a, 2 52p-4 30p, A 3 37p-3 43p.
23. 12 02a-12 38a, 5 08a-5 15a, 7 06a-7 10a, 12 36p-1 03p, 4 09p-4 43p
24. 10 02p-10 08p, 10 33p-10 45p, 11 05p to past midnight
25. Continued to 1 32a, 4 44p-6 15p.
30. 1 44p-2 24p, 3 18p-3 38p

HOURLY PRECIPITATION



June was hot with record breaking temperatures The average maximum of 87 1 is a new record for June The old record was 86 3 set in 1954 The average monthly temperature of 75 8 is second only to June of 1933 when the average was 76 2 degrees A temperature of 90 or above was recorded on 13 days Only 2 Junes, in 42 years of records for Midway Airport, had more 90 degree days June of 1933 and 1954 each had 16 The normal June frequency is 6 days The 100 degree weather on the 27th represented the first time in more than 10 years that 100 or higher was recorded in Chicago The previous occurrence was 100 even on September 7, 1960 When the mercury reached 101 on the 27th a 15 year record was established This was the highest since 103 occurred on July 1, 1956 A high of 101 occurred on two consecutive days, the 27th and 28th Only two other Junes, that of 1933 and 1953, had two 100 degree days In 1953 the two days were consecutive New daily maximum records were established on the 5th, 6th and 27th and the daily maximum record for the 28th was equalled Locally heavy rains on the first caused minor flooding mostly of basements Late afternoon thunderstorms on 6th, with high winds, hail and locally heavy rains resulted in downed trees and power lines and some flooding Late on the 18th thunderstorms again moved across the area Scattered wind and lightning damage was reported and basements were again flooded On the afternoon of the 20th similar damage resulted from more thunderstorms.

Prevailing wind directions are indicated in tens of degrees from true North For example 09 is East, 18 is South, 27 is West and 36 is North.

I hereby certify that this is an official U S Government publication.

John J Sullivan

John J Sullivan, Meteorologist
National Weather Service
1810 W Pershing Rd
Chicago, Ill 60609

U S DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE

LOCAL CLIMATOLOGICAL DATA

CHICAGO, ILLINOIS
O'HARE INTERNATIONAL AIRPORT
JUNE 1971

Latitude 41 ° 59 ' N Longitude 87° 54 ' W Elevation (ground) 658 ft CENTRAL Standard time used

UNIVERSITY OF CHICAGO
5730 WOODLAWN AVE

Date	Temperature (°F) Maximum	Minimum	Average	Departure from normal	Degree days (base 65°)	Precipitation Total (Water equivalent) (In.)	Snow Sleet (In.)	Snow, Sleet, or Ice on ground at 6 A M. (In)	Wind Prevailing direction †	Average speed (m.p.h.)	Fastest mile Speed (m.p.h.) *	Fastest mile Direction †	Sunshine Total (hours and minutes)	Percent of possible	Sky cover Sunrise to sunset (tenths)	Midnight to midnight (tenths)	Thunderstorm or distant lightning	Weather restricting visibility to ¼ mile or less	TEMPERATURES °F MAX	MIN	AVG	DEGREE DAYS	Date
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	71	55	63	0	2	47	0	0	04	8 2	18	32			9	9	T		66	56	61	4	1
2	74	56	65	+ 1	0	05	0	0	26	9.2	22	27			7	6	T		76	57	67	0	2
3	85	53	69	+ 5	0	0	0	0	21	5 8	14	07			3	2			80	57	69	0	3
4	90	60	75	+11	0	0	0	0	27	6 0	16	06			4	4			86	60	73	0	4
5	92	68	80	+15	0	0	0	0	22	9.9	24	23			6	5			94	68	81	0	5
6	92	68	80	+15	0	09	0	0	16	9 6	31	30			7	5	T		90	65	78	0	6
7	86	63	75	+ 9	0	0	0	0	23	17 5	32	25			5	4			88	64	76	0	7
8	67	49	58	- 8	7	0	0	0	03	13 0	23	02			4	3			64	49	57	8	8
9	72	48	60	- 6	5	0	0	0	05	9 5	21	07			5	4			67	49	58	7	9
10	79	53	66	- 1	0	0	0	0	11	10 7	20	09			7	6			71	52	62	3	10
11	86	65	76	+ 9	0	18	0	0	19	9 5	35	24			10	9	T		86	68	77	0	11
12	89	67	78	+10	0	0	0	0	25	10 4	18	26			6	6			91	67	79	0	12
13	89	62	76	+ 8	0	02	0	0	26	8 0	29	03			8	7			82	59	71	0	13
14	76	59	68	0	0	0	0	0	02	8 4	16	04			5	5			75	57	66	0	14
15	81	58	70	+ 1	0	0	0	0	01	8 6	16	03			2	3			72	57	65	0	15
16	86	56	71	+ 2	0	0	0	0	10	6 7	16	07			1	1			84	57	71	0	16
17	88	60	74	+ 5	0	0	0	0	19	7.4	15	19			4	3			89	63	76	0	17
18	90	66	78	+ 8	0	37	0	0	21	10 1	28	02			7	7	T		93	66	80	0	18
19	87	69	78	+ 8	0	T	0	0	05	7 4	16	28			3	4	T		82	65	74	0	19
20	91	64	78	+ 8	0	T	0	0	23	10 7	25	03			9	9	T		92	61	77	0	20
21	76	58	67	- 3	0	0	0	0	01	12 2	21	01			4	3			71	59	65	0	21
22	84	57	71	+ 1	0	37	0	0	26	6 3	31	32			7	8	T		85	57	71	0	22
23	85	68	77	+ 6	0	49	0	0	16	5 5	25	32			6	6	T		84	66	75	0	23
24	91	65	78	+ 7	0	.15	0	0	18	6 5	36	31			7	7	T		85	64	75	0	24
25	81	62	72	+ 1	0	04	0	0	02	9 4	25	18			9	10	T		80	59	70	0	25
26	82	61	72	+ 1	0	0	0	0	11	6 9	15	13			1	3			76	60	68	0	26
27	96	69	83	+12	0	0	0	0	22	8 8	22	26			3	2			98	67	83	0	27
28	97	75	86	+14	0	0	0	0	24	9 1	18	21			1	0			99	78	89	0	28
29	95	73	84	+12	0	0	0	0	18	9 4	21	18			0	0			95	75	85	0	29
30	93	72	83	+11	0	39	0	0	[illegible]		[illegible]				6	7	T		94	76	85	0	30
Sum	2551	1859	—	—	—	2 62	0	—	—	269 8	—	—	—	—	158	148	—	—	2495	1858	—	22	Sum
	85 0	62 0	—	—	—	—	—	—	—	9 0	Fastest	Dir	Possible	%	5 3	4 9	—	—	83 2	61 9	72 6	—	Avg
	Sums 7 8 9 and in the Hourly Precipitation table indicates an amount too small to measure									Misc.	36	31											Sums

TEMPERATURE (°F)

Average monthly	73 5
Departure from normal	+ 5 5
Highest 97 on	28
Lowest 48 on	9
Number of days with —	
Max 32° or below	0
Max 90° or above	10
Min 32 or below	0
Min 0° or below	0

HEATING DEGREE DAYS (base 65°)

Total this month	14
Departure from normal	- 58
Seasonal total (since July 1)	6300
Seasonal departure from normal	-339

BAROMETRIC PRESSURE (In.)

Avg station (elev 674 feet, m s l)			29.232
Highest sea level	30 21	on	4
Lowest sea level	29 68	on	13

PRECIPITATION (In.)

Total for the month	2 62
Departure from normal	- 1 34
Greatest in 24 hours	0 86 on 22-23
Snow, Sleet—	
Total for the month	0
Greatest in 24 hours	0 on
Greatest depth on ground	0 on
Dates of — Hail	NONE
Sleet NONE	Glaze/Rime NONE

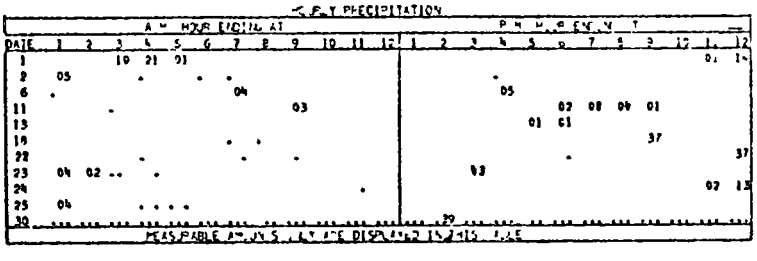
Symbols used in columns 18 19

A = Hail
BS = Blowing snow
DL = Distant lightning
D = Dust
E = Sleet
F = Fog
H = Haze
K = Smoke
L = Drizzle
N = Sand
R = Rain
S = Snow
T = Thunderstorm
ZL = Freezing drizzle
ZR = Freezing rain

Character and Duration of Each Precipitation Period

(Rain or Drizzle unless otherwise indicated m-A M.s p-P M.)

DATE	
1	1 41a-5 01a, 10 01a-12 40p, 10 43p to past midnight
2	Continued to 12 22a
6.	6 08a-6 28a, 3 40p 5 10p
11	7 44a-8 20a, 8 47a-10 04a, 5 27p-9 03p.
13.	4 49p-5 12p
18	6 40p-7 10p, 8 05p-9 40p
19.	9 45p-10 38p
20	6 07a-6 24a, 6 46a-7 32a, 2 40p-3 10p
22	11 01p to past midnight
23	Continued to 1 43a, 4 35a-4 37a, 5 23a-5 43a, 2 28p-3 00p
24	10 01p to past midnight
25	Continued to 1 45a
30.	1 01p-1 40p, 2 01p-2 45p, 3 10p-3 40p



† Also on earlier dates
* Fastest observed one minute wind speed
† Figures in columns 10 and 13 indicate directions in tens of degrees from true North for example 09 is East, 18 is South, 27 is West and 36 is North

SUBSCRIPTION PRICE: Monthly Local Climatological Data $1 00 per year including Annual Summary Single copy prices 10 cents for Monthly and 15 cents for Annual Summary Checks and money orders should be made payable and remittances and correspondence should be sent to Superintendent of Documents, U S. Government Printing Office, Washington, D C 20402

JUNE 1971

Comparative DAILY PRECIPITATION Chicago Area

Station	Day of Month																													Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
Highland Park, Ill. Water Plant	.51	20				.14					18		10					1 84	03	68		05	1 12	06	.15					.54		5 69
Glenview, Ill U S. Naval Air Station	1 01	06				.18					.78		12					1 26	01	T		44	23	20	02					26		
Sanitary District of Chicago Howard & McCormick, Skokie	31	11				1 13					65		35					1 03		22		20	.24	.10	04					.23		4 66
National Weather Service O'Hare International Airport	.47	.05				09					.18		02					37	T	T		.37	49	15	04					.39		3 62
Sanitary District of Chicago Lawrence & Francisco	31	11				80					26		01					82		.14		12	49	10	05					33		3.54
City of Chicago 4950 Wilson	.40	20				1 06					22		03					79		03		11	33	.10	07					.24		3 49
Chicago of Chicago 1747 N. Springfield	.47	06				1 02					82		13					1 22		03		15	31							.03		4 76
Sanitary District of Chicago 100 E Erie St	.35	.61									23		01					83		01		.05	.98	04	09					T		4 00
City of Chicago 1000 E Ohio St	.31	.13				.63					21		12					96		1 02		05	.89	0*	98							4 52
Berwyn, Ill 1644 S Gunderson Paul Kubecka	43	.10				1 12					40		.17					85		27		.10	70	10	.08					.06		4 67
§ 2418 S Christiana Ave Raymond Bierylo	53	.10				57	T				30												60		14	T				T		2 24
Sanitary District of Chicago 3838 S. Racine Ave	33	07				36					.31	T	04					93		34		.19		06	03					T		2 66
Sanitary District of Chicago 40th & Laramie, Stickney	.43	08				.31					30		39					09		62			25	08	07					T		3 53
§ LaGrange Park, 845 N. Spring Charles Fieg	41	11				49					81	.01	02						.36	.44			83		.3	T	T		T	T		3 65
University of Chicago 5730 S Woodlawn Ave	82	05				89					72	02	09					71		37			20	03	08					02		4 30
National Weather Service 6233 S Cicero Ave	.47	07				29					.24		05					40		34			07	07	07					01		2 18
Oak Lawn, Ill 8501 S Mobil Fred Lachowski	49	05				50					.48		01					.63		46			10	10	07					.11		3 00
City of Chicago 79th & Lake Michigan	31	00				50					26		22					86		21			24	02	08							2 78
City of Chicago 351 W. 104th St	58	14				74					32		30					62		08		01		14	13							3 12
Sanitary District of Chicago 126th & S. Lawrence	50	16				.19					47		24					83		04				01	12					04		2.66

GPO 822-16

AMOUNTS ARE FOR "MIDNIGHT" TO MIDNIGHT", EXCEPT AS NOTED, § 7 P M ; "T" INDICATES AN AMOUNT TOO SMALL TO MEASURE INC MEANS INCOMPLETE M MEANS MISSING

US GPO CHICAGO 7/6/71-2000

JUNE 1971 HOURLY TEMPERATURES-MIDWAY AIRPORT

DATE	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	67	62	69	62	61	62	6	63	64	63	71	70	66	67	67	69	79	6[illegible]	66	66	6[illegible]	6[illegible]	61	6[illegible]
2	59	60	59	6[illegible]	63	64	65	67	69	68	69	70	71	73	73	74	74	73	7[illegible]	70	68	69	6[illegible]	64
3	62	62	61	60	60	60	64	69	73	75	78	79	81	82	84	85	8[illegible]	81	76	73	70	69	69	70
4	71	69	69	66	67	66	69	74	79	83	87	88	90	92	92	92	91	87	8[illegible]	78	74	75	74	7[illegible]
5	75	75	72	73	75	73	76	80	82	85	89	91	93	94	95	96	95	94	93	92	88	87	84	84
6	83	83	77	78	79	78	78	77	78	83	87	90	9[illegible]	9[illegible]	9[illegible]	87	81	71	7[illegible]	74	73	7[illegible]	74	71
7	70	70	71	71	69	71	73	75	78	81	84	87	87	88	88	86	85	83	81	78	73	71	70	70
8	69	64	60	59	59	59	60	62	64	65	66	66	66	65	66	65	64	63	61	[illegible]8	55	5[illegible]	54	51
9	50	49	49	50	[illegible]0	51	[illegible]5	58	60	64	66	68	69	70	69	70	70	70	68	6[illegible]	64	61	56	56
10	54	54	53	54	55	57	62	64	66	69	72	74	77	79	79	77	74	73	72	71	71	69	69	70
11	69	69	70	70	70	70	71	69	72	74	71	73	78	81	84	85	86	8[illegible]	71	70	70	73	70	70
12	70	73	69	68	68	68	69	70	72	76	79	83	86	88	[illegible]0	88	89	88	87	85	82	81	81	80
13	79	77	76	76	72	70	72	74	75	80	83	85	87	88	[illegible]89	84	8[illegible]	83	73	7[illegible]	7[illegible]	67	68	66
14	64	64	64	64	63	6[illegible]	64	67	70	74	74	75	76	76	7[illegible]	74	74	71	69	67	65	64	63	
15	63	64	64	62	62	62	65	69	73	75	77	80	80	80	91	83	82	81	77	72	71	65	6[illegible]	62
16	62	6[illegible]	6[illegible]	62	69	6[illegible]	67	72	76	80	83	8[illegible]	8[illegible]	85	89	88	87	8[illegible]	84	83	77	73	73	72
17	71	71	70	70	68	[illegible]9	71	75	79	83	[illegible]6	88	89	87	9[illegible]	92	93	87	85	83	79	79	79	76
18	74	72	71	73	69	67	71	76	80	83	86	88	88	92	91	9[illegible]	9[illegible]	94	89	89	85	70	73	74
19	73	73	73	7[illegible]	71	72	73	76	79	82	[illegible]2	79	81	88	91	87	89	[illegible]4	82	77	*	81	[illegible]0	77
20	78	79	77	76	79	79	77	7	77	8[illegible]	84	8[illegible]	[illegible]8	9[illegible]	9[illegible]	9[illegible]	72	73	72	78	7	75	76	77
21	6[illegible]	65	65	64	64	64	6[illegible]	[illegible]7	[illegible]7	69	73	73	71	7[illegible]	7[illegible]	74	73	73	7[illegible]	71	[illegible]7	66	65	63
22	[illegible]1	57	[illegible]8	[illegible]9	61	[illegible]0	64	65	73	79	73	77	[illegible]8	80	81	82	82	82	81	79	77	75	76	74
23	70	68	69	69	69	69	68	69	73	75	[illegible]3	81	8[illegible]	77	81	8[illegible]	73	74	7[illegible]	7	74	71	70	72
24	70	69	68	68	67	67	68	74	79	8	84	87	87	89	90	92	92	91	89	87	8[illegible]	8[illegible]	82	79
25	71	73	73	72	71	71	71	73	73	76	77	51	8	83	[illegible]2	72	73	66	6[illegible]	64	62	63	60	62
26	62	62	61	61	60	60	62	65	68	7[illegible]	83	82	78	83	84	81	85	8	[illegible]9	76	74	71	73	73
27	73	71	74	74	74	75	78	82	86	91	93	91	96	98	[illegible]2	1[illegible]3	1[illegible]3	96	9[illegible]	91	83	87	86	84
[illegible]8	8[illegible]	8[illegible]	78	77	77	77	78	81	86	83	9[illegible]	94	96	9[illegible]	[illegible]3	101	[illegible]8	9[illegible]	9	9[illegible]	[illegible]3	[illegible]3	3	86
29	82	77	7[illegible]	77	76	75	75	79	81	8[illegible]	89	91	93	95	9[illegible]	93	9[illegible]	9	9	9[illegible]	89	8[illegible]	84	84	83
30	81	80	78	78	77	76	76	79	84	87	9[illegible]	9	9[illegible]	95	85	79	[illegible]8	5[illegible]	81	[illegible]1	[illegible]1	83	77	76

in which, u = wind velocity (met/sec)
v = exit velocity (met/sec)
Q_o = gas flow rate (met^3/sec) measured at ambient conditions of temperature and pressure.

Example 7. Gas is released from a chimney whose exit radius is $R_c = 2.0$ met, at a velocity, $v = 20$ met/sec, and a temperature of 250 °C. What will be the magnitude of the velocity-rise, H_v, if the wind velocity, $u = 10$ met/sec. The temperature of the ambient air, $T_o = 25$ °C.

From the equation of continuity,

$$Q = \pi R_c^2 \ (v) = \pi (2.0)^2 \ (20) = 252 \text{ met}^3/\text{sec}$$

The mass flow rate is,

$$M \text{ (kg(m)/sec)} = \rho Q = \rho_o \ Q_o$$

in which the zero subscripts refer to ambient conditions. Hence,

$$Q_o = \frac{\rho}{\rho_o} Q$$

From the general gas law, Eq. (4),

$$\rho = \frac{p}{g R^* T} \qquad \text{and} \qquad \rho_o = \frac{p_o}{g R^* T_o}$$

Accordingly,

$$\frac{\rho}{\rho_o} = \frac{T_o}{T}$$

and so

$$Q_o = \frac{T_o}{T} = \frac{273 + 25}{273 + 250} \ (252) = 144 \text{ met}^3/\text{seg}$$

From Eq. (29), $H_v = \dfrac{4.71}{1 + 0.43(\frac{10}{20})} \ \dfrac{\sqrt{(144)(20)}}{10} = 21.0$ met

---

With reference to Eq. (28), it is not entirely true that the three height terms are strictly additive. However, this assumption is satisfactory for approximate computation.

Example 8. A hot gas is emitted from a chimney of height, H_o, = 100 met, into a stable atmosphere in which, $dT/dz = -0.0060$ °C per meter, and wind velocity, $u = 10$ met/sec. What will be the approximate value of the effective height of emission, H?

It seems obvious enought that the higher the chimney the better. Determination of the necessary height is frequently set by the thermodynamics and fluid mechanics of the chimney itself. Structural and aerodynamic considerations are involved as well. Obviously, a controlling factor may be the cost of the structure. In the final analysis, however, the minimum height must be determined on the basis of downwind concentrations of gas components and particulate matter, particularly near the ground.

Many codes, specifications, and guidelines have been developed regarding the question of chimney heights. Gilpin (2) discusses some of these and provides numerous references dealing with this question. However, to give a scale on this topic for the present purpose, we have in mind chimney heights in the range, 50 to 250 meters.

A very important factor for the attainment of maximum efficiency of chimney operation is the exit velocity of the gas or smoke. If this velocity is too large, the hot gas plume will entrain, by turbulent shear stresses, too much cold ambient air as it ascends. This will reduce the plume temperature and consequently the plume will not rise to a desirable high level. At the other extreme, if the exit velocity is too small, a so-called "downwash" condition may be introduced. Downwash occurs when the chimney gases are drawn downwards by the vortices and eddies created in the wake of the chimney by the wind. On this point, Strauss (7) reports the results of Sherlock and Stalker. These investigators have shown that downwash is prevented if the exit velocity is greater than 1.5 times the wind velocity. Typical design velocities for exist velocities are in the range, 15 to 25 met/sec. At 15 met/sec, downwash would be unlikely for wind velocities less than 10 met/sec or about 35 km/hr. For larger wind velocities, of course, there is a "trade-off" in the sense that high wind speeds and the associated greater turbulence levels mix and transport exhaust gases more effectively. For existing chimneys, it may be desirable to install a venturi nozzle at the top of the stack to increase the exit velocity.

The "effective" emission height of a chimney, H, can be approximated by the relationship,

$$H = H_o + H_v + H_p \tag{28}$$

in which H_o is the actual height of the structure, H_v is the rise of the plume d to the exit velocity of the gas, and H_p is the height of the buoyant plume, given by Eq. (25). Bosanquet, Carey and Halton have studied the problem associated with the velocity-rise term of Eq. (28) and their results are summarized in Strauss (7). They show that,

$$H_v = \frac{4.77}{1 + 0.43\,(u/v)} \frac{\sqrt{Q_o v}}{u} \tag{29}$$

Example 6. Smoke is emitted from a chimney of height, H_o = 100 met and exit radius, R_c = 2.0 met. In the absence of a horizontal wind, to what maximum height above ground level would the plume of Example 5 ascend? What would be the leveling-off elevation of the plume above ground surface?

From Example 5, H_m = 198 met

From Fig. 6, $H_t = H_o - z' + H_m$; with $z' = 8.9\ (2.0) = 17.8 = 18$ met

$H_t = 100 - 18 + 198 = 280$ met

and $H = 100 - 18 + 150 = 232$ met

Referring to Eqs. (25) and (26) and also to Fig. 2, we note that when the actual temperature gradient is such that a lapse condition exists, i.e., the atmosphere is unstable, then the denominators of Eqs. (25) and (26) become imaginary numbers. It follows that these solutions are valid only for stable atmospheres. Turner (10) summarizes the analysis which Batchelor has made for unstable atmospheres in which the density distribution in the ambient air is of the form,

$$\frac{g}{\rho_o}\frac{d\rho_e}{dz} = C z^m \qquad (27)$$

in which C is a positive constant. Theoretically, in an unstable atmosphere, a plume will rise to an infinite height. However, in reality it will ascend only until an equilibrium condition is attained one way or another. In any event, the problem of plume rise in an unstable atmosphere is not the critical problem. As in all aspects of air pollution, it is the stable atmosphere, with its associated temperature inversion, that creates the worst conditions for air contamination.

3.2 Emission of a Gas from a Chimney. Whether we like it or not, in most instances the only feasible way to dispose of an industrial gas or smoke is to release it to the atmosphere and rely on subsequent mixing in the atmosphere to reduce the concentration of the gas constituents or particulate matter to acceptable levels. If the gas or smoke is released at an elevation high above the ground and if the effects of buoyancy, mixing, and mass transport by the wind are all favorable then the problem of contamination will at least be minimized. Needless to say, all feasible means should be used to reduce the pollutants in the gas or smoke before release to the atmosphere through a chimney.

It follows that it is imperative that a chimney be designed and operated in a way to minimize the concentration of pollutants in the air, especially near the ground surface. Of course, there are many factors, mostly beyond our control, which may aggravate or alleviate the situation. Topography, wind direction, temperature gradient, cloud cover, rainfall, and other environmental features affect the degree to which a chimney can function effectively.

We may now put Eq. (23) into a form more useful for application. Substituting, $g = 9.8$ met/sec^2, $C_p = 240$ cal/kg ^oC

$\rho_o = 1.2$ kg/met^3, $T_o = 20\ ^oC = 293\ ^oK$

and with $z_1 = 2.13$ to determine H_p; $z_1 = 2.8$ to determine H_m

we obtain,

$$H_p = 1.07 \frac{Q_H^{1/4}}{\left(\frac{dT}{dz} + \Gamma\right)^{3/8}} \tag{25}$$

and

$$H_m = 1.41 \frac{Q_H^{1/4}}{\left(\frac{dT}{dz} + \Gamma\right)^{3/8}} \tag{26}$$

in which the appropriate units are respectively meters, cal/sec, and ^oC.

Example 5. A plume is created by the emission of a hot gas from a point source into an atmosphere in which the temperature decreases at the rate, $dT/dz = -0.0060\ ^oC$ per meter. The amount of heat released from the point source is, $Q_H = 10 \times 10^4$ cal/sec. To what maximum height, H_m, will the plume ascend? What will be the leveling-off height, H_p?

From Eq. (26), $H_m = (1.41) \dfrac{(10 \times 10^4)^{1/4}}{(-0.0060 + 0.0098)^{3/8}} = 198$ meters

From Eq. (25), $H_p = 150$ meters

The preceeding analysis is based on the assumption that the plume is emitted from a point source. In a real situation the flow originates from a source of finite radius, from a chimney of radius, R_c, for example. Thus the concept of a "virtual origin" is presented and the nature of the "correction" associated with this feature is obvious in Fig. 6. The study of Morton, Taylor and Turner (3) shows that $R/z = 6\alpha/5$. Using $\alpha = 0.093$, then $R/z = 0.112$, and from Fig. 6 it is clear that $z' = 8.9\ R_c$.

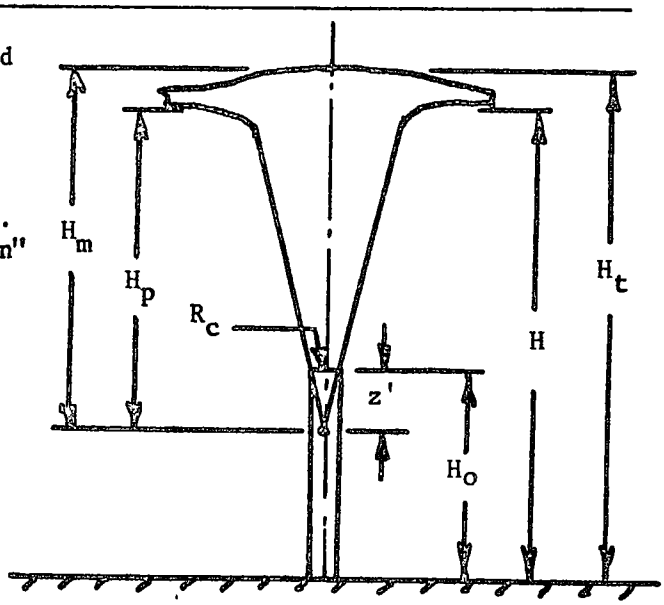


Fig. 6

$$q_f = 2\pi R \alpha w(z) \tag{19}$$

in which α is an entrainment constant. Utilizing this relationship and the profile equations given by Eqs. (17) and (18), we integrate the mass, momentum, and buoyancy equations over the plume cross-section to obtain,

$$\frac{d}{dz}\left(R^2 w\right) = 2\alpha R w \tag{20}$$

$$\frac{d}{dz}\left(R^2 w^2\right) = 2R^2 g \frac{\rho_e - \rho}{\rho_o} \tag{21}$$

$$\frac{d}{dz}\left(R^2 w g \frac{\rho_e - \rho}{\rho_o}\right) = 2R^2 w \frac{g}{\rho_o}\frac{d\rho_e}{dz} \tag{22}$$

These equations, together with the presumed-known relationship, $\rho_e = \rho_e(z)$, permit the determination of w, R, and g $(\rho_e - \rho)/\rho_o$ as functions of z.

Numerical solutions of these differential equations were obtained by Morton, Taylor and Turner (3). They have shown that the height of the plume is,

$$z = 0.410\,\alpha^{-\frac{1}{2}}\left(\frac{g Q_H}{C_p \rho_o T_o}\right)^{\frac{1}{4}} G^{-\frac{3}{8}} z_1 \tag{23}$$

in which C_p is the specific heat of air, Q_H is the rate of heat emitted from the source in cal/sec, and G is defined as

$$G = \frac{g}{T_o}\left(\frac{dT}{dz} + \Gamma\right) \tag{24}$$

Two values of plume heights were determined by these authors in their analysis:

a) The plume height, H_p, corresponding to the height at which the buoyancy difference between the plume and ambient air just becomes zero. In this case, $z_1 = 2.13$ in Eq. (23).

b) Although the buoyancy difference is zero at H_p, a remaining momentum in the plume carries it to an additional height, H_m. Thereafter the plume spreads radially and descends to a slightly lower level, approximated by H_p. For the case of the maximum height, H_m, the value of $z_1 = 2.8$ in Eq. (23).

The magnitude of the entrainment constant, α, has been studied by numerous investigators. Turner (10) has reported values ranging from 0.08 to 0.12. In the following, the result of Morton, Taylor and Turner (3) will be employed, viz., $\alpha = 0.093$.

3.0 Plumes and Chimneys

3.1 Theory of Buoyant Plumes. Next we consider the problem of a buoyant plume in an otherwise quiescent atmosphere. An example of such a phenomenon is illustrated in nature by the rise of a liquid effluent from a sewer outfall in the ocean or by the rise of a column of smoke from a chimney.

A definition sketch for the analysis is presented in Fig. 5. A gas is emitted from a point source at z = 0, r = 0. The temperature of the gas is presumed larger than the temperature of the ambient air and since the emitted gas is hotter than the air in the surrounding region, it has a lesser density. This creates a net positive buoyant force in the vertical direction and the emitted gas rises, creating a plume. In this analysis, a stable atmosphere is assumed, i.e., a temperature inversion exists. Our primary interest in this phenomenon is to determine the maximum elevation of ascent of the plume, H_m, and an approximate value of the leveling-off elevation, H_L. It is emphasized that there is no horizontal wind. This problem has been studied by Morton, Taylor and Turner (3) and the following is based largely on their analysis.

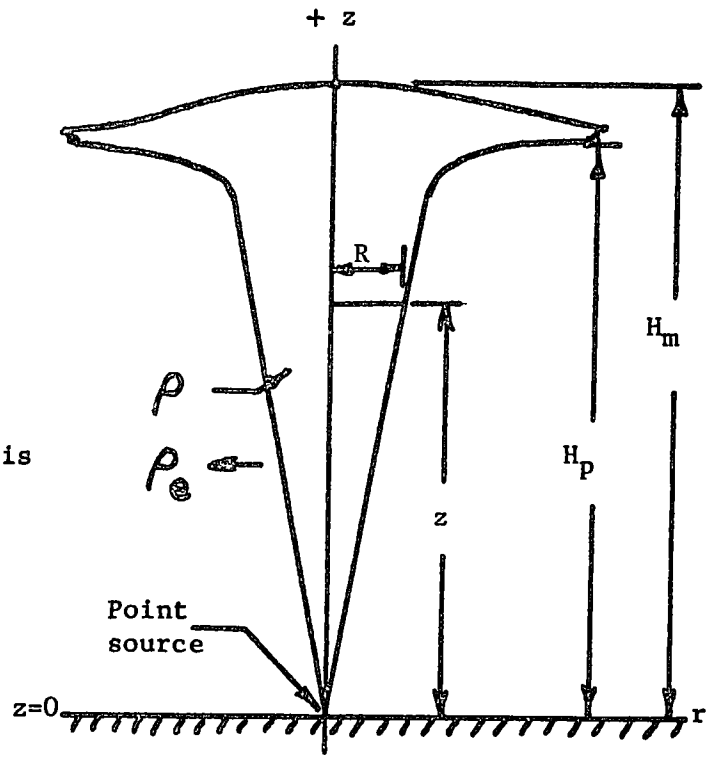


Fig. 5

An assumption is made that the vertical velocity and the net positive buoyant force in the plume are described by normal distribution curves of the form,

$$w(z,r) = w(z)\, e^{-r^2/R^2} \tag{17}$$

and

$$g\,\frac{\rho_e-\rho}{\rho_o}(z,r) = g\,\frac{\rho_e-\rho}{\rho_o}(z)\, e^{-r^2/R^2} \tag{18}$$

in which ρ_o is the density of the ambient air at z = 0, ρ_e is its density at any elevation, z, and ρ is the variable density of the gas in the plume. As the plume arises, ambient air is entrained into the plume by turbulent shear stresses and this entrained air mixes and rises with the gas in the plume.

It is assumed that the rate of entrainment of ambient air into the plume is given by

A feature which complicates even further this very difficult problem of wind structure in the atmosphere is the effect of the Richardson number. The qualitative plot of Fig. 3, given by Sutton (9), shows that even the shape of the relationship between wind velocity and the logarithm of the elevation above the ground surface depends on the Richardson number.

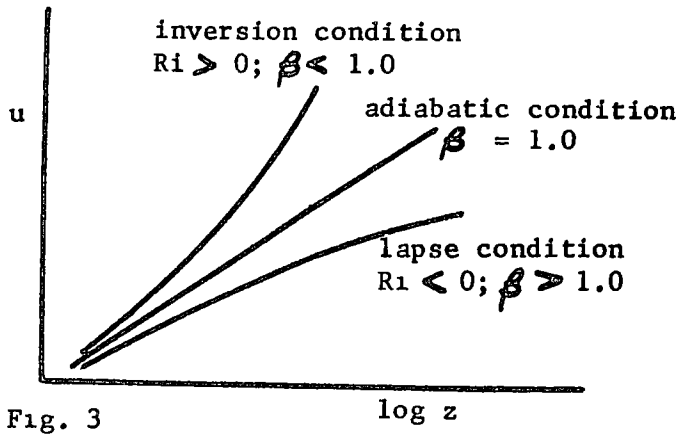


Fig. 3

As reported in Priestley (5), Deacon has attempted to take this effect of the Richardson number into account by writing a generalized equation for the wind velocity profile,

$$\frac{u}{u_*} = \frac{1}{\kappa(1-\beta)}\left[\left(\frac{z}{z_0}\right)^{1-\beta} - 1\right] \qquad (16)$$

in which β is a dimensionless number dependent on Ri.

When Ri > 0, inversion condition exists, and $\beta < 1$
Ri = 0, adiabatic condition exists, $\beta = 1$
Ri < 0, lapse condition exists, $\beta > 1$

It is not difficult to show that Eq. (16) reduces to Eq. (15) when $\beta = 1$. A correlation between β and Ri, published in Priestley (5), is presented in Fig. 4.

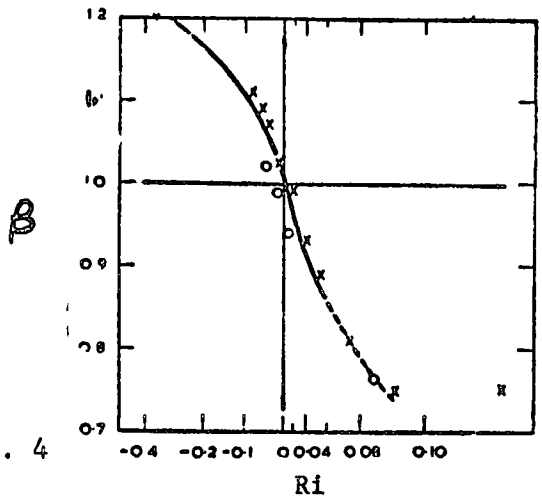


Fig. 4

Example 4. Extending the question of Example 3, what would be the wind velocity at an elevation of 100 meters if (a) Ri = +0.04 (inversion condition) and (b) Ri = -0.10 (lapse condition)?

From Fig. 4, (a) $\beta = 0.85$ and (b) $\beta = 1.10$

From Eq. (16),

(a) $$u = \frac{(0.60)}{(0.4)(1 - 0.85)}\left[\left(\frac{100}{0.07}\right)^{1-0.85} - 1\right] = 19.7 \text{ met/sec}$$

(b) $$u = \frac{(0.60)}{(0.4)(1 - 1.10)}\left[\left(\frac{100}{0.07}\right)^{1-1.10} - 1\right] = 7.7 \text{ met/sec}$$

---

in which z_1 is a reference height at which the velocity is u_1. Though there is a measure of theoretical basis in this equation it is essentially an empirical relationship. Numerous wind tunnel and pipe flow experiments have shown that m = 1/7. However, in boundary layers associated with atmospheric phenomena, the value of m extends over a very broad range and its precise value is difficult to assign without actual measurements in the topography of a particular setting. This point is illustrated in a recent publication by Cermak (1).

Without doubt a far more useful expression for the velocity distribution in a turbulent boundary layer is,

$$\frac{u}{u_*} = \frac{1}{\kappa} \log_e \frac{z}{z_o} \qquad (15)$$

This logarithmic form stems from Prandtl's mixing length theory and from assumptions presented by von Karman regarding the magnitude of the mixing length. In Eq. (15), u_* is the friction velocity ($u_* = \sqrt{\tau_o/\rho}$, τ_o is the shear stress at the boundary) and κ is the dimensionless von Karman constant; ordinarily, $\kappa = 0.4$. The quantity, z_o, is the so-called roughness height. Though it is related fundamentally to the equivalent sand-roughness of Nikuradse, it is in fact a parameter very difficult to determine a priori. In most cases the roughness height must be determined from field or model measurements.

As mentioned, values of the friction velocity and roughness height are rarely known with precision. The following table, given by Sutton (9), lists some representative values. More importantly, the table reveals how dependent these quantitative values, z_o and u_*, are on the qualitative features of a particular topography.

Representative Values of z_o and u_* for Natural Surfaces

Type of Surface	z_o, cm	u_*, cm/sec
Very smooth (mud flats, ice)	0.001	16
Lawn, grass up to 1 cm high	0.1	26
Downland, this grass up to 10 cm high	0.7	36
Thick grass, up to 10 cm high	2.3	45
Thin grass, up to 50 cm high	5	55
Thick grass, up to 50 cm high	9	63

Example 3. Over an extensive area covered by rather thick grass we determine that the roughness height, z_o = 7 cm and the friction velocity, u_* = 60 cm/sec. On this basis what would be the mean wind velocity at an elevation of 100 meters?

From Eq. (15), $u = \frac{u_*}{\kappa} \log_e \frac{z}{z_o} = \frac{(0.60)(2.3)}{(0.4)} \log_{10} \frac{100}{0.07} = 10.7$ met/sec

---

With regard to the Richardson number in its Eq. (12) form we can make the following statements:

a.) If $d\theta/dz$ is a large positive quantity, that is, if the temperature increases rapidly with increasing elevation, then the atmosphere is stable and inversion conditions prevail. The only mixing that can occur is that caused by the Reynold's stresses produced by the ambient wind, i.e., relatively small-scale mechanical turbulence. In this instance, $Ri \gg 0$.

b.) At the other extreme, if the temperature decreases sharply with an increase in elevation, the colder and hence heavier air at the top produces an unstable atmosphere and a so-called lapse condition results. In this case, large-scale mixing is produced by thermal convection, i.e., by density differences. Under these conditions, $d\theta/dz \ll 0$, and so $Ri \ll 0$.

In this regard, a brief table based on information given by Panofsky (4)* is presented below.

Ri	Mixing Characteristics
$+ 0.25 \ll Ri$	Little or no vertical mixing
$0 \ll Ri \ll +0.25$	Mechanical turbulence, weakened by stratification
$Ri = 0$	Mechanical turbulence only
$- 0.03 \ll Ri \ll 0$	Mechanical turbulence and thermal convection, but mixing mostly due to mechanical turbulence
$Ri = - 0.03$	Onset of mixing by thermal convection
$Ri \ll -0.04$	Convection mixing dominates

2.2 Wind Structure. For many decades the subject of wind structure has been studied by numerous investigators. In this connection, the primary question is: by what amount does the average velocity of the wind increase with an increase in distance above a ground or sea surface?

This question is a basic one in the theory of turbulent boundary layers and it has been examined by Prandtl, von Karman, Blasius, Nikuradse and a great many others. The results of the research of these investigators are well-summarized in Schlichting (6).

A simple and widely-used expression for velocity distributions in atmospheric boundary layers is

$$\frac{u}{u_1} = \left(\frac{z}{z_1}\right)^m \qquad (14)$$

*Numerals shown in parentheses identify publications listed in Section 5: References.

The term in the brackets of the right-hand member of Eq. (10) is the difference between the actual temperature gradient and the adiabatic lapse rate. The sign and magnitude of this difference is all-important in determining whether or not and the degree to which an atmosphere is unstable (lapse condition) or stable (inversion condition). This point is illustrated in Fig. 2.

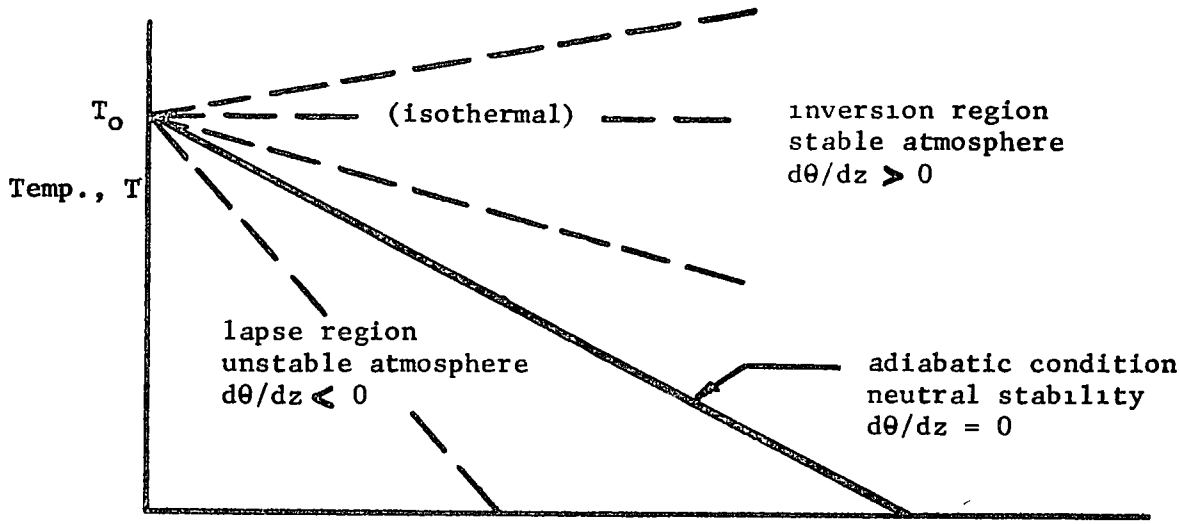


Fig. 2

The dashed lines in Fig. 2 are examples of actual temperature distributions in an atmosphere. The solid line refers to the adiabatic lapse relationship of Eq. (6); this line is the boundary between the region in which the atmosphere is stable ($d\theta/dz > 0$) and the region in which it is unstable ($d\theta/dz < 0$).

A very useful parameter for expressing stability and mixing conditions in the atmosphere is the Richardson number, Ri. This is defined,

$$Ri = \frac{g\left(\frac{dT}{dz} + \Gamma\right)}{T\left(\frac{du}{dz}\right)^2} = \frac{g\,\frac{d\theta}{dz}}{\theta\left(\frac{du}{dz}\right)^2} \qquad (12)$$

in which u is the horizontal wind velocity at altitude, z. In another form, the Richardson number can be written,

$$Ri = \frac{gL}{V^2}\left(\frac{\Delta T}{T}\right) \qquad (13)$$

where ΔT is a temperature difference and L and V are respectively a characteristic length and a characteristic velocity. In the form of Eq. (13), it is noted that the Richardson number has the appearance of the reciprocal of a Froude number. In other words, this dimension-less number is a ratio of a buoyant force due to a weight difference, $F_T = \gamma L^3(\Delta T/T)$, to an inertial force, $F_I = \rho L^2 V^2$.

Next the general gas law is introduced into our analysis,

$$\rho = \frac{p}{g R^* T} \qquad (4)$$

in which p is the absolute pressure, T is the absolute temperature (^{o}Kelvin = ^{o}Centigrade + 273) and R^* = 29.27 met/^{o}C for air. Utilizing this relationship with those of Eq. (2) and Eq. (3), an expression for the temperature distribution is obtained,

$$T = T_0 - \frac{k-1}{k R^*} z \qquad (5)$$

or

$$T = T_0 - \Gamma z \qquad (6)$$

in which, for air,

$$\Gamma = \frac{k-1}{k R^*} = \frac{1.4 - 1}{(1.4)(29.27)} = 0.0098 \ ^{o}C/met \qquad (7)$$

This quantity, Γ, is termed the dry adiabatic lapse rate and has the approximate value of 1.0 ^{o}C per 100 meters change in elevation.

Example 2. Assuming an adiabatic lapse rate, what would be the temperature at an altitude of 500 meters if the temperature at ground-level were 30 ^{o}C?

From Eq. (6), $T = 30 - (0.0098)(500) = 30 - 5 = 25\ ^{o}C$

Next we differentiate Eq. (6) with respect to z and obtain,

$$\frac{dT}{dz} = -\Gamma \qquad (8)$$

Needless to say, actual variations of temperature with altitude and actual lapse rates rarely correspond to the theoretical adiabatic relationships expressed by Eqs. (6) and (8). Hence a new quantity is introduced, viz θ, the potential temperature. This quantity is defined as the temperature which a fluid element would acquire when brought adiabatically from the environment of its existing pressure to the environment of a reference pressure. That is,

$$\theta = T_0 \left(\frac{p_0}{p} \right)^{(k-1)/k} \qquad (9)$$

Differentiating this equation we obtain,

$$\frac{1}{\theta} \frac{d\theta}{dz} = \frac{1}{T} \left(\frac{dT}{dz} + \Gamma \right) \qquad (10)$$

and from this result and Eq. (6)

$$\theta \doteq T + \Gamma z \qquad (11)$$

2.0 Environmental Factors

2.1 Lapse Rates and Inversions. We begin our analysis with an examination of how the temperature changes with respect to altitude above the ground surface. With reference to the definition diagram of Fig. 1, it is not difficult to show that

$$\frac{dp}{dz} = -\gamma = -\rho g \qquad (1)$$

when the acceleration of the fluid element, $A_o\, dz$, in the z-direction is zero. In Eq. (1), p is the pressure, γ is the specific weight of the fluid, ρ is its density, and g is the gravitational body force per unit mass.

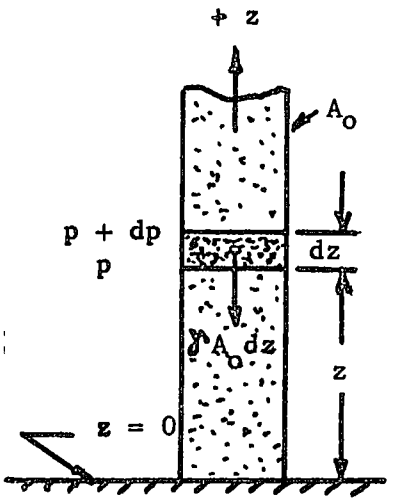


Fig. 1

If this fluid element is displaced vertically with no exchange of heat between the element and the surrounding atmosphere, then we have the adiabatic condition that

$$\frac{\rho}{\rho_o} = \left(\frac{p}{p_o}\right)^{1/k} \qquad (2)$$

in which $k = C_p/C_v$, the ratio of the specific heats at constant pressure and constant volume; for air, k = 1.4. The zero subscripts refer to a certain datum, for example, conditions at sea-level or at a particular ground-level.

Substituting Eq. (2) into Eq. (1), we obtain an expression for the pressure distribution

$$p = p_o \left[1 - \frac{k-1}{k}\,\frac{\rho_o g z}{p_o}\right]^{k/(k-1)} \qquad (3)$$

Example 1. If the pressure in the atmosphere varies according to the adiabatic relationship of Eq. (2), what would be the pressure at the elevation of Mexico City if the sea-level pressure is 760 mm. Hg, i.e , 10,300 kg(f)/met^2 = 101,000 newtons/met^2?

With z = 2,200 met; ρ_o = 1.20 kg(m)/met^3; g = 9.8 met/seg^2
and p_o = 101,000 newtons/met^2

From Eq. (3); $p = p_o \left[1 - \frac{(1.4 - 1)}{(1.4)}\,\frac{(1.20)(9.8)(2,200)}{(101,000)}\right]^{\frac{1.4}{1.4 - 1}}$

$$p = p_o\,(0.767)$$

With p_o = 760 mm. Hg, the pressure at Mexico City on this basis would be p = 585 mm. Hg.

ATMOSPHERIC DIFFUSION

by Dr. Robert B. Banks

1.0 Introduction

Professor Abel Wolman of Johns Hopkins University once remarked, half in jest, that "the solution to pollution is dilution."

But the jest was associated more with the Ogden Nash type poem than it was with the fact of the matter. It is true that we do rely on the enormous quantity of air in the world, about 5×10^{18} kilograms, to act as a gigantic reservoir to receive and dilute our gaseous waste products. However, as everyone knows, a main difficulty arises in the fact that the sources of these waste products are becoming more-and-more geographically concentrated and the "local sinks" for accepting and diluting these gaseous wastes are getting clogged-up.

On the following pages topics are presented which relate to various phenomena concerning the movement and dilution of air-borne wastes. Though we may have a small problem in precise definitions of words, we shall consider that mechanisms like molecular diffusion, eddy viscosity, thermal convection, turbulent boundary layers, mass transport, mechanical dispersion and the like are all included under the general heading of "atmospheric diffusion."

In sequence, the following subjects are discussed:

- Lapse rates and inversions
- Wind structure
- Theory of buoyant plumes
- Emission of a gas from a chimney
- Concentration distributions

Ten numerical examples are presented on the following pages. There has been an attempt to provide a measure of continuity in these examples, i.e., one picks up where the other left off. Finally ten references are included for the benefit of those who wish to examine this complex problem of "atmospheric diffusion" to greater extent.

ATMOSPHERIC DIFFUSION

By Dr. Robert B. Banks

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Presented at a Course on

ATMOSPHERIC POLLUTION CONTROL

National Autonomous University of Mexico

November 20-December 4, 1971

B. Line Operations (cont.)

3. Enforcement Services (Cont.)

c. Hearing and Court Cases

Arranges court dates and location for hearing cases of pollution violations. Schedules for appearance of Patrol Officers. Maintains transcripts and records of court hearings. Records fines.
Facillitates the hearings of cases for appeal to the Citizen Appeals Board (All rules and cases can be heard by the appeals board, this board usually only hears special cases. They may grant relief from enforcement and set time schedules for controls) It is independant of control from this agency)

B.Line Opperations(cont.)

2. Technical services:

a. Administrative:

Prepare reports, supplement plan and Evaluation Section (A,S), technical consultants

b. Meteorological Services:

Forcast Air Stagnation Potential, collect air quality data, statistical condintioning of data, prepare data reports (Quarterly Reports). Maintain daily and hourly reports of air quality (Telephone 312-644-9090 for current hours data).

c. Laboratory:

Maintain Telemetry equipment, analize fuels for Sulfer, analize for pollutants from routine sensors, analize for pollutant from spocial samples, portable monetoring, maintain all analytical and technical equipment, trace metals, add seve as consultants on technical and instrumental matters to the director.

d. Field Testing and Maintenance; and monetoring:

Service all monetoring stations with changes in chemicals and filterpapers, Maintain and construct physical facilities and housing for monetoring instruments. Conduct Smoke Scpols. Provide messenger services. Provide labor force.
Conduct Stack Samples (Sepparate Group) as requested by other divisions (B, 1 or 2) for cirtificate of opperations or enforcement.

3. Enforcement Searvicew :

a. Abatement Patrol and Complaints:

Radio dispatched automobile patrol for smoke emissions, noise, solid wast and water pollution. Whites tickets for violations. Appear and testify in courts of law against violators. Investigate all complaints and reffer to other sections if necessary. Answer all compaintants in writing. Receive all complaints either by telephone or letter. Maintain complaint files and records. Enforce all regulations in the field.

b. Annual Inspections:

Inspect all significant [illegible] combustion devices such as boilers and incinorators . (Not single family homes). Issue notices of deffective equipment and bad practices of opperation or maintenance. (must be answered and corrected, if not a ticket can be issued). Maintain records of devices, their location, type, foal, owners, and sizes. Fees range from $5 to $20 according to size. Each device is considered sepparate.

B. Line Operations:

1. Engineering Services:

a. Field Evaluations:

1) Plant Evaluations:
Visits to factories to evaluate all equipment both Process and combustion for Pollution potential. Recommend award of certificate of operation to plans and permit section ~~(~~ (B,1,b,2)) if equipment is in order, or to Industrial evaluation Section (B,1,b,1),) if not. Also collects data for Emission Inventory section (B,1,a,2),).

2). Emission Inventory:
Collects data from all parts of the organization concerning emissions from:
Large point souces
Smaller sources filed as area sources
Files data for refferencing and data processing by other divisions.

3). Emission Control:
Acts as field consultants on control programs for both industrial and private sources. Inspection of installation of control devices as prescribed by other engineering subdivisions.

b. Plan Evaluations:

1). Industrial Evaluation Section:
Evaluation and criticism of plans proposed by industries for Installation of both control devices and new installations that will create possible pollution. Fees are charged on a prescribed scale and vary according to time and personell required for complete evaluation and report. This group also acts in an advisory capacity. Plans are either denied adn new plans requested, or recommended for a certificate of INSTALLATION, and after completion and testing , A certificate of OPPERATION. These permits are awarded by the Plans and Permit section (B,1,b,2),)

2). Plans and Permits:
This group criticises all proposed plans of Installation and awards a certificate of installation if plans seem adequate. There is much communication between this section and the Industrial evaluation section. This section awards permits for all new installations for idustrial and commercial activities of larger size. All other permits are awarded by the enforcement section for annual inspection for certificates of opperation (B,3,b). All cirtificates and bills are mailed from another city agency distant from this agency.

SUGGESTED OUTLINE OF ADMINISTRATION OF AND AIR POLLUTION AGENCY (After city of Chicago)

I. The program must answer the following questions:

1. Is problem doffined adaquately;

a. Inventory of Emissions

b. Air Quality: SO_2, Particulate, CO, Hydrocarbons, O_3, NO_x, Trace metals, H_2S, and others as needed.

2. How bad is the problem? What specifically is the problem?

3. Is the government aware of the problem and its magnitude?

4. Are the proper administrative programs existing? What needs to be done to create such a program? What Laws need to be passed?

5. What are the resources available for solving the problem?

6. Are these resources adaquate? What additional resources are needed?

7. What will be the control tactics or strategy?

8. Will the proposed strategy work? (Sucess orientation).

9. What will be the schedule for the completion of each part of the control strategy? What will be the final completion date?

10. What are, and what will be the future problems? What advance planing must be done for to be ready for these future problems?

II. In order to answer some of the above questions the following opperational Agency is suggested as an example. (Patterned after the City of Chicago agency).

A. Executive Programs:

1. Administration: Executives and secretaries; records and handling of requisitions for services and equipment, and payments of bills.

2. Public Information: Pamphlets, speeches, Information management, Public phone calls, Quarterly newspaper, Protocol, tours.

3. Program Planing and Research: Special studies, Future programs, resourcing or finding new information, activities not taken care of by line operations.

B. Line Opperations:

1. Engineering Services:

B. Line Operations (cont.)

3. Enforcement Services (Cont.)

c. Hearing and Court Cases:

Arrages court dates and location for hearing cases of pollution violations. Schedules for appearance of Patrol Officers. Maintains transcripts and records of court hearings. Records fines.
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3. Program Planing and Research: Special studies, Future programs, resourcing or finding new information, activities not taken care of by line opperations.

B. Line Opperations:

1. Engineering Services:

Calibration of Instruments

1) Gas dilution method
   - Compressed Gas (SO_2, NO_2 etc)
   - Compressed Air or N_2 (for dilution)
   - Flow meters & valves
   - Technique is difficult
   - Accuracy is doubtful

2) Permeation Tubes (6) (for SO_2, NO_2, H_2S)
   - ~~Constant~~ Temp. bath
   - Air pump or Compressed air, N_2 etc.
   - Flow meter
   - Technique is difficult
   - Accuracy is good – calibration can be done on permeation tube w. micro-balance or good analytical balance.

3) Gas mixtures (22)
   - CO & HC only
   - Simple to use

Portable Monitoring Methods

1) Plastic bag
   Mylar film 1 mil thick (14)
   " Tone 1 mil thick, 1" wide
   Plastic air Pump (13)
   Very useful for survey of CO, NO, SO_2?, NO_2?
   Only one instrument needed
   Inexpensive & simple

2) Portable Instrument
   Requirement: Light weight ~ 10-15 kg
   DC operation (12 v. for automobile)
   or Low power consumption (can be used w. DC → AC Inverter)

   SO_2 (4, 5, 9?)
   NO_2, NO, NOx (4, 5, 9?) } $1,500 - $3,000
   O_3 (4)
   H_2S (19)

3) Portable bubbler Technique (1, 15)

4) " Particulate (1, 15, 16)

5) Special methods
   H_2S Tiles
   Sulfation Plate (7, 21 etc)

Telemetered Monitoring System 1- cf. article by S. Booroo; Article about Los Angeles System; article on specifications from E.P.A.

Automated or Instrumental Methods of Monitoring

1) Particulates

a) Tape Sampler (Coefficient Of Haze) (1, 3, 12 etc.)
Non-specific - measures "soiling" property of air - optical density
Very useful for relative particulate monitoring
Automatic recording or manual data handling available
Moderately expensive ~$200 - $1000
Also useful for H_2S, F^-, HF etc. using special sensitive tape (see below).

b) Direct Mass Monitors
Beta-scattering principle (European Instrument)
Quartz crystal frequency difference principle
Thermal Systems, Inc. (2)

c) Portable particle analysis equipment (1, 12, 15, 16)

2) Gases

a) CO ~~(1, 8 etc.)~~ Infrared (7, 8 etc.)
expensive $2,500 - $6,000
Gas chromatography (17, 8 etc.)
also measures CH_4 + Total HC

b) SO_2 - Conductivity (5, 8, 3 etc.) $2,000 - $4,000
Coulometry (8 etc.) $3,000
Parasonline (4) $1,500

c) NO_2, NO, NO_x
Saltzman (4) $2,000 (5) $3,000
Chemiluminescent (18)

d) O_3 Chemiluminescent (C_2H_4) (18, 1 etc.) $5,000
" (Al) (4) $2,500

e) H_2S Tape Sampler (19, 1, 3)

Manual Monitoring Methods *

1) Particulate

a) Dustfall Jar - 30-day averaged values
collects large particles $\geq$ 30 u
inexpensive
shows trends

b) Hi-volume Sampler - (3, 12 + others)
24-hr averaged values
collects particles < 5 u
moderately expensive (~$200)
Filters can be used for many other analyses besides simple mass concentration data
e.g. Soluble fraction
Inorganic
Organic
Trace metals etc. (by Atomic Absorption (8, 11 etc.)

c & d - automatic methods - see below

2) Gases

a) Bubbler Technique (3, 1, 12 etc.) - for SO_2, NO_2, NO, H_2S, O_3, OX, HCl, Cl_2 etc.

2 - 24 hr. integrated values
inexpensive, but requires supporting laboratory facilities. (e.g. automatic analyzer (23) cannot be used for CO, HC

b) Sulfation Plate + Candle - SOx
Inexpensive & relatively simple to use

c) $Pb(Acetate)_2$ Tiles - for H_2S (c)
Inexpensive & simple to use

d) Hand pump and sensitive colorimetric tubes (12) mostly for high concentrations and qualitative data

e) Plastic bags - cf. Portable Methods

* Numbers in parentheses refer to suppliers of equipment. A list of addresses will be sent by Dr. Snitzler before end of course.

REM INC.

2000 Colorado Avenue Santa Monica, California 90404 213 828 6078

REM ATMOSPHERIC CHEMILUMINESCENT NO-NO_x MONITOR - Model 652

Specifications (continued)

Instrument Case:	Instrument is provided for both (a) mounting on laboratory bench, with tilt stand which elevates the front of the monitor by 2"; and (b) mounting into standard 19" rack.
Weight:	36 lbs. (cabinet weight).
Dimensions	Cabinet: 19.75" wide x 10" high x 18" deep. Rack: 19.06" wide x 8 - 3/4" high x 16.94" deep.

REM INC.

2000 Colorado Avenue Santa Monica, California 90404 213 828 6078

REM ATMOSPHERIC CHEMILUMINESCENT NO-NO_x MONITOR - Model 652

Specifications

Data display	Digital four digit Nixie tube display with printer option. Printer will record date, time and concentration of NO_x. Analog output, 0 - 10 volts.
Sensitivity (PPM):	0.1 ppm.
Range (PPM):	0 - 100; 0 - 1000; 0 - 10,000
Time constant:	4 sec (0 - 100 ppm); 2 sec. (0 - 1,000); 4 sec (0 - 10,000). Response time of NO Ozone reaction and instrument are instantaneous. Response time only applies when switching from one range to another, i.e., 0 - 1,000 ppm to 0 - 10,000 ppm range, etc.
Atmospheric Interferences:	None
Precision of Measurement:	$\pm$ 0.5% (plus or minus least significant digit)
Zero Drift:	Too low to measure
Linearity:	.1 ppm - 10,000 ppm.
Electronics:	Completely solid state.
Power Requirements:	105 - 125 v; 50 440 Hz; single phase; 55 watts normal line.
Operating Temperature:	Continuous duty at full load from 0 to 50° ambient.

VIII

/

REM INC.

K. KINCAID SAKS ENTERPRISES
P. O. BOX 369
(312) 964-1777 LISLE, ILLINOIS 60532

2000 Colorado Avenue Santa Monica, California 90404 213 828 6078

REM CHEMILUMINESCENT NO-NO_x MONITOR - Model 652

FOR

VEHICULAR EMISSIONS, STACK FLUE GASES

Features

1. Atmospheric pressure O_3, NO chemiluminescent reaction.
2. Measures NO specifically.
3. Can Differentiate between NO and NO_2, and determine NO_2 by difference method.
4. No atmospheric interferences.
5. Instantaneous response to NO.
6. Dry reaction--Gas phase. Chemiluminescent reaction (Ozone + NO).
7. Digital Data Display. (4 Digit Nixie Display)
8. Electronics completely solid state
9. Has direct telemetering capability as well as analog output for data recording.
10. Self-contained unit, no vacuum pump necessary.

The REM Model 652 Atmospheric Chemiluminescent NO Monitor is based on the reduction of NO_2 by hot catalysts and the subsequent chemiluminescent reaction between NO and Ozone. $NO + O_3 \longrightarrow NO_2^* \longrightarrow NO_2 + h\nu(\lambda \approx .6 - 3)$. Light is emitted when electronically excited NO_2 molecules revert to their ground state. The light output is directly proportional to the NO concentration.

REM INC.

3107 PICO BOULEVARD SANTA MONICA, CALIFORNIA 90405 TEL. (213) 828-6469

REM ATMOSPHERIC CHEMILUMINESCENT NO_X MONITOR - Model 642

Specifications (continued)

Instrument Case:	Instrument is provided for both (a) mounting on laboratory bench, with tilt stand which elevates the front of the monitor by 2"; and (b) mounting into standard 19" rack.
Weight:	36 lbs. (cabinet weight).
Dimensions:	Cabinet: 19.75" wide x 10" high x 18" deep. Rack: 19.06" wide x 8-3/4" high x 16.94" deep.

REM INC.

3107 PICO BOULEVARD SANTA MONICA, CALIFORNIA 90405 TEL. (213) 828-6469

REM ATMOSPHERIC CHEMILUMINESCENT NO_x MONITOR - Model 642

Specifications

Data display:	Digital four digit Nixie tube display with printer option. Printer will record date, time and concentration of NO_x. Analog output, 0 - 10 volts.
Sensitivity (PPHM):	0.01
Range (PPHM):	0 - 200; 0 - 20; 0 - 2.
Time constant:	4 sec (0 - 300 pphm); 2 sec. (0 - 2 pphm); 4 sec. (0 - 20 pphm). Response time of NO Ozone reaction and instrument are instantaneous. Response time only applies when switching from one range to another, i.e., 0 - 20 pphm to 0 - 200 pphm range, etc.
Atmospheric Interferences:	None
Precision of Measurement:	± 1% (plus or minus lease significant digit)
Linearity:	0.01 pphm - 300 pphm.
Electronics:	Completely solid state.
Power Requirements:	105 - 125 v; 50 - 440 Hz; single phase; 55 watts normal line.
Operating Temperature:	Continuous duty at full load from 0 to 50° Ambient.

VII

REM INC.

K. KINCAID SAKS ENTERPRISES
P. O. BOX 369
(312) 964-1777 LISLE, ILLINOIS 60532

3107 PICO BOULEVARD SANTA MONICA, CALIFORNIA 90405 TEL. (213) 828-6469

REM ATMOSPHERIC CHEMILUMINESCENT NO_X MONITOR - Model 642

Features

1. Measures NO_x specifically.
2. Can differentiate between NO and NO_2.
3. No atmospheric interferences.
4. Instantaneous response to NO_x.
5. Dry reaction--Gas phase.
   Chemiluminescent reaction (Ozone + NO_x).
6. Digital Data Display.
7. Electronics completely solid state.
8. Has direct telemetering capability as well as analog output for data recording.

The REM Model 642 Atmospheric Chemiluminescent NO_x Monitor is based on the reduction of NO_2 by hot catalysts and the subsequent chemiluminescent reaction between NO and Ozone. This instrument is designed for continuous operation at the atmospheric level. This monitor provides the first commercial system based on a dry gas phase reaction. There are no known interferences with the NO, O_3 reaction, and the instrument is designed to determine NO, NO_x or NO_2 specifically.

PRELIMINARY

TABLE III
Monthly Averages of
Total Dustfall
Chicago, Illinois

Comparison of 1965 & 1964 Readings
(Rdgs. in Tons/Sq. mile/ month)

MONTH	1965	1964	% CHANGE	REMARKS
JANUARY *	56.7	No Data		
FEBRUARY *	65.3	" "		
MARCH	50.0	50.1	- 0.2	
APRIL	51.4	69.3	-25.8	Prevail. Winds from 90 degrees in 1965; 180 degress in 1964.
MAY	45.2	48.6	- 7.0	
JUNE	45.1	42.4	+ 6.4	
JULY	27.1	28.3	- 4.2	
AUGUST	25.0	26.3	- 5.0	
SEPTEMBER	19.9	29.2	-31.8	Precipitation 6.21"in 1965; 2.50" in 1964
OCTOBER	33.1	32.7	+ 1.2	
NOVEMBER	40.5	39.6	+ 2.3	
DECEMBER	30.7	30.0	+ 2.3	
AVERAGES*	36.8	39.7	- 7.3	
STANDARD DEVIATION	10.3	12.9		

* NOT INCLUDED IN AVERAGES.

Department of Air Pollution Control

Technical Services Division

January 19, 1966

TABLE II

SUMMARY OF SUSPENDED PARTICULATES

CHICAGO, ILLINOIS

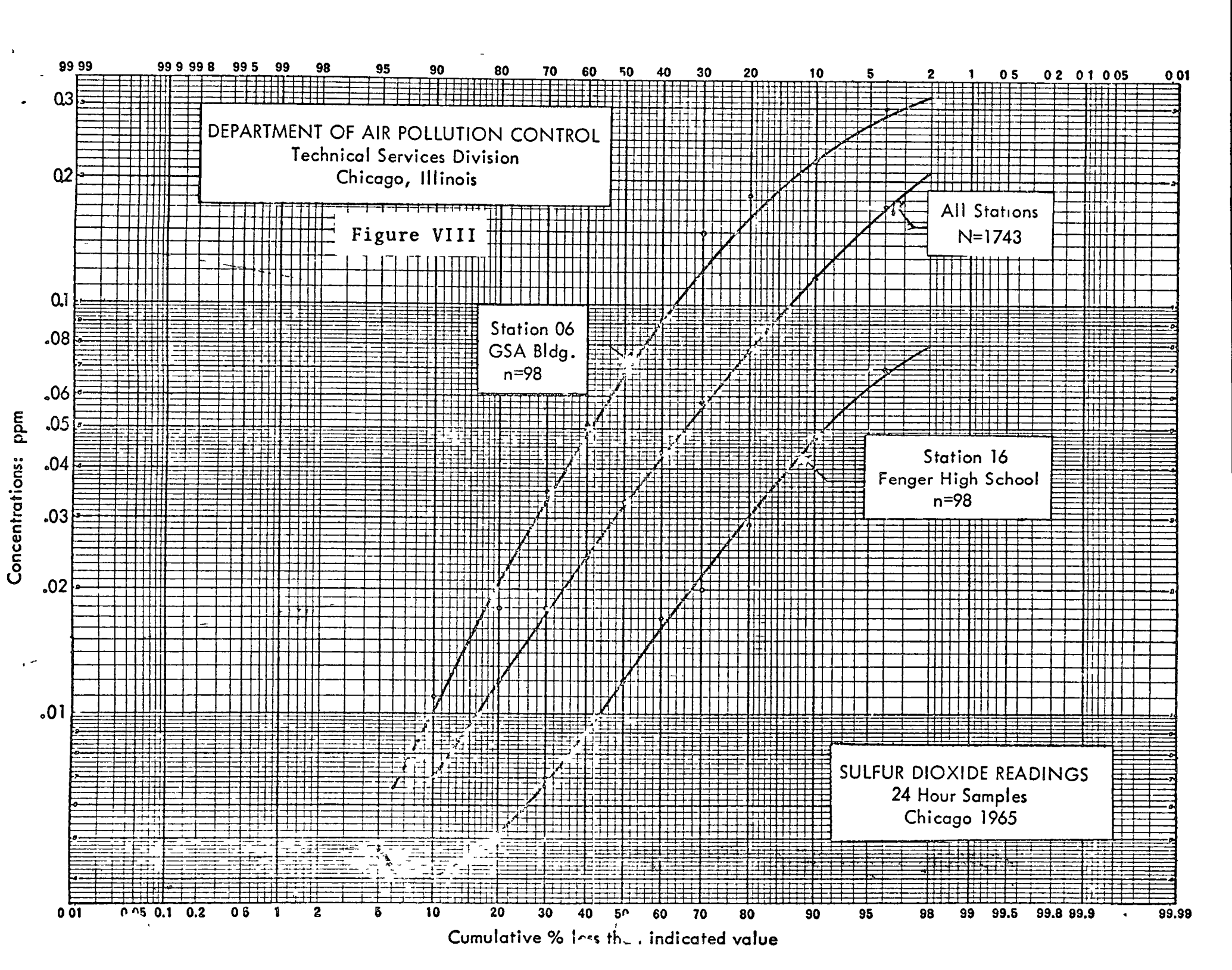
December 1963 - November 1964

	Station	No, of Samples	x	Med.	Correlation	
I	A 1	134	90	76		
	C 3	136	95	85	r 3.1	.98
II	B 2	138	128	120		
	T 20	132	118	110	r20.2	.90
III	D 4	131	175	155		
	F 6	130	173	150	r 4.6	.85
	G 7	128	158	150	r 4.7	.90
	I 9	122	154	140	r 4.9	.71
IV	L 12	134	170	175	r 6.9	.73
	J 10	135	140	125	r12.15	.53
V	K 11	132	123	115	r10.11	.84
	N 14	133	116	115	r11.14	.85
	O 15	138	126	118		
	P 16	126	121	100		
VI	Q 17	137	136	115	r17.16	.70
	R 18	135	120	100	r17.18	.77
VII	H 8	134	136	125		
VIII	M 13	131	111	100		
All	Stations		132			

TABLE I

Some Statistics on the Concentrations of Three Major Pollutants in Chicago 1965

Period	No. of Observations	Average	Low	% of Avge.	High	% of Avge.
Sulfur Dioxide, ppm						
Annual	1743	0.051	0.000	---	0.407	800
Tuesdays	854	.054	.000	---	.360	670
Thursdays	889	.048	.000	---	.407	850
Winter	418	.073	.001	1.4	.407	556
Spring	443	.037	.000	---	.190	510
Summer	451	.024	.000	---	.153	638
Fall	431	.070	.001	1.4	.288	412
Suspended Particulates, ug/m^3						
Annual	2755	132	13	9.9	534	404
Sundays	859	117	22	18.8	425	363
Tuesdays	936	143	21	14.7	420	294
Thursdays		134	13	9.7	534	399
Winter	624	134	22	16.4	423	315
Spring	702	136	13	9.6	534	393
Summer	705	111	21	18.9	420	378
Fall	724	144	27	18.8	465	323
Total Dustfall, $tons/mile^2/month$						
Annual	218	41.0	5.6	13.6	157.0	383
Winter	60	57.3	18.0	31.4	157.0	274
Spring	59	47.3	28.0	59.2	92.4	195
Summer	60	24.0	5.6	23.3	40.9	170
Fall	59	35.4	10.7	30.2	129.7	366


DEPARTMENT OF AIR POLLUTION CONTROL
Technical Services Division
Chicago, Illinois
Figure VIII
All Stations
N=1743
Station 06
GSA Bldg.
n=98
Station 16
Fenger High School
n=98
SULFUR DIOXIDE READINGS
24 Hour Samples
Chicago 1965
Concentrations: ppm
Cumulative % less than indicated value
99.99 99.9 99.8 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
0.3 0.2 0.1 .08 .06 .05 .04 .03 .02 .01
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.8 99.9 99.99

CODEX BOOK COMPANY INC NORWOOD MASSACHUSETTS
PRINTED IN U S A

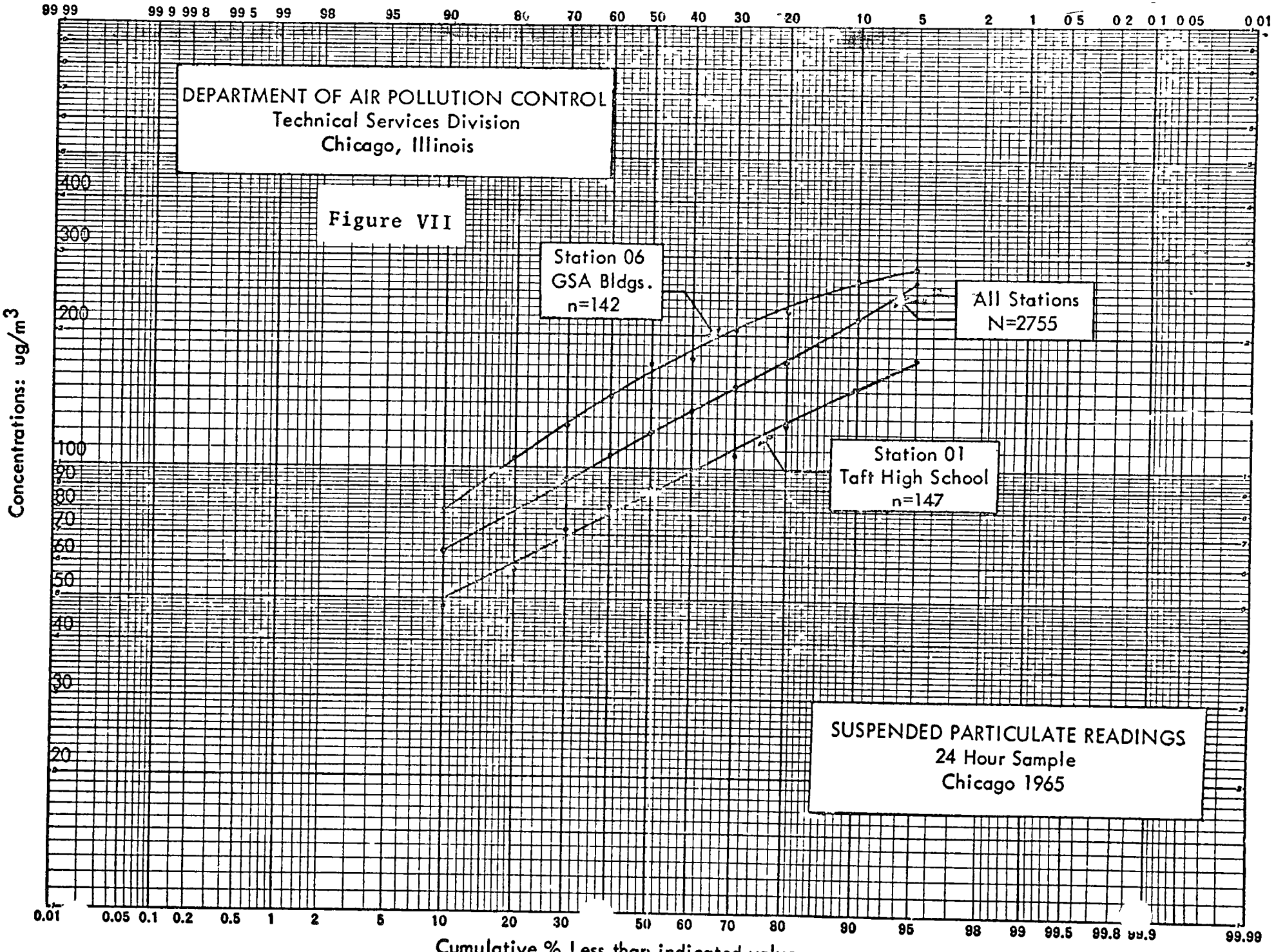


Figure VI

AIR MONITORING PROGRAM

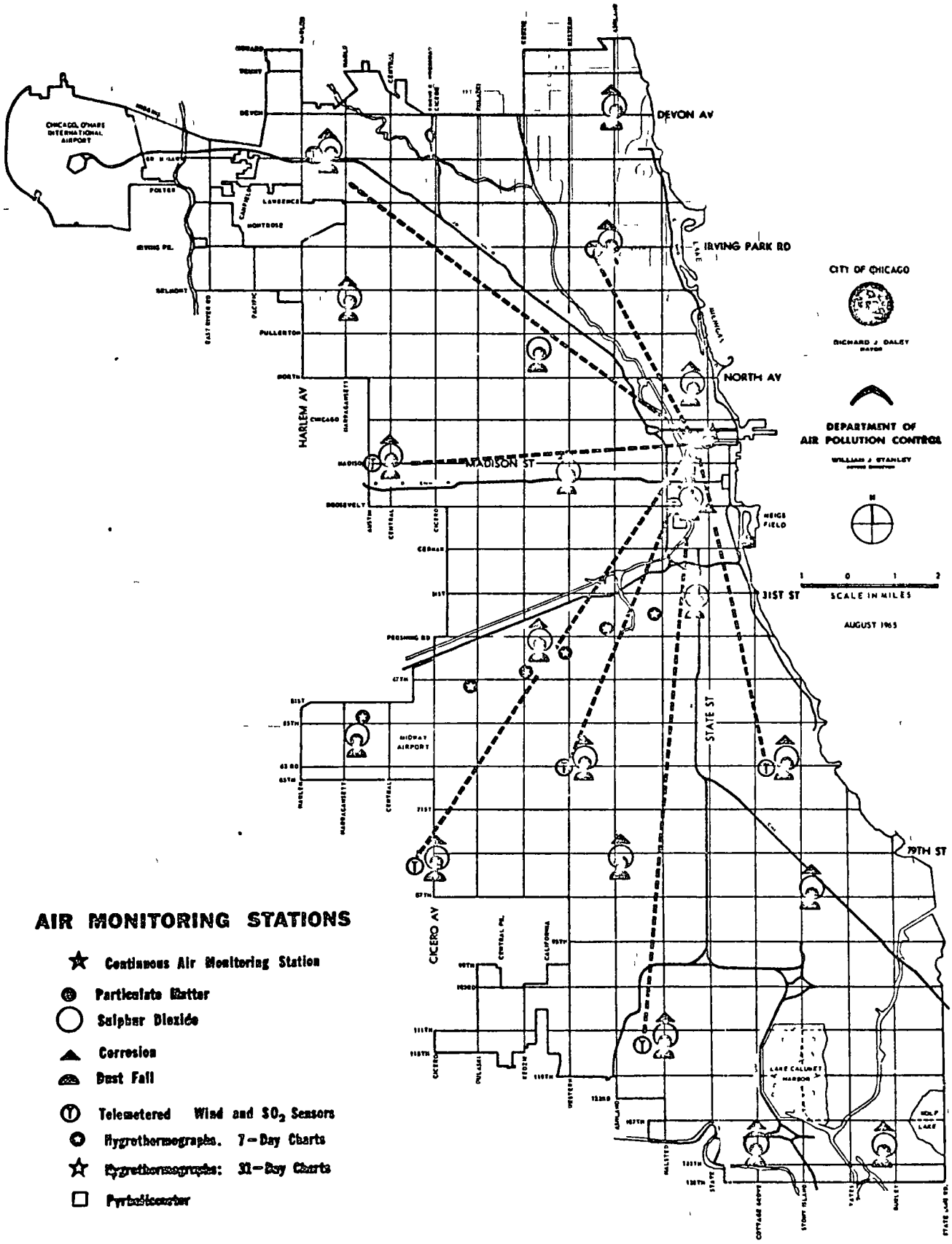


Figure .

CITY OF CHICAGO
CLEANER AIR SYSTEMS CONTROL CENTER

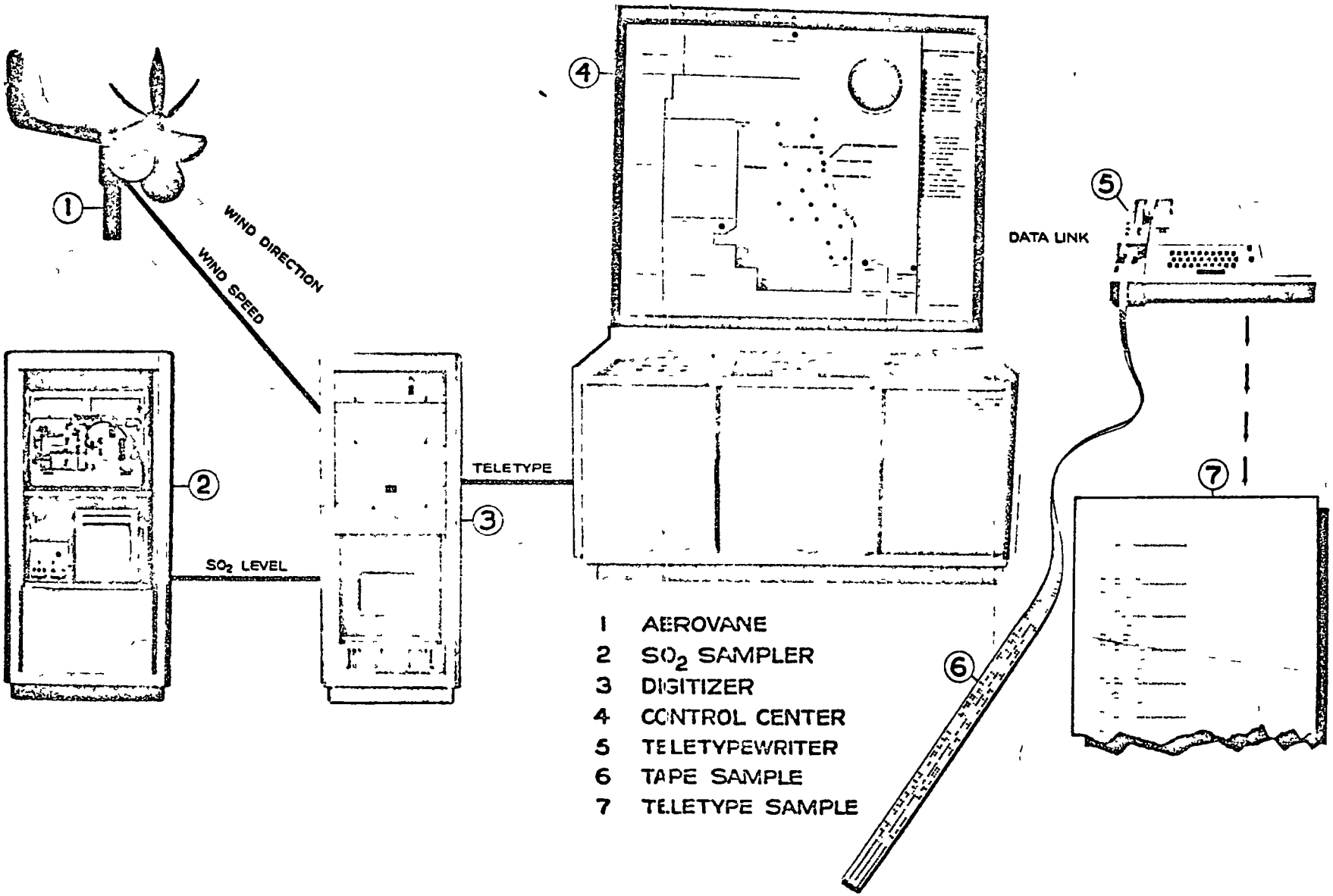


Figure IV

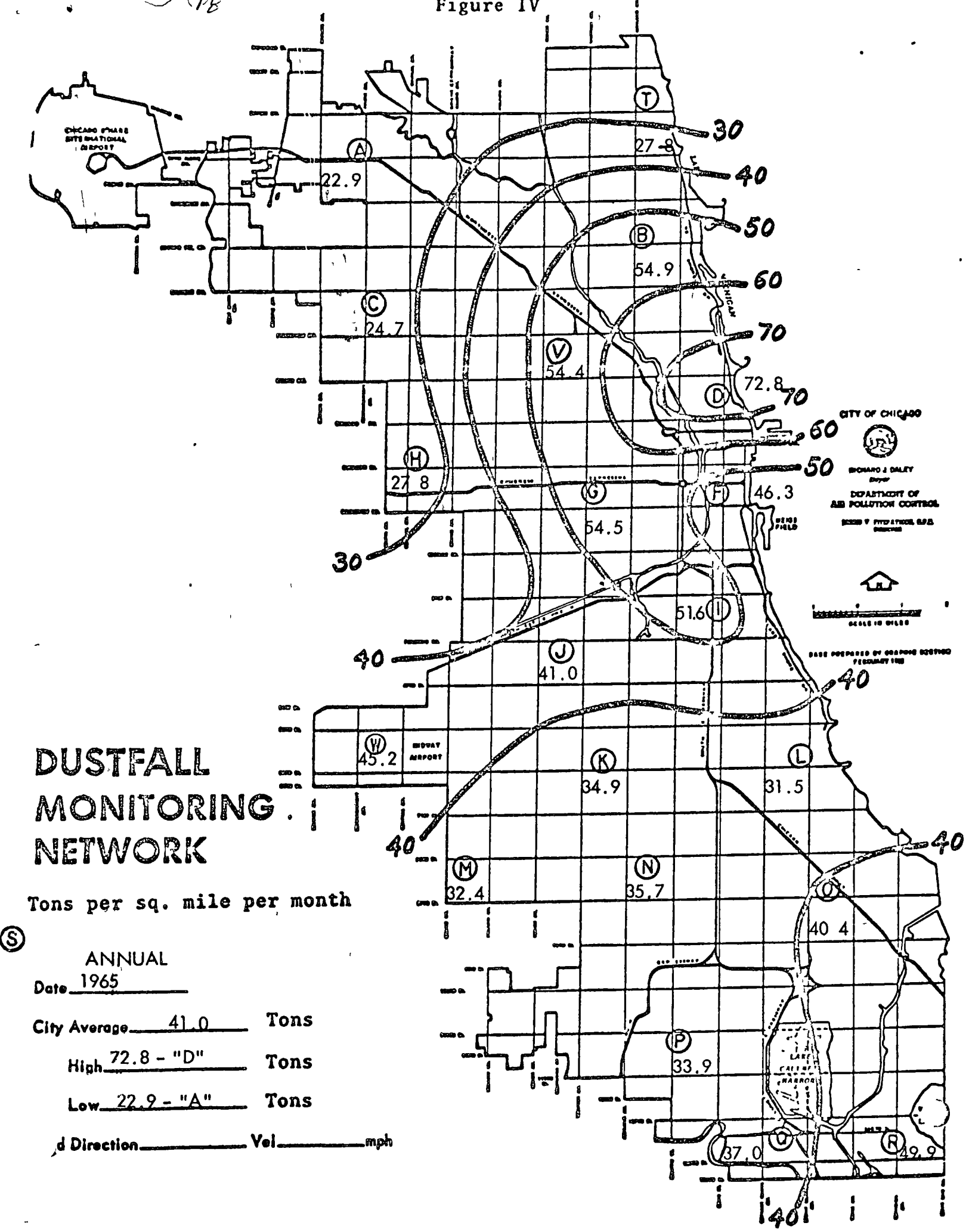

DUSTFALL
MONITORING
NETWORK
Tons per sq. mile per month
ANNUAL
Date 1965
City Average 41.0 Tons
High 72.8 - "D" Tons
Low 22.9 - "A" Tons
d Direction Vel mph
A 22.9
B 54.9
C 24.7
D 72.8
F 46.3
G 54.5
H 27.8
I 51.6
J 41.0
K 34.9
L 31.5
M 32.4
N 35.7
O 40.4
P 33.9
Q 37.0
R 49.9
S
T 27.8
V 54.4
W 45.2
CITY OF CHICAGO
DEPARTMENT OF
AIR POLLUTION CONTROL
30
40
50
60
70

Figure III

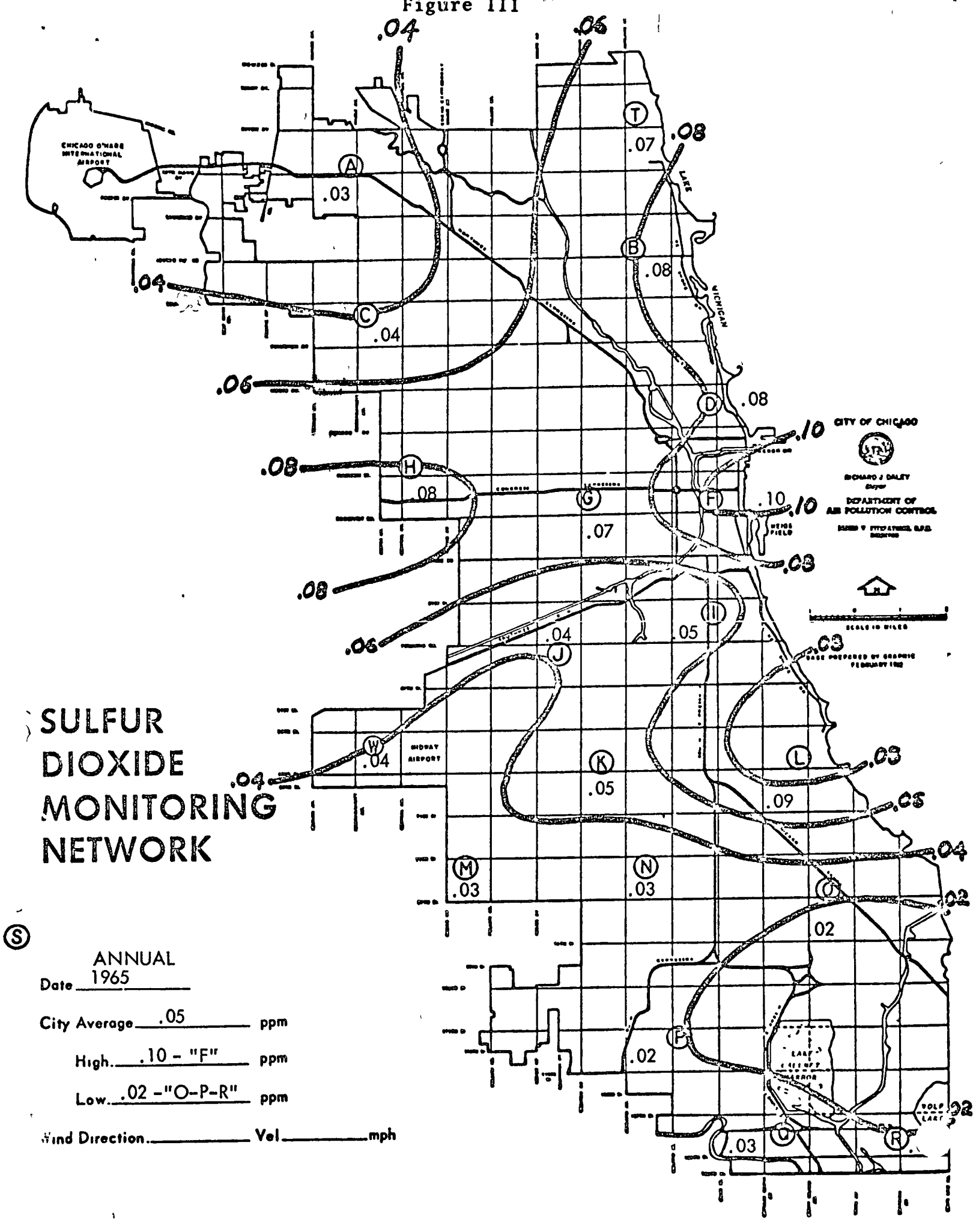

SULFUR DIOXIDE MONITORING NETWORK
CHICAGO O'HARE INTERNATIONAL AIRPORT
MIDWAY AIRPORT
LAKE MICHIGAN
CITY OF CHICAGO
RICHARD J DALEY
Mayor
DEPARTMENT OF AIR POLLUTION CONTROL
A .03
B .08
C .04
D .08
F .10
G .07
H .08
I .03
J .04
K .05
L .03
M .03
N .03
O .02
P .02
Q .02
R .03
S
T .07
W .04
.04
.06
.08
.10
.09
.05
ANNUAL
Date 1965
City Average .05 ppm
High .10 - "F" ppm
Low .02 - "O-P-R" ppm
Wind Direction _____ Vel _____ mph

Figure II

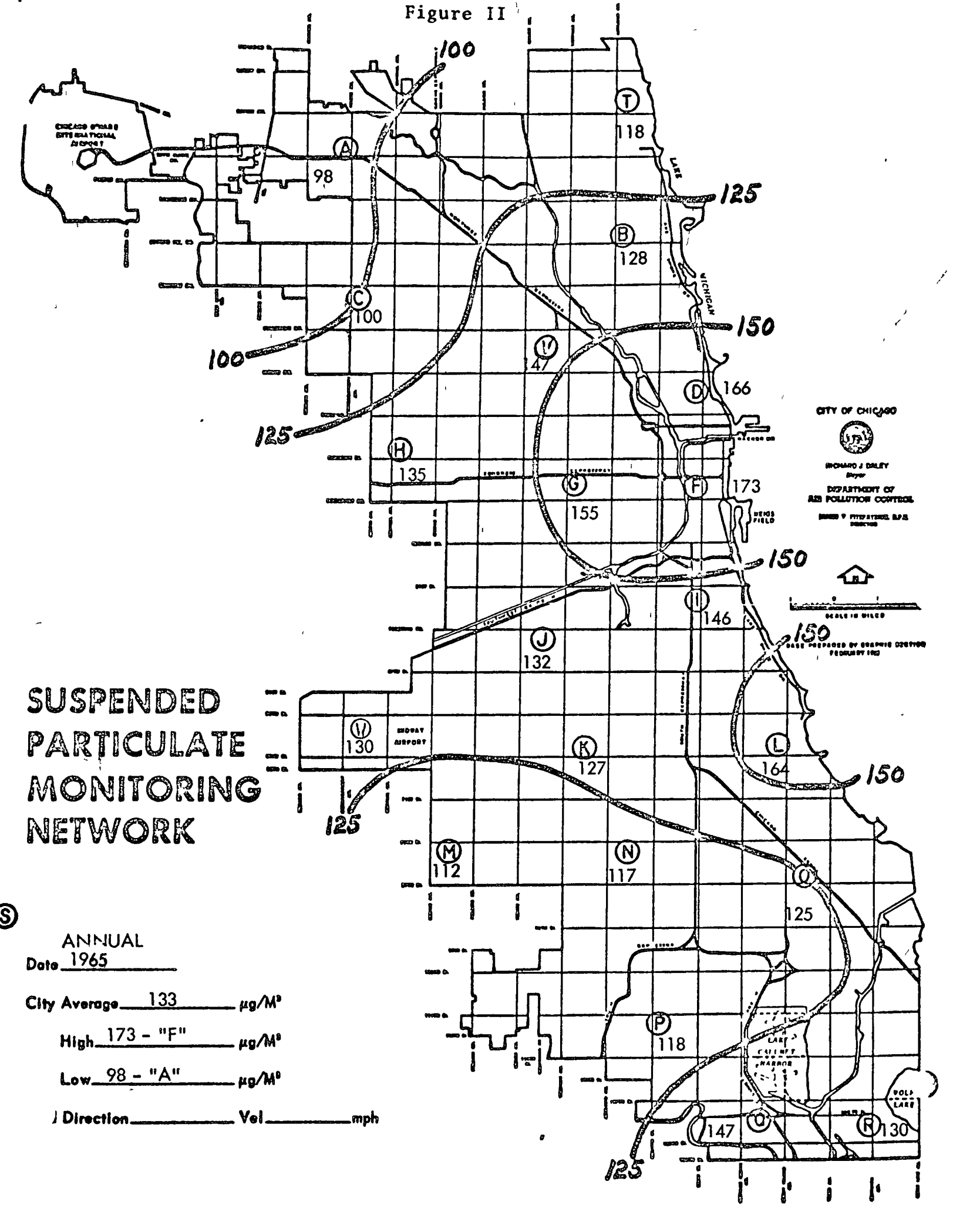
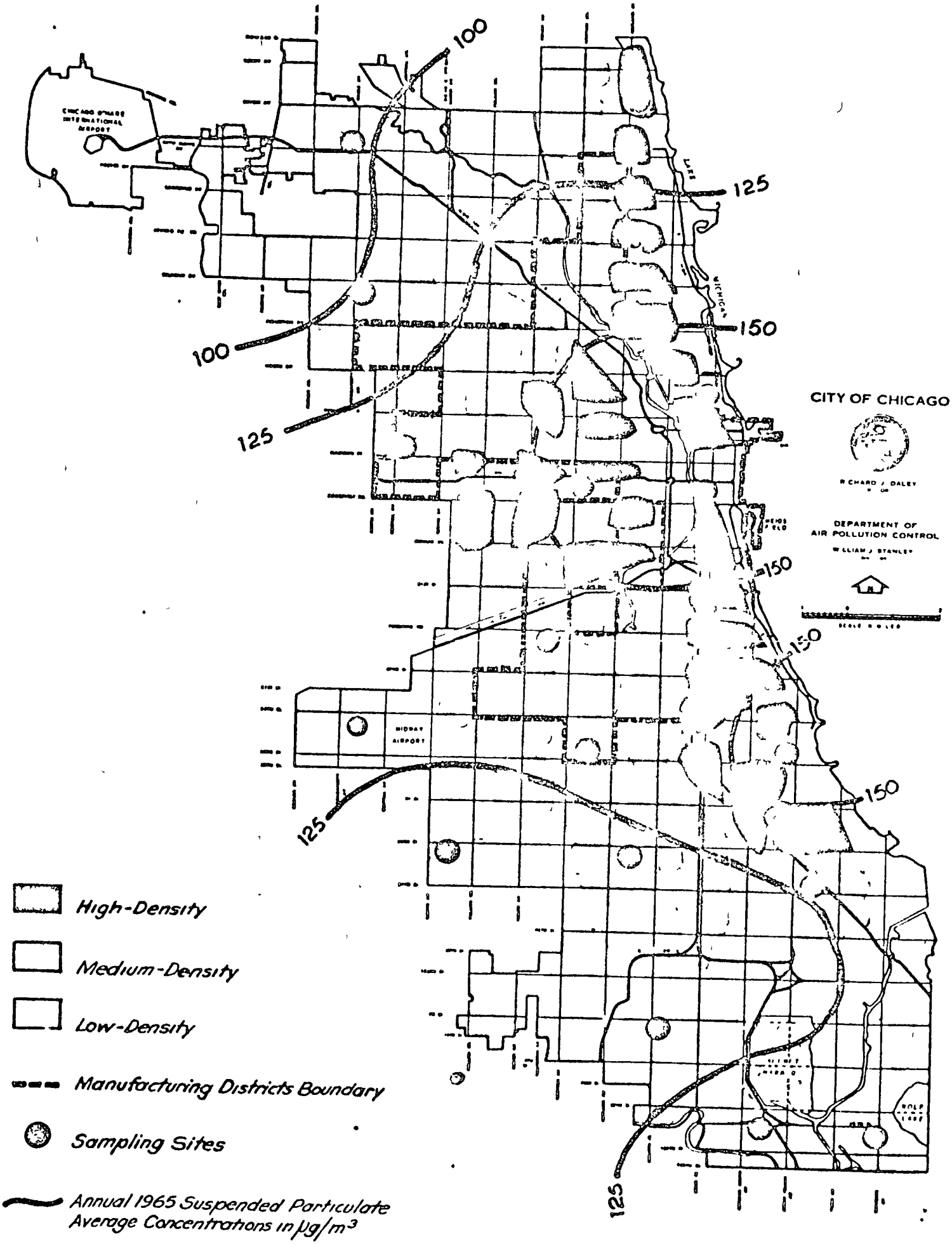

SUSPENDED PARTICULATE MONITORING NETWORK
ANNUAL
Date 1965
City Average 133 µg/M³
High 173 - "F" µg/M³
Low 98 - "A" µg/M³
Direction Vel mph
CITY OF CHICAGO
RICHARD J DALEY
DEPARTMENT OF AIR POLLUTION CONTROL
A 98
B 128
C 100
D 166
F 173
G 155
H 135
J 132
K 127
L 164
M 112
N 117
O 125
P 118
Q 147
R 130
T 118
U 130
100
125
150

Figure 1


100
125
150
CITY OF CHICAGO
DEPARTMENT OF
AIR POLLUTION CONTROL
High-Density
Medium-Density
Low-Density
Manufacturing Districts Boundary
Sampling Sites
Annual 1965 Suspended Particulate
Average Concentrations in µg/m³

CITY OF CHICAGO
DEPARTMENT OF AIR POLLUTION CONTROL - TECHNICAL SERVICES DIVISION
SUSPENDED PARTICULATE, SULFUR DIOXIDE AND DUSTFALL MONITORING NETWORK
SAMPLING STATIONS

A - Taft High School - - - - - - - - - - - - - 5625 N. Natoma Avenue
B - Lake View High School - - - - - - - - - 4015 N. Ashland Avenue
C - Steinmetz High School - - - - - - - - - - 3030 N. Mobile Avenue
D - Cooley Voc. High School - - - - - - - - 1225 N. Sedgwick Street
E - South District Filtration Plant - - - - - - 3300 East Cheltenham Place
F - G.S.A. Building - - - - - - - - - - - - 538 S. Clark Street
G - Crane High School - - - - - - - - - - - - 2245 W. Jackson Blvd.
H - Austin High School - - - - - - - - - - - - 231 N. Pine St.
I - Farr Dormitory - - - - - - - - - - - - - 3300 S. Michigan Avenue
J - Kelly High School - - - - - - - - - - - - 4136 S. California Avenue
K - Lindblom High School - - - - - - - - - - 6130 S. Wolcott Avenue
L - Hyde Park High School - - - - - - - - - - 6220 S. Stony Island Avenue
M - Stevenson Elementary School - - - - - - - 8010 S. Kostner Avenue
N - Calumet High School - - - - - - - - - - 8131 S. May Street
O - Chicago Vocational High School - - - - - 2100 E. 87th Street
P - Fenger High School - - - - - - - - - - - - 11220 S. Wallace Street
Q - Carver High School - - - - - - - - - - - - 801 E. 133rd Place
R - Clay Elementary School - - - - - - - - - 13231 S. Burley Avenue
S - Argonne National Laboratory - - - - - - - Argonne, Illinois
T - Sullivan High School - - - - - - - - - - 6631 N. Bosworth Avenue
U - Von Steuben High School - - - - - - - - 5039 N. Kimball Avenue
V - Illinois Bell Telephone Company - - - - - 2940 W. Cortland Avenue
W - Hale Elementary School - - - - - - - - - 6140 S. Melvina Avenue

APPENDIX

Advantages of the System

The system is so constructed that expansion to twenty plus stations may be accomplished by installing additional circuit modules and adding chassis by merely tying into existing connectors. Each remote station will be able to accept inputs from as many as five different air quality analyzers.

Encoders allow the user to utilize any of the available analyzer instruments by tying onto the shaft of the recorder which in most cases is an integral part of the analyzer. It also presents linearized and scaled output and no data interpretation is required. They add no errors to the analyzer accuracy. Digital transmission precludes any degradation of system accuracy. Using teletype recording equipment allows the use of lowest cost telephone lines.

Minimal modification is required for tying the system to an on-line computer for complete pollution monitoring.

CONCLUSION

The Telemetered Air Monitoring Network information will be used to:

1. Advise the public of the air quality in the City of Chicago.
2. Provide the back-up information with which health studies will be correlated.
3. Provide the information to determine the effectiveness of the enforcement program in reducing sulphur dioxide.
4. Provide an enforcement tool to pinpoint large emittors of sulphur dioxide.
5. Provide the information to support the design and operation of a diffusion model for the City of Chicago.
6. Establish air quality standards as an aid to enforcement.
7. Develop an air pollution climatology for the City of Chicago.

station. Data gathered at each remote site include sulphur dioxide in parts per million, a five-minute integrated wind direction to the nearest degree and a five-minute integrated wind speed to the nearest one-tenth knot. (Figure 5) (Figure 6)

Fifteen-minute intervals were selected because of their representativeness over a 24-hour period, thereby precluding the likelihood of excessive highs and lows occurring without being detected. A new and rather unique meteorological method is employed in the recording of 15-minute intervals inasmuch as wind speed and direction are "integrated," i.e., readings on wind speed and direction are taken every five seconds and are stored in the electronic memory; the information is then averaged by the computer for 15-minute readings and recorded. The problem of eliminating ambiguity of readings of wind speed and direction was solved by suing two Selson motors counter-clockwise.

At pre-slected intervals the central station clock signals the beginning of a recording cycle. The programmer starts the printer and tape punch and initiates the recording of the date-time group and parameter data which is utilized by the computer for the analysis assigned to the block of data. The programmer then interrogates the first station, and it immediately transmits its three-digit identification followed by the air quality and wind data. This is repeated for all stations with a total transmission time of 40 seconds.

The central station control panel allows for automatic or manual selection of signals for zero checks, calibration checks, and changes of sampling and recording intervals. Further, it contains provisions for by-passing a station in the event of line or equipment difficulties, initiation of demand recording cycles and indicators to show functions taking place. The central console incorporates a graphic display representing the metropolitan Chicago area with indicators that illuminate each station location when the station is transmitting data.

CONTINUOUS AIR MONITORING TELEMETERED NETWORK

In evaluating various approaches to a data-gathering and logging system certain factors had to be considered: cost, reliability, simplicity for ease of maintenance, data handling, availability of service, and manufacturers with proven experience in all phases of the system requirements. Specifications for the system on order were developed with these general considerations in mind and by evaluating the technical aspects of a number of systems available.

To obtain reliability of data telemetered to a central location and ease of maintenance it was decided to digitize at remote sites by installing a shaft encoder on each chemical analyzer and meteorological sensor. Solid state design electronics was specified because of its inherent reliability in addition to lending itself to modular plug-in construction, making maintenance a matter of merely replacing a plug-in module and repairing the defective unit at a more convenient time.

Teletype transmission of data to the central station offered the use of the lowest cost leased line available from the telephone company. At the central station the transmitted data are printed on a page printer in addition to being recorded on punched paper tape for subsequent computer handling. The remote stations utilize solid state distributors in lieu of the electro-mechanical units normally used for teletype transmission. They are controlled by a precision clock and should require virtually no maintenance or adjustment.

Systems Operation

The Air Quality Monitoring System finally purchased consists of eight remote stations, each having a sulphur dioxide analyzer and an aerovane. It is designed for recording data at 15-minute intervals by transmitting sequentially from each remote station to the central

The statistical analysis of the twenty stations revealed an adequate grouping of eight subsets with the stations in each subset comprising the same regional area. Moreover, the readings of pollutants were reasonably similar at the different stations located within the same subset. (Table 2) For example, stations A and C, located in the northwest protion of the city, had median concentrations of suspended particulates of 76 and 85 ug/m^3 respectively. In addition, the correlation coefficient between measurements made on the same day at these stations was $r=0.98$, indicating nearly a one-to-one correspondence. For all practical purposes, either one of these stations could be selected to represent that general area of the city.

By June of 1965 seven months of SO_2 data at nineteen stations had become available. A check was made on the adequacy of the chosen sites based on the correspondence between the average SO_2 concentration for these stations and that for the total network. In addition, eight stations were independently selected, using a graphic method, based on the correspondence of graphed data of individual stations with those of averages of the network. Table 3 shows the results of these checks. Though the alternate network thus obtained revealed a somewhat better correlation coefficient, it was not as adequate geographically. Thus, the original eight station choice was retained; however, station P was substituted for station Q.

Finally, two additional criteria were used in selecting one station from each of the eight subsets:

(1) Health studies under the direction of Dr. Mark Lepper, Chairman of Preventive Medicine, University of Illinois School of Medicine, required a broad socio-economic distribution.

(2) Wide geographic distribution was desirable to obtain suitable meteorological coverage.

In the isopleth map (Figure 3) the sulphur dioxide lines tend to parallel the lake shore, i.e., the high population zones, indicating a slower decay of concentration toward the northwes and southwest. The highest concentrations are in the Hyde Park-Kenwood area, the location of station L.

Dustfall

While dustfall is not as important as either sulphur dioxide or suspended particulates, from a public health point of view, it is included here only briefly for the sake of completeness. At the twenty dustfall stations that compose the network, the yearly average was 41.0 tons/ square mile/ month. The dustfall concentrations follow the pattern of density of population and industrial concentration as well as reflect seasonal variation because of heating, particularly due to the use of low-grade fuels. During the heating season, solubles and combustibles are particularly high. The insolubles and non-combustibles appear to follow wind patterns, showing higher concentrations in spring and summer months. (Figure 4)

LOCATION OF STATIONS FOR THE CONTINUOUS AIR MONITORING PROGRAM

As the Department's Five-Year Air Resource Management Program progressed, it became apparent that continuous air quality data must be available, not simply bi-weekly or tri-weekly information gathered by air sampling technicians. A statistical analysis of two year's of data on suspended particulates and sulphur dioxide was made to determine the adequate number of stations and their location throughout the city. The stations selected had to meet two criteria: (1) they must be truly representative of the geographical coverage of the city, and (2) they must provide an estimate of air quality not significantly different from the data acquired from the twenty-station networks.

Sulphur Dioxide

A graphic summary of sulphur dioxide data from all twenty stations during 1965 has been plotted on a map of the city of Chicago. (Figure 3) It should be noted that in relation to the range of average levels of suspended particulates, the range of average levels of sulphur dioxide is quite small by comparison. For example, the average concentration of sulphur dioxide for the year ranged from 0.03 ppm for station R to 0.11 ppm for station L. Station L, it should be noted, also recorded the highest levels of suspended particulate matter.

Sampling of pollutants has indicated that meteorological factors play a significant role in concentrations. Daily analysis of data reveals that wind speed is inversely proportional to the concentration levels of pollutants. Heavier concentrations are recorded with light wind speeds rather than with stronger wind speeds.

In the case of sulphur dioxide, there is a very pronounced seasonal cycle in Chicago, indicative of a relationship with heating demands. The correlation coefficient between these two variables was 0.97. Generally speaking, the average levels during the winter are over three times those observed during the summer. Again, station L is most outstanding with summer and winter levels of 0.03 ppm and 0.15 ppm respectively. The maximum 24-hour average concentration of sulphur dioxide recorded at station L was 0.32 ppm. By referring to the cumulative frequency distribution for all stations for the year, it can be seen that one percent of the total of 1743 samples exceeded a concentration of 0.26 ppm.

data have been available on suspended particulates throughout 1964 and 1965; concentrations have been recorded on punch cards and analyzed statistically by computer.

A detailed summary of all suspended particulate data for 1965 is presented in Table I. * This summary contains the inclusive dates for which data were obtained from each station as well as the number of samples and cumulative frequency distributions giving the percent of all samples equal to or less than stated concentrations in ug/m^3. On the basis of this information it is now possible to determine the geographic variability of suspended particulate matter in the city of Chicago.

The median concentrations of suspended particulates for the twenty stations during 1965 are plotted on a map of the city (Figure 2). For example, on the basis of median concentration it is apparent that stations A and C (90 and 91 ug/m^3 respectively) ranked as the least polluted areas of the city, while station F (171 ug/m^3) was the most heavily polluted from the standpoint of total suspended particulate matter. The median concentration for all twenty stations was 119 ug/m^3.

As part of this analysis data were summarized by day of the week for all twenty stations. No significant difference is noted in the levels of suspended particulates between Tuesdays and Thursdays throughout the year 1965. Similarly, data were analyzed according to season of the year, revealing that concentrations are rather uniform on a seasonal basis.

The annual isopleth for suspended particulates (Figure 2) corresponds fairly well with the population and industry concentration, particularly with the former. The concentrations reduce westward, rapidly on the north and near south, slowly at the center. The far south (the location of heavy industries) shows a higher concentration than the far southwest.

* See Appendix for all Tables and Figures.

filter in a 24-hour period. Starting at midnight of the previous day, sampling is conducted on Sundays, Tuesdays, and Thursdays. The filters are weighed before and after the sampling; before each weighing the filters are stored at constant temperature and humidity for 16 hours. Filters are analyzed at the Department's laboratory for concentrations of sulphate, nitrates, and phosphates, and several types of metal. Concentrations are reported in micrograms per cubic meter (ug/m^3).

The West-Gaeke analytical procedure is used for sulphur dioxide. It consists of bubbling approximately 240 liters of air through 20 milliliters of 0.1 normal sodium tetrachloro mercurate solution (Na_2HgCl_4). Samples are taken in duplicate for 24 hours on Tuesdays and Thursdays only. The concentration is determined colorimetrically and reported in parts per million by volume.

Dustfall measurements are made by collecting the settled material in glass jars containing 1-3" of water. The jars are 6" in diameter (1/5 square foot area) and are set approximately 54" above roof level at the test site. The jars are exposed for 25-31 days and then replaced with new ones while the contents of the exposed jars are being analyzed. The material is analyzed for soluble and insoluble portions: for chloroform soluble, hydrochloric acid soluble, combustible and inert components. Results are reported in tons/square mile/month. For example, 100 tons is roughly 150 pounds of grit per person per year.

SUMMARY OF RESULTS

Suspended Particulate Matter

Of the twenty stations originally planned for suspended particulate sampling only eighteen provided continuous data from March 1963 through December 1963. Continuous

With no significant topographical features other than buildings and with the lakefront parallel to the eastern border of the city, it was therefore determined that any reasonable geographic distribution of sampling sites would provide the desired synoptic profile of the atmosphere over the city. Furthermore, winds from any quadrant would transport pollutants to two or more stations.

Another significant factor in site selection was uniformity of elevation for sampling stations. To attain the optimum level of 50 to 60 feet above ground level, public schools, most of which are 3 or 4 stories high, were selected. The 358 structures available afforded an adequate horizontal selection, ready accessibility, security for our equipment as well as cooperation for a public agency.

One final determination in site selection aside from population density, locations of industrial and commercial firms, and meteorological conditions was an adequate number of sampling stations. An analysis of Chicago's 220 square miles indicated that nineteen sites would be sufficient to establish a city-wide profile of air pollution An additional site was selected in a predominantly rural area outside the city to determine the concentration of pollutants in a relatively clean area. Argonne National Laboratory was selected as this control site.

The twenty stations have proven satisfactory for sampling of the three major types of pollution: sulphur dioxide, suspended particulates, and dustfall. The activation of each of the three pollutant networks took place gradually during 1963-64; however, continuous data on all three types have been provided since December, 1964.

Testing and Sampling Procedures

Sampling for suspended particulate concentrations consists of passing about 2,400 cubic meters of air (or 84,000 cubic feet) through a 6" x 9" area of flash-fired glass mat

SITE SELECTION

After a careful review of the geographic distribution of the population, commercial and industrial operations, and meteorological considerations, a total of twenty sampling sites was selected to provide a synoptic profile of the atmosphere. The following description is offered to explain the methodology of site selection.

The population of Chicago is concentrated on the lake shore and follows an east-west line through the center of the city; the concentration of older multiple-dwelling units follows a similar pattern.

In view of possible site locations, use was made of a study conducted by the Department of City Planning entitled "Locational Patterns of Manufacturing Industries," which indicated the location of industrial establishments in the city. (Figure 1)

Meteorological Conditions and Their Relationship to Site Choices

An important consideration in defining the meteorological effects of an area is local topography. Chicago is approximately eight to ten miles wide and extends north-south for about 25 miles along the western shore near the southern end of Lake Michigan. The entire area is essentially a level plain slightly higher than the surface of Lake Michigan, which is 580 feet above mean sea-level.

The surface features have too slight an effect on air movement to cause any noticeable drainage or channelling of winds. The city's buildings are a much more prominent landscape feature than its topography, particularly true in the central business area with its many high-rises reaching 500-600 feet above the street surfaces.

An important effect on local winds is caused by temperature differences between Lake Michigan and the adjacent land area. Not infrequently parts of the city near the lake shore are cooled by easterly breezes off the lake, extending several miles on shore.

amendments in 1962 against open burning of debris from demolition (effective in July, 1964) and in 1963 against all forms of polluting emissions have strengthened the control of noxious atmospheric contaminants. Moreover, the exclusion of certain industries from the norms of the Ordinance--for example, the steel and coffee-roasting industries--was corrected when the "research clause" was deleted in the revised Code.

In October, 1962, the Department of Air Pollution Control entered a technical assistance project with the U. S, Public Health Service to plan a dynamic air management program for the city. The time had arrived once more for Chicago to broaden its concept of air pollution control and to devise more modern methods of assuring clean air for its citizens. The outgrowth of the planning was a Five-Year Air Resource Management Program, inaugurated in 1963, consisting of a comprehensive eight-point program involving an organized team of scientitsts, engineers, technicians, enforcement officers, and administrative personnel. The eight objectives constituting the program summarize the operations of the Department:

1. to determine the effect of air pollution on the health of Chicagoans
2. to inventory all potential sources of air pollution
3. to improve the monitoring of pollutants
4. to improve the analysis of pollutants
5. to determine the transport and dispersion of pollutants.
6. to recommend effective legislation for air pollution control
7. to increase metropolitan activity in the control of air pollution
8. to provide the public with a thorough understanding of air pollution.

The background has now been presented for a description of the Department's activities in the organization and operation of a total air monitoring program, leading eventually to the establishment of its Telemetered Network.

INTRODUCTION

To place the Telemetered Air Monitoring Program of Chicago's Department of Air Pollution Control in proper perspective, a brief orientation to the Department's development seems highly appropriate. Rather than present a lengthy list of historical memorabilia, only the major benchmarks will be isolated here.

The nation's pioneer municipal ordinance against dense smoke emissions from industrial and commercial establishments was enacted in 1881. A separate city department was organized in 1907, when permits were first required for the installation of fuel-burning equipment. Ten years later the Department codified the first definitions concerning the use of high and low volatile coals. In 1938 the nation's first large-scale program for the inspection of fuel and refuse burning equipment was inaugurated.

Scientific advancement in the areas of medical knowledge and technology has greatly increased over the years. As knowledge about the nature, causes, effects, and control of air contaminants became more refined, so too did the city's efforts to utilize the information. Recognizing the urgency of combatting the increasing problem of air contamination in a large industrial complex, Chicago re-organized the original Department of Smoke Abatement in 1952, re-naming it the Department of Air Pollution Control. The new name was indicative of a widening of the Department's jurisdiction and reflective of its expanded activities in the monitoring and analysis of various pollutants.

A landmark in the cause for cleaner air in Chicago was the enactment of a more comprehensive municipal ordinance in 1958, which became effective in May, 1959. The new ordinance regulates industrial, manufacturing, and chemical processes; steam and diesel locomotives; the handling, storage, and transportation of materials; open burning; the sale and use of high volatile fuels; and the sale of refuse-burning equipment. Subsequent

II

CITY OF CHICAGO

AIR QUALITY TELEMETERING SYSTEM*

by

Samuel G. Booras 1/

* For presentation during June, 1966 Great Lakes Regional Meeting of the American Chemical Society in Chicago, Illinois.

1/ Assistant Director, Technical Services Division City of Chicago, Department of Air Pollution Control

POLLUTANT	AMBIENT AIR LEVEL $\mu g/m^3$ (ppm or other)	AVERAGING TIME Hours
1. Sulfur dioxide	1048 (0.4)	24
and		
Particulate*	750 (about 6 coh's)	24
2. Carbon monoxide	57,500 (50)	8
	86,250 (75)	4
	143,750 (125)	1
3. Photochemical oxidant	785 (0.4)**	4
	1176 (0.6)**	2
	1372 (0.7)**	1

* It seems reasonable that the product of 24 hour mean values for sulfur dioxide and particulate be used to trigger an emergency episode plan. This recommendation is made with the full knowledge that there is no information that documents equivalent effects for the various combinations. A 24 hour mean of 786×10^3 for the product of SO_2 and particulates both measured in $\mu g/m^3$, or maximum values, as indicated below could be so used.

Sulfur Dioxide $\mu g/m^3$ (ppm)	and	Particulate $\mu g/m^3$ (COH)
2620 (1.0)	and	any particulate level
or 2096 (0.8)	and	375 (3)
or 1572 (0.6)	and	500 (4)
or 1048 (0.4)	and	750 (6)
or 786 (0.3)	and	1000 (8)
or any	and	1500 (10)

** Oxidant expressed as ozone.

Photochemical Oxidants:

Oxidants are not expected to increase mortality at the levels experienced today. However it is probable that the level indicated could inflict irreversible bronchial damage in more susceptible individuals. Because the atmospheric levels of photochemical oxidants are determined by the quantities of hydrocarbons and NO_x emitted into the air some hours earlier and the intensity and duration of sunlight is not possible to measure hazardous levels of oxidant and then take remedial action in time for it to be effective. For this reason, the four hour mean is given as an imminent and substantial endangerment level so that earliest measurements and predictions of meteorological conditions can be utilized to give the maximum time to prevent the occurrence of a severe air pollution episode. Even earlier predictions of peak levels for oxidants can be made with mathematical models for the chemical conversion of hydrocarbons and NO_x into oxidants. To accomodate this possibility a one-hour maximum is given based upon the peak anticipated to be associated with the two or four hour mean values.

Levels selected are based upon research demonstrating increased airway resistance at 0.6 ppm (1176 $\mu g/m^3$) O_3 and severe throat irritation and cough at 1.0 ppm (1960 $\mu g/m^3$) (Goldsmith and Nadel, Calif. State Dept. of P. H., Berkeley, 1966; Young et al., J. Appl. Physiol. 19:765).

Carbon Monoxide:

CO values representing imminent and substantial endangerment to human health are based initially on values determined to produce a COHb level of approximately 7%, a level similar to that self-inflicted by a moderate cigarette smoker. The one exception is the exposure value for one hour. In a single hour 125 ppm (143,750 $\mu g/m^3$) CO would raise COHb to approximately 4.5% but the value was established as maximum after consideration was given to the manner in which CO builds up and decreases. A one hour value of 125 ppm (143,750 $\mu g/m^3$) would almost certainly include a three hour mean exposure to at least 80 ppm (92,000 $\mu g/m^3$).

A COHb level of 7% was determined to exceed the maximum to which the significant portion of our population with myocardial illness should be exposed on the basis of research which demonstrated that 5% COHb was the threshold level for visual impairment, reduced psychomotor response, poorer time interval discrimination and that above 5% COHb there is increased lactate production in patients with coronary heart disease and increased coronary blood flow in patients with non-coronary heart disease. (Ayres et al., Arch. Env. H., 18:699; McFarland et al., Aviation Med. 15:381; Schulte, Arch, Env. H. 7:524; Beard and Wertheim, Am. J. Pub. H. 57:2012)

SO_2 and Particulates:

The effects of SO_2 air pollution independent of suspended particulate matter are very difficult to assess, particularly because, in a natural situation, it is impossible to have one present in the complete absence of the other and each seems to enhance the totality of effects produced. For this reason, a medial pollution level for the combination which probably would cause increased mortality was selected as the first imminent and substantial endangerment level. The selection of this value was based on evidence obtained in New York City which indicated that increased mortality was associated with air pollution episodes in which the 24 hour mean SO_2 concentration was between 0.5 and 0.6 ppm (1310 and 1572 $\mu g/m^3$) and the smoke shade values were above 5 coh units*. This first level was 0.4 ppm (1048 $\mu g/m^3$) SO_2 and 6 coh units (McCarroll and Bradley, Am. J. Pub. H. 56:1933, 1966; Glasser, Greenburg and Field, Arch. Env. H. 15:684, 1967). Then other deviations from these initial figures, likely to produce similar results were indicated. Finally maximum permissible levels for each pollutant regardless of the other were established.

The formula derived for a 24 hour mean is; any combination of SO_2 and particulate in $\mu g/m^3$ the product of which is 786×10^3 or higher, with the maximum SO_2 being 2620 $\mu g/m^3$ and the maximum for particulate being 1500 $\mu g/m^3$. 1 ppm

*Values are given in ppm and coh's because they are the units of the original studies.

AMBIENT LEVELS OF AIR POLLUTION REPRESENTING IMMINENT AND SUBSTANTIAL ENDANGERMENT TO HUMAN HEALTH

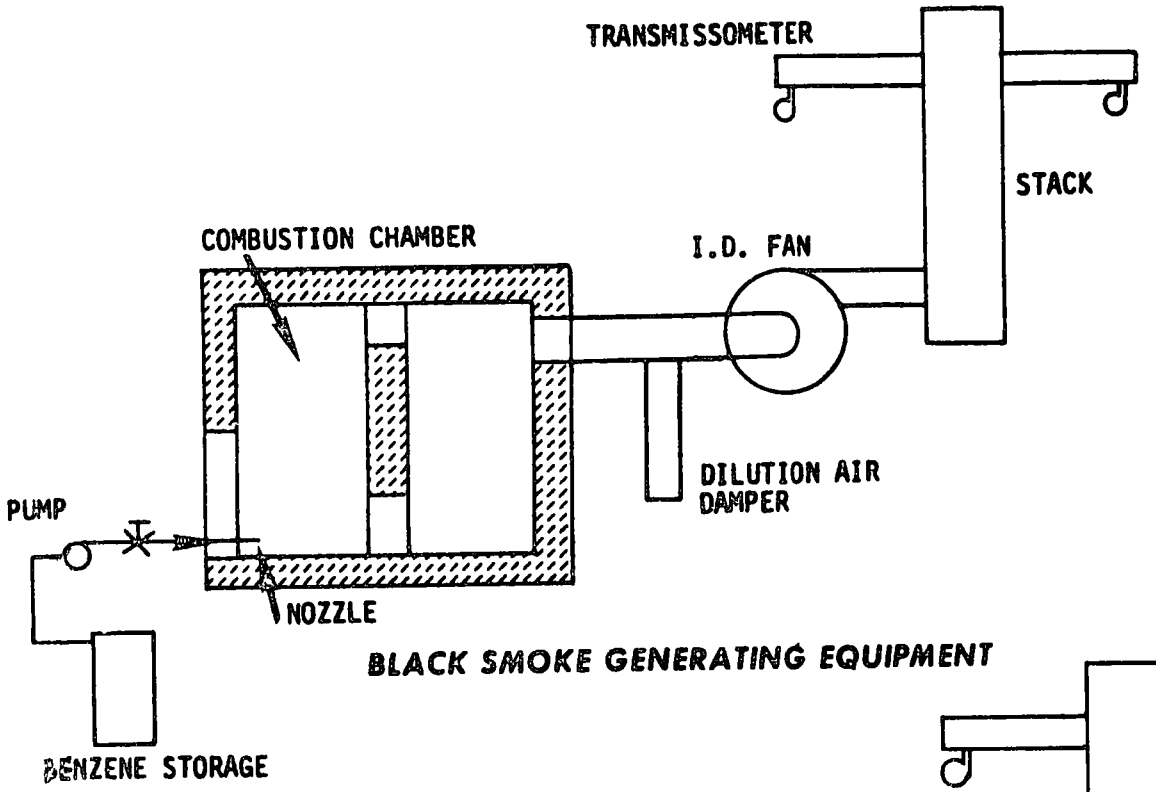
The Division of Health Effects Research has been requested to indicate for the National Air Pollution Control Administration levels of pollution in ambient air which represent imminent and substantial endangerment to human health. Such levels have been indicated for SO_2, particulates, CO and photochemical oxidants. In most instances, the levels chosen are based on the best information available even though it usually is inadequate. Therefore, it is not likely that a unanimity of opinion will exist even among the most knowledgeable of individuals. Consequently, it has been deemed desirable to state the bases upon which selections of levels are made so that they can be evaluated and in an effort to assure some consistency in the selection process.

The levels of air pollution suggested herein are ones not to be reached. Where an Air Quality Standard is exceeded and the prediction can reasonably be made that such elevated levels could become reality even for a short period of time, an emergency plan should be implemented to prevent these levels from occurring. The levels never to be reached are based on the following criteria: (a) The endangerment refers to the health of populations rather than individuals, even though it is recognized that a single death represents a substantial development to the person who dies and (b) The endangerment usually relates to levels of air pollution associated with increased mortality; however, in some instances it may relate to the occurrence of other less dramatic irreversible body damage or incapacitating reversible damage.

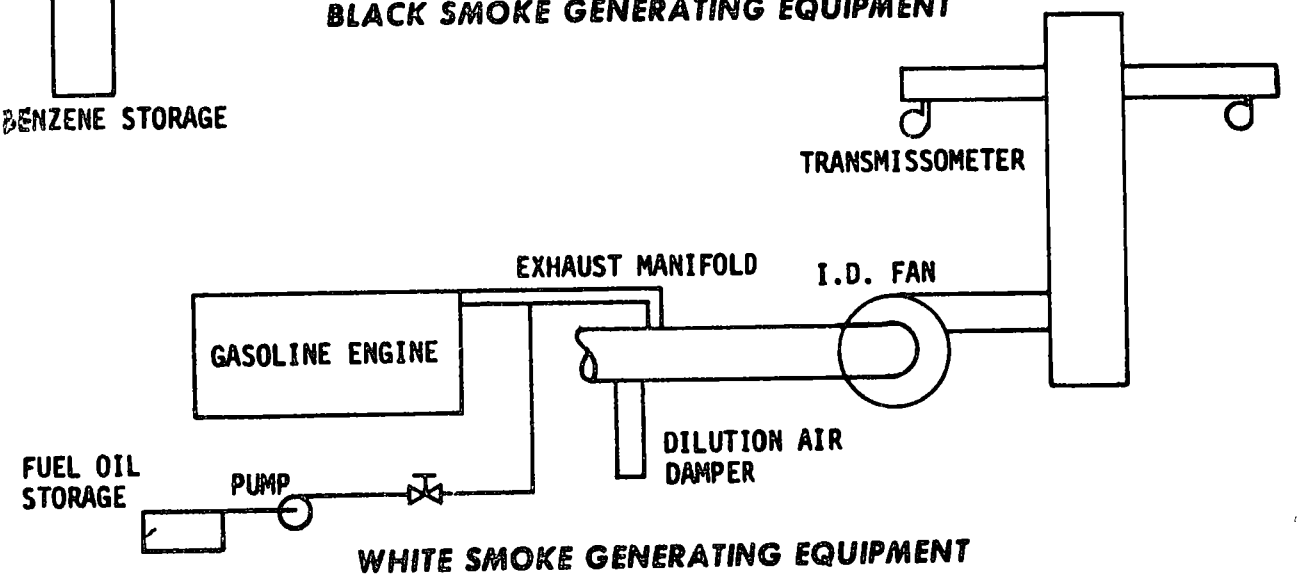
Based on these criteria, the following levels are given as representing imminent and substantial endangerment to human health.

IV

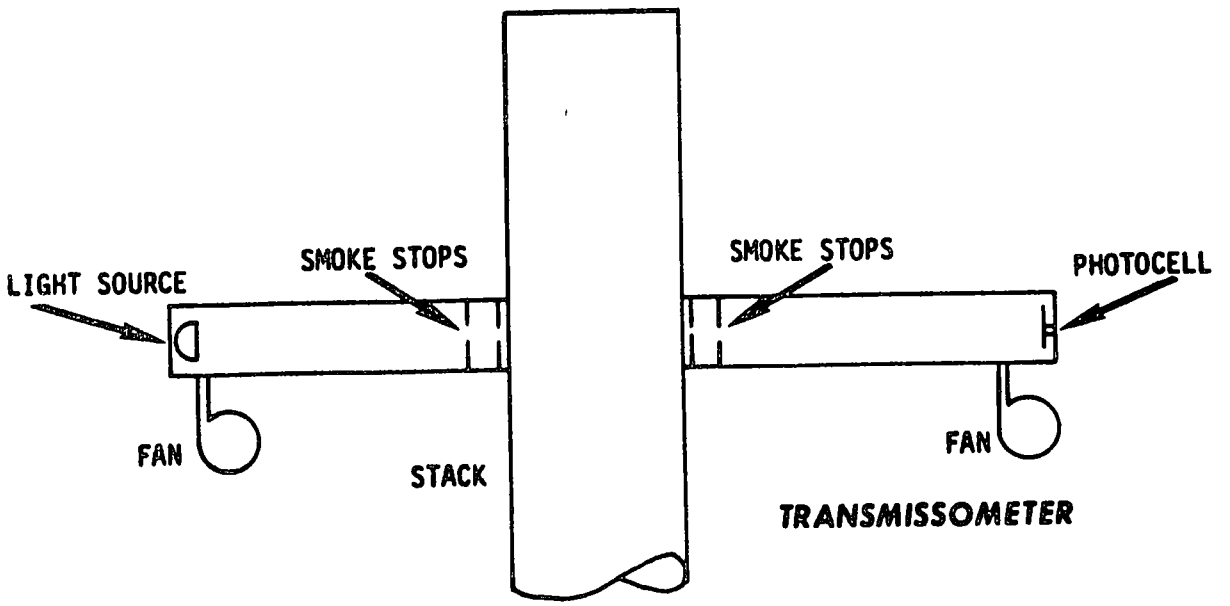
AMBIENT LEVELS OF AIR POLLUTION REPRESENTING IMMINENT AND SUBSTANTIAL ENDANGERMENT TO HUMAN HEALTH



BLACK SMOKE GENERATING EQUIPMENT



WHITE SMOKE GENERATING EQUIPMENT



TRANSMISSOMETER

Figure 3

NATIONAL CENTER FOR AIR POLLUTION CONTROL

SMOKE SCHOOL TRAINING FORM

1. Name of Observer _____
2. Affiliation _____
3. Date _____ Time _____
4. Wind Speed _____ Direction _____ Sky Condition _____
5. Observers Position _____
6. Corrected By _____

(Record Black of Gray Smoke in Ringelmann No. - 1/4 Unit Smallest Division)

(Record All Other Smoke in % Opacity - 5% Smallest Division)

RUN NO. 1 B

Reading No.	Observer Reading	Transmissometer Reading	+Deviation	-Deviation
1	2	3		20
2	2 1/2	3 1/2		20
3	3	4		20
4	1 3/4	2		5
5	1/2	1		10
6	1/4	1/2		5
7	1	1 1/2		10
8	2	2 1/2		10
9	3	3	--	--
10	3 1/4	3 1/2		5
11	4	4	--	--
12	4 1/4	5		5

Reading No.	Observer Reading	Transmissometer Reading	+Deviation	-Deviation
13	1/2	1		10
14	1 1/2	2		5
15	2 1/2	3		10
16	5	4 1/2	10	
17	2 1/2	2 1/2	--	--
18	1 1/2	1 1/2	--	--
19	2 1/4	2 1/4	--	--
20	3	3 1/2		10
21	2	2	--	--
22	1 1/2	1 1/2	--	--
23	3/4	1		5
24	1/2	1/2	--	--
25	5	5	--	--

RUN NO. 2 W

Reading No.	Observer Reading	Transmissometer Reading	+Deviation	-Deviation
1	20	10	10	
2	25	20	5	
3	30	30	--	--
4	35	40		5
5	40	50		10
6	50	60		10
7	60	70		10
8	75	80		5
9	85	90		5
10	80	80	--	--
11	60	65		5
12	55	55	--	--

Reading No.	Observer Reading	Transmissometer Reading	+Deviation	-Deviation
13	50	45	5	
14	30	35		5
15	20	25		5
16	15	15	--	--
17	5	5	--	--
18	25	25	--	--
19	35	35	--	--
20	45	45	--	--
21	55	55	--	--
22	65	65	--	--
23	70	75		5
24	85	85	--	--
25	65	70		5

		1B	2W
7.	Run Number		
8.	Number Correct	9	11
9.	Number of Plus Deviations	1	3
10.	Number of Minus Deviations	15	11
11.	Average Plus Deviations = $\frac{\text{Sum of Plus Deviations}}{\text{No. of Plus Deviations}}$	10	6.7
12.	Average Minus Deviations = $\frac{\text{Sum of Minus Deviations}}{\text{No. of Minus Deviations}}$	10	6.4
13.	Average Deviation = $\frac{(\text{Sum of Plus Deviations}) + (\text{Sum of Minus Deviations})}{\text{Total No. of Readings}}$	6.4	3.6
14.	No. of Readings 20% Deviation and Over	3	0

Figure 2

NATIONAL CENTER FOR AIR POLLUTION CONTROL

PLUME OBSERVATION RECORD FORM

Date _____ Source location _____

Observer _____ Address _____

Checked by _____

Start Time 9:00 AM

Observation point _____

Stack-distance from ___ Ht. ___

Wind-speed ___ Direct. ___

Sky condition _____

Type of installation _____

Fuel _____

Observ. Ended 10:00 AM

Smoke Density Tabulation

No. Units		X	Equiv. No. 1 Units
113	Units No. 0		0
	Units No. 1/2		
52	Units No. 1		52
	Units No. 1-1/2		
34	Units No. 2		68
	Units No. 2-1/2		
27	Units No. 3		81
	Units No. 3-1/2		
7	Units No. 4		28
	Units No. 4-1/2		
7	Units No. 5		35
140	Total Units		
	Total Equiv. No. 1 Units	=	264

Aver. Smoke Density =

$$\frac{\text{Equiv. No. 1 Units} \times 20\%}{\text{Total Units}}$$

= 22%

Sec. / Min.	0	15	30	45	Sec. / Min.	0	15	30	45
0	--	--	--	--	30	1	1	1	1
1	--	--	--	--	31	1	1	1	1
2	--	--	--	--	32	--	--	--	--
3	1	1	1	1	33	--	--	--	--
4	1	1	1	1	34	--	--	--	--
5	2	2	2	2	35	1	1	1	1
6	2	3	3	3	36	1	1	1	1
7	3	3	3	3	37	1	1	1	1
8	2	2	1	1	38	1	1	--	--
9	1	1	--	--	39	--	--	--	--
10	--	--	--	--	40	--	--	--	--
11	--	--	--	--	41	--	--	--	--
12	--	--	--	--	42	--	--	--	--
13	--	--	--	--	43	--	--	--	--
14	--	--	--	--	44	1	1	2	2
15	--	--	--	--	45	2	2	3	3
16	--	--	--	--	46	3	3	3	3
17	--	--	--	--	47	3	3	4	3
18	--	--	--	--	48	2	2	2	2
19	2	2	2	2	49	2	2	2	2
20	2	2	2	2	50	2	1	1	1
21	2	2	2	2	51	1	1	1	1
22	3	3	3	3	52	1	1	1	--
23	3	4	4	4	53	--	--	--	--
24	4	5	5	5	54	--	--	--	--
25	5	5	5	5	55	--	--	--	--
26	4	4	3	3	56	--	--	--	--
27	3	3	3	3	57	--	--	--	--
28	2	2	1	1	58	--	--	--	--
29	1	1	1	1	59	--	--	--	--

Remarks: _____

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3. Los Angeles, County of, Air Pollution Control District, APCD Rules and Regulations, Chapter 2, Schedule 6, Regulation 4, Prohibitions - Rule 50-p. 17.

4. People vs Plywood Manufacturers of California, 291 P. Ed. 587/1955/ California.

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of light behind the plume and evaluate the transmission of this light through the plume. This is nothing new to the trained inspector since he has practiced this method on the smoke generator.

5. Any hour means any consecutive sixty minute period.
6. Photographs should be taken before or after but not during visual determinations.
7. The same general rules apply to reading emissions from moving sources.

C. Plumes Containing Steam

Accuracy in reading is naturally effected when plumes contain a large amount of steam. Steam is not often considered to be an air contaminated, yet it does retard the transmission of light through the plume. It is noted, however, that the steam dissipates a short distance from the source. Opacity readings may be taken immediately beyond this point, if steam is to be discounted, although this gives the source a decided advantage. If the source still appears to be in violation, it may be necessary to wait for a hot, dry day, when the steam dissipates upon entering the atmosphere, to record a series of readings.

A device designed to install on the stack and heat the exhaust, so as to eliminate steam, and then measure the transmission of light through the plume has been discussed in Chemical Engineering[9]

D. Night Readings

To read at night it is necessary to either choose or place a source

clear view of the stack and background.

6. Readings should be made through the densest part of the plume and where the plume is no wider than the diameter of the stack.
7. An inspector should not study the plume as this will soon produce fatigue and cause erroueous readings, instead, he should glance at the plume and record his observation immediately, looking away from the plume between readings.

B. Recording Visible Emissions

The rules listed below are generally those used by the County of Los Angeles Air Pollution Control Distrist. These are just meant to be a guideline and may vary entirely with the wording of the law.

1. All information should be recorded in the appropriate space on the form (Figure 2).
2. Readings should be taken at 15 second intervals and entered on the form.
3. Any changes in the color of the plume should be noted under remarks on the form.
4. A Notice of Violation should not be issued unless the source exceeded the Ringelmann number or opacity rule for at least one minute in any one hour beyond the time allowed by the rule.

opacity or more for a set of 50 consecutive readings consistency must be shown in all his readings under all conditions of light. Additional training is necessary if an inspector does not meet all of the above standards.[8]

IV. FIELD EVALUATION OF PLUMES

A. After his training in a smoke school and qualifying on the smoke generator, the inspector is ready to apply what he has learned in the field. Although there are general rules or guidelines which should be followed as closely as possible, they cannot be held as hard and fast rules and often the inspector is called upon to use his good judgement. In general the rules are as follows:

1. Gray and black smoke is read in densities and recorded in Ringelmann numbers.
2. Any other colored emissions are read in opacities and record in percentages.
3. If possible, the sun should be at the observer's back during daylight hours.
4. The light source should be behind the plume during hours of darkness.
5. If possible, readings should be taken at right angles to the wind direction and from any distance necessary to obtain a

to number five Ringelmann and zero to one hundred percent equivalent opacity. The light to photo-cell path is approximately four feet in length, but only one foot of length is exposed to the smoke. The remaining three feet are continually flushed with ambient air to prevent smoke buildup. The apparatus is calibrated using several grades of neutral density filters.[7]

2. Conduct of School

Training on the smoke generator begins with the familiarization of the personnel with known densities of black and white smoke. Upon the sound of the bell, the instructor calls out the reading from the meter. After the familiarization period of about 1 hour duration, the personnel are ready for testing for record. Readings are taken at the sound of the bell and after each set of 25 readings, the transmissometer readings are entered and the deviations calculated (Figure 3). Approximately 16 sets of readings are taken for record in the course of a smoke school.

An inspector qualifies, by the County of Los Angeles Air Pollution Control Distric Standards, as an expert smoke reader when his average deviation (Figure 3) is not more than 10 percent and no reading varies 1 Ringelmann or 20%

READING VISIBLE EMISSION

I. INTRODUCTION

A. One of the first aids devised to measure emissions to the atmosphere was the Ringelmann Chart (Figure 1). This was developed by Maximilian Ringelmann in the late 1800's and has been a useful tool ever since, at least in controlling visible emissions, which constitutes the nuisance form of air pollution. Since the Ringelmann Chart is thoroughly covered in the Bureau of Mines Information Circular No. 8333 (May, 1967), it is printed below in part.

"INTRODUCTION

The Ringelmann Smoke Chart, giving shades of gray by which the density of columns of smoke rising from stacks may be compared, was developed by Professor Maximilian Ringelmann of Paris. Ringelmann, born in 1861, was professor of agricultural engineering at l'Institute National Agronomique and Director de la Station d'Essais de Machines in Paris in 1888, and held those positions for many years thereafter.

"The chart apparently was introduced into the United States by William Kent in an article published in Engineering News

READING VISIBLE EMISSION

BY

Jerome J. Rom

Engineering Section
Field Operations Activity
Abatement and Control Program
National Center for Air Pollution Control
Durham, N. C.

National Center for Air Pollution Control
Bureau of Disease Prevention and Environmental Control
Public Health Service
U.S. Department of Health, Education and Welfare

April, 1968

difference in test procedures, there is a necessary revision of the numerical value of the standards. Thus, if the revised test procedures are used beginning in 1973, the numerical value of the carbon monoxide standard will be changed from 39.0 grams per mile to 28.0, the hydrocarbon standard from 3.4 grams per mile to 3.0, and the nitrogen oxides standard from 3.0 to 3.1. These do not represent actual changes in the standards, but rather numerical revisions needed to properly relate the standards to the testing and measuring method used.

####

CHANGES IN TEST PROCEDURE

The test procedures now in effect were first put to use to test the 1972 model year vehicles for conformance with the standards. This exhaust emission test was designed to determine mass emissions of exhaust pollutants while simulating an average trip of 7.5 miles in an urban area from a cold start. The test consists of engine startup and vehicle operation on a chassis dynamometer through a specified driving schedule. A proportional part of the exhaust is collected in a bag, and the composite sample is analyzed for the various gases.

As a result of experience with the testing procedure, and based on more recent studies of vehicle operational experience, some changes in the procedure have been made to become effective with the 1975 model year testing program. Most of these are technical changes, but one bears mentioning.

Under current test procedures, which had originally been proposed to be applicable to 1975 and 76 vehicles, the entire test is composed of a single vehicle-run on a dynamometer that begins with the vehicle completely cold. Analysis of vehicle operation data shows that in addition to the usual early morning cold-start, vehicles make several hot-starts each day. A test procedure was developed that also includes a hot-start, (which presents special engineering problems to assure that emissions are controlled under these conditions) and that is weighted to reflect the emissions from a car over a twenty-four hour period (instead of solely during the morning commute-trip as in the present procedure). Analysis of results obtained show that, for purposes of protecting air quality in the most critical areas, the alternate test procedure will more accurately weight the cold-start operation of vehicles during the early morning hours than would the use of the current test procedure.

The new procedure will involve a dynamometer run that will consist of two tests--a "cold" start test begun after the vehicle has been shut off for 12 hours, followed by a "hot" start test, begun after the same engine has been turned off for ten minutes following the first cold test. The samples for each test will be collected in separate bags, the contents analyzed, and the results combined in a weighted manner so that the total result to be compared with the standard will consist of 43 per cent of the cold start emissions and 57 per cent of the hot start emissions.

ADDITIONAL PROPOSALS

In addition to the final regulations published, there also was published a notice of proposed rule-making that would make the changes in test procedures applicable beginning with the NO_x emission controls for the 1973 model year. These are the same changes that have been finalized for the 1975 model year. It may be noted that, because of the

The 1970 Amendments to the Clean Air Act require that emissions of carbon monoxide and hydrocarbons from 1975 and later model year cars be reduced by at least 90 per cent from the emissions allowed for the 1970 models. These new standards, promulgated today, will limit exhaust emissions of carbon monoxide to 3.4 grams per vehicle mile and of hydrocarbons to 0.41 grams per vehicle mile.

A point of possible confusion is that the 1975 standards initially proposed on February 26, 1971, were 4.7 grams of carbon monoxide and 0.46 grams of hydrocarbons per vehicle mile. These represented a 90 per cent reduction from the allowed emission levels in 1970. However, they were related to the testing method currently used. A different, more representative testing method will be used to check the 1975 cars. Therefore, it was necessary to make tests of the current method and the 1975 method to determine their equivalency in comparison to 1970 model year automobiles. These tests established that a car having the 1970 allowable emissions of 47 grams of carbon monoxide and 4.6 grams of hydrocarbons per vehicle mile in terms of the current test method, would have emission values of 34 grams and 4.1 grams, respectively, in terms of the method to be used in 1975. Thus, in establishing the final value of the 1975 standards, the latter emission values are the ones to which the 90 per cent reduction is applied.

1973 OXIDES OF NITROGEN STANDARD

Previous Federal motor vehicle emission standards have not included nitrogen oxides. The standard of 3.0 grams per mile, to be effective with the 1973 models, will be the first limitation of emissions of this contaminant from motor vehicles by the Federal government. By comparison, emissions from uncontrolled 1971 vehicles is approximately 4 grams per mile.

1976 OXIDES OF NITROGEN STANDARD

The 1970 Amendments to the Clean Air Act require that emissions of nitrogen oxides from 1976 and later model year cars be reduced by at least 90 per cent from the levels emitted by 1971 cars that did not have control systems for oxides of nitrogen.

A series of tests on such 1971 cars showed that nitrogen oxides emissions were 4.0 grams per vehicle mile. A 90 per cent reduction thus places the 1976 standard at 0.40 grams per vehicle mile.

NITROGEN OXIDES TESTING PROCEDURE

The testing procedure is similar to the one used for carbon monoxide and hydrocarbons except, of course, that different instruments are used to measure the level of nitrogen oxides in the exhaust gases. Some changes in the general procedure from that currently used have been introduced to begin with the 1975 model year. These are described below. It is further proposed that these test procedures be applied for in testing the 1973 emission standard.

BACKGROUND INFORMATION

ON

AUTO EMISSION STANDARDS

This statement contains background information on major features of the regulations relating to control of air pollution from motor vehicles, as published in the Federal Register on June 29, 1971.

Five major subject areas are involved:

1. Establishment of final exhaust emission standards for carbon monoxide and hydrocarbons to begin with the 1975 model year. As called for by the 1970 Clean Air Amendments signed by President Nixon on December 31, 1970, these require a 90 per cent reduction from the levels allowed by the standards in effect for the 1970 model year.

2. Establishment of a new exhaust emission standard for nitrogen oxides to begin with the 1973 model year. This is not specifically required by the Clean Air Act, but the Act does give EPA authority to set such a standard for any emission it believes causes or contributes to air pollution endangering public health or welfare.

3. The setting of a final exhaust emission standard for nitrogen oxides to begin with the 1976 model year. As called for by the 1970 Amendments, this requires a 90 per cent reduction from the emissions from 1971 model cars that had no nitrogen oxides control systems.

4. Establishment of a testing procedure for prototype vehicles to determine compliance with the nitrogen oxides emission standards.

5. Changes from the present test procedure to become effective with the 1975 model year testing program.

1975 CARBON MONOXIDE AND HYDROCARBON STANDARDS

The first Federal motor vehicle exhaust standards, issued under authority of the Clean Air Act Amendments of 1965, went into effect beginning with the 1968 model year. Limits were placed on emissions of carbon monoxide and hydrocarbons. For the 1970 model year, the exhaust standards were tightened. A new testing and sampling procedure, along with revised values of the standards to restate the levels in terms of the new testing procedure, went into effect for the 1972 models--now being tested for certification purposes.

that have already been set to begin with the 1975 model year. Interested persons wishing to submit comments on this proposal have 60 days to send four copies of such comments to the Administrator, Environmental Protection Agency, Attention: Office of Air Programs, Parklawn Building, 5600 Fishers Lane, Rockville, Maryland 20852.

####

expressed its concern in this regard by writing the requirements for the 1975 and 1976 standards into law."

Ruckelshaus stated that significant reductions in auto emissions from today's levels are essential to achieve the goal of clean air. The standards announced today provide for a 90% reduction in the levels of auto emissions, as required by the Clean Air Act.

The purpose of the National Air Quality Standards is to protect the public health and welfare. These air standards were announced by EPA last April 30. Achievement of these standards requires restrictions on auto exhaust because automobiles are the source of nearly two-thirds of the carbon monoxide, more than half of the hydrocarbons, and some two-fifths of the nitrogen oxides emissions into the air of the United States each year.

Adoption of the standards for 1975 and 1976 is called for under the Clean Air Amendments signed into law by President Nixon in December, 1970. The 1973 nitrogen oxides standard is not specifically required by the amendments, but the legislation gives EPA authority to set such a standard.

In addition to the regulations announced today, EPA administrator Ruckelshaus also promulgated proposed regulations to adopt, beginning with the 1973 model year, the test procedure changes

(more)

on emissions of nitrogen oxides from motor vehicles. By comparison, emissions from 1971 cars that are not equipped with nitrogen oxides control systems are 4.0 grams per vehicle mile.

-- A further reduction in the nitrogen oxides limit to 0.4 grams per vehicle mile beginning with the 1976 model year.

-- Changes in the present EPA testing procedure, beginning with the 1975 model year, which will more accurately reflect the driving experience of the motor vehicle population in major urban areas.

In announcing the revisions, Ruckelshaus said: "I realize these are stringent standards which will challenge the ingenuity of American industry. At public hearings May 6 and 7, the automotive industry indicated that achievement of the standards -- particularly those for oxides of nitrogen -- by the established deadlines would be extremely difficult. The costs resulting from implementation of these requirements will be substantial both to the industry and the consumer.

"But even though the achievement of these standards poses major engineering difficulties and will be costly and may, in the case of NO_x emissions, require technological breakthroughs beyond the present state of the art, the need to protect the Nation's health demands that effective control of automobile emissions must be placed high on our list of National environmental priorities. The Congress clearly

(more)

ENVIRONMENTAL NEWS

ENVIRONMENTAL PROTECTION AGENCY, WASHINGTON, D C. 2046

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FOR RELEASE A.M.'s, WEDNESDAY, JUNE 30, 1971

REGULATIONS TO CONTROL AUTO POLLUTION ANNOUNCED

Administrator William D. Ruckelshaus of the Environmental Protection Agency today announced a series of final regulations by which 1975 and 1976 model cars will be judged for their compliance with the Clean Air Act of 1970.

Major provisions include:

-- Standards for carbon monoxide and hydrocarbons beginning with the 1975 model year. These would limit emissions to 3.4 grams of carbon monoxide and 0.41 grams of hydrocarbons per vehicle mile. By comparison, allowable emissions from 1970 automobiles were 34.0 grams of carbon monoxide and 4.1 grams of hydrocarbons per vehicle mile. The 90% reduction in permissible levels is called for in the Clean Air Act.

-- A new exhaust emission standard for nitrogen oxides, which will limit emissions to 3.0 grams per vehicle mile beginning with the 1973 model year. This will be the first Federal limit placed

(more)

Function	Year							
	Present							
	State Agency	Local agencies	State agency	Local agencies	State agency	Local agencies	State agency	Local agencies
Enforcement activities								
Operating fund								
Capital funds								
Contract funds								
Implementation services								
Operating fund								
Capital fund								
Contract funds								
Technical services								
Operating fund								
Capital funds								
Contract funds								
Management services								
Operating funds								
Capital funds								
Contract funds								
Total operating funds								
Total capital funds								
Total contract funds								
Total funds								

[FR Doc 71-4648 Filed 4-6-71,8 45 am]

APPENDIX J—REQUIRED HYDROCARBON EMISSION CONTROL AS A FUNCTION OF OXIDANT CONCENTRATION

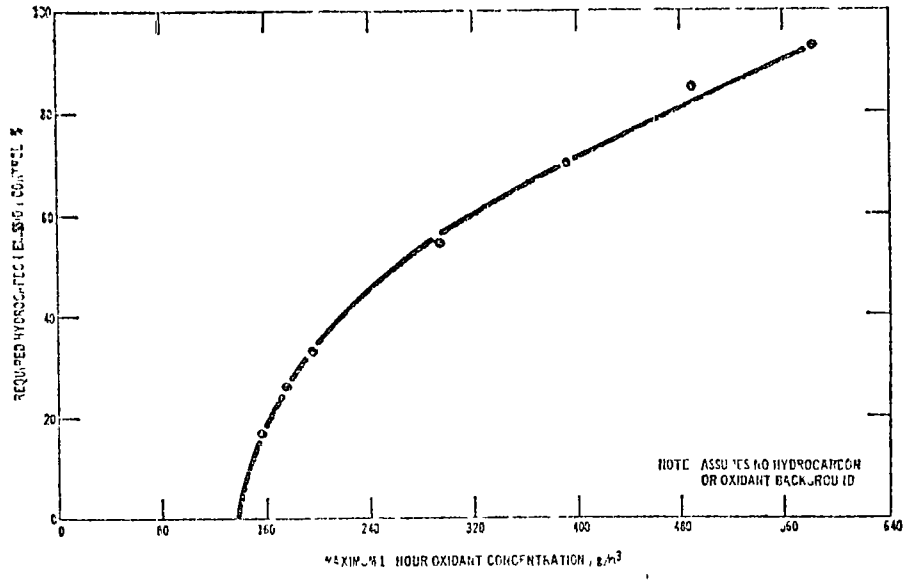

Figure 1. Required hydrocarbon emission control as a function of oxidant concentration

REFERENCE: AIR QUALITY CRITERIA FOR NITROGEN OXIDES. ENVIRONMENTAL PROTECTION AGENCY, AIR POLLUTION CONTROL OFFICE, WASHINGTON, D.C., JANUARY 1971

APPENDIX K—CONTROL AGENCY FUNCTIONS

Man-year estimates by function for State of _____ portion of _____ AQCR

Function	Year							
	Present							
	State agency	Local agencies	State agency	Local agencies	State agency	Local agencies	State agency	Local agencies
Enforcement service (Subtotal)								
Schools/industries								
Complaints and field patrol								
Planning services (Subtotal)								
Point system								
Emission inventories								
Source census								
Review new legislation, etc.								
Technical services (Subtotal)								
Operation of monitoring network								
Special studies								
Instrument calibration and maintenance								
Laboratory operations								
Data processing								
Management services (Subtotal)								
Policy, PR, Strategies, etc.								
Staff training								
Administrative and clerical support								
Totals								

Fund estimates for State of _____ portion of _____ AQCR
(Funds in $1,000)

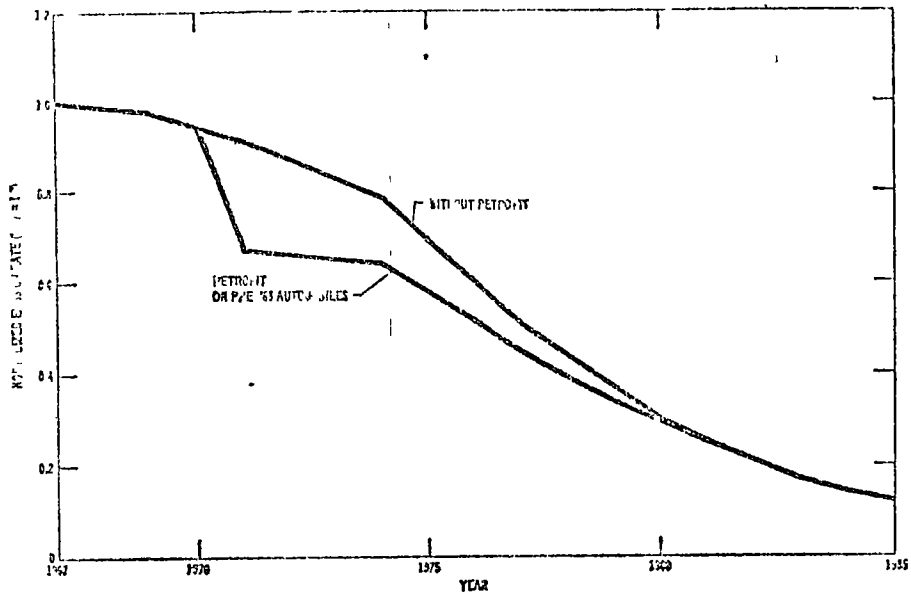

Figure 2 Projected national urban normalized carbon monoxide emissions.

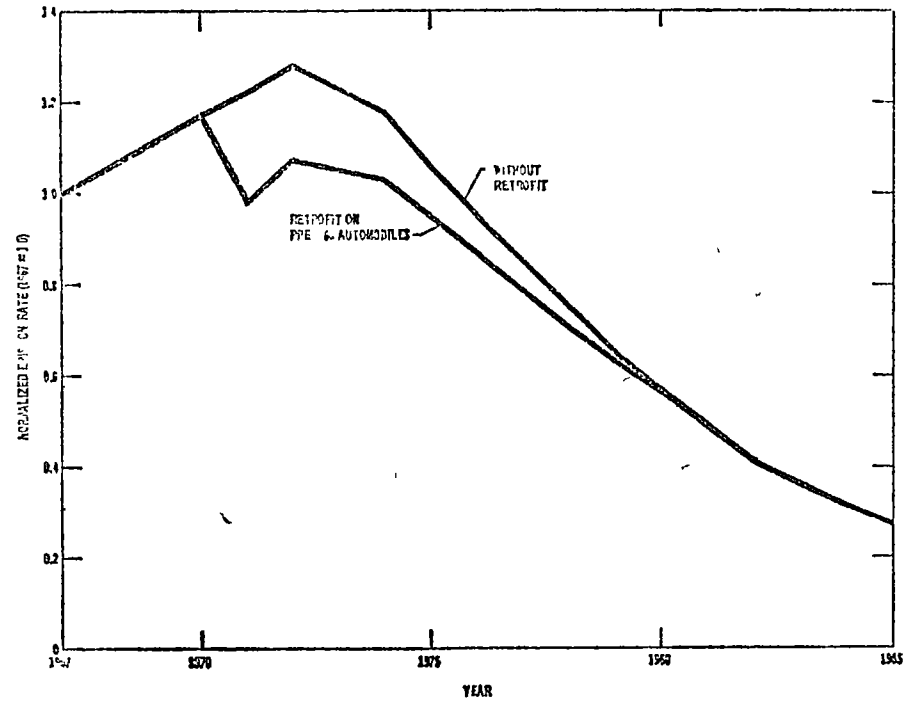

Figure 3 Projected national urban normalized nitrogen oxides emissions

APPENDIX H—AIR QUALITY DATA SUMMARY

Pollutant	Sampling site location[1]	Sampling interval (months)	Start date	End date	Number of samples	Maximum 1 hour	Maximum 3 hours (6 p.m.)	Maximum 8 hours	Maximum 24 hours	Annual arithmetic mean	Std dev	Annual geo mean	Geo std dev
Particulate matter	X	X	X	X	X				X	X	X	X	X
Sulfur oxides (SO_2)	X	X	X	X	X				X	X	X	X	X
Hydrocarbons	X	X	X	X	X			X	X	X	X	X	X
Photochemical oxidants	X	X	X	X	X	X				X	X	X	X
Carbon monoxide	X	X	X	X	X	X		X		X	X	X	X
Hydrocarbons	X	X	X	X	X		X			X	X	X	X

X=Data or information required.
[1] UTM Grid coordinate or equivalent.

APPENDIX I—PROJECTED MOTOR VEHICLE EMISSIONS

The assumptions listed below were made in calculating the projected national urban emission from motor vehicles as shown in Figures 1-3.

a. Emission factors are based on the new Federal test procedure (1) which has an average route speed of 18 miles per hour.

b. Emission control devices are assumed to just meet present and proposed standards when new but deteriorate with age. Deterioration factors are adopted from data given in Reference 2.

c. Increases in urban vehicle-miles of travel for automobiles from Reference 3.

d. Distribution of automobiles by age from Reference 4.

e. Relative miles of travel for automobiles (i.e. new cars are driven more than older ones) from Reference 5.

f. Vehicle-mile projections for trucks from Reference 6.

g. Efficiency of retrofit devices is based on data reported by General Motors Corp., Reference 7; Ford Motor Co., Reference 8; and Chrysler Corp. Reference 9 for the retrofits kits supplied by each manufacturer. The Ford and Chrysler figures also include the effect of a tuneup. The following reduction figures are considered representative of emission reduction capabilities of retrofit devices:

HC—50%
CO—37%
NO_x—40%

Retrofit was considered only for pre-1968 automobiles. These devices were assumed to deteriorate in the same way as factory-installed control devices.

Figures 1-3 can be used to approximate air quality levels resulting from the Federal Motor Vehicle Control Program and retrofitting of all pre-1968 automobiles. The following equation calculates the expected air quality concentration for any given year:

$$AQ_1 = AQ_0\left[\frac{(E_1)}{E_0}\Gamma_0 + (1-\Gamma_0)(GF)\right]$$

where

Subscripts 0 and 1 denote the base year and future year of interest, respectively.

AQ = Air quality (measured or estimated) in region.

E = Normalized emissions from Figures 1-3.

Γ = Fraction of motor vehicle emissions to total emissions of each pollutant in region.

GF = Growth factor for emission increases from stationary sources.

This equation can be applied directly for carbon monoxide and also for nitrogen dioxide (if all nitrogen oxides emissions are assumed to be measured as nitrogen dioxide). Use of this equation to calculate future photochemical oxidant levels requires an assumption as to how photochemical oxidant varies with hydrocarbon levels. If it is assumed that any increase or decrease in hydrocarbon emissions will result in a proportional increase or decrease in photochemical oxidant, then the equation can be used relatively easily. The emission data (E, Γ, and GF) should be for hydrocarbons while the base year air quality should be measured photochemical oxidant concentrations. From the estimated photochemical oxidant air quality, the percent hydrocarbon reduction necessary to achieve the national ambient air quality standard is obtained from Appendix J.

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9 Used Car Control System Hot Cycle Emissions Before and After Installation," Chrysler Corp.

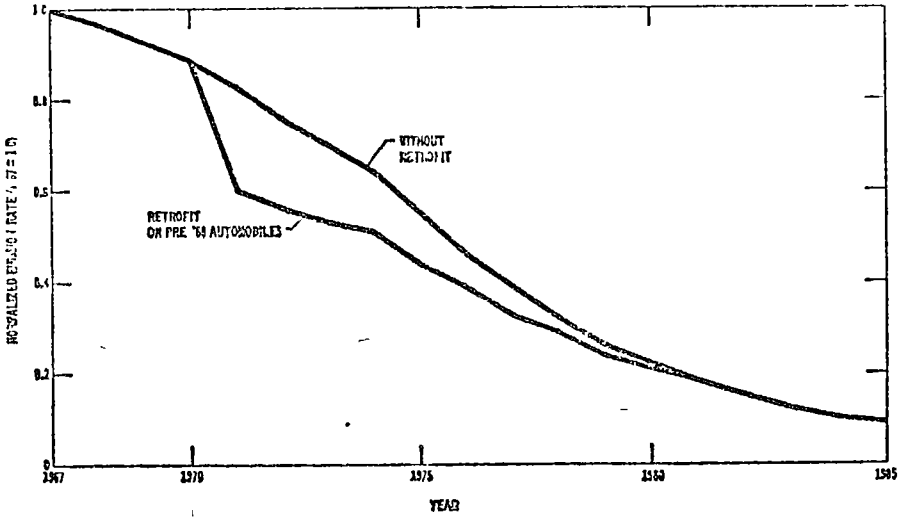

Figure 1 Projected national urban normalized hydrocarbon emissions.

B Commercial and Institutional Fuel
1 Anthracite Coal (plus type and size of unit)—tons/year
2 Bituminous Coal (plus type and size of unit)—tons/year
3 Distillate Oil (plus type and size of unit)—10 gal/year
4 Residual Oil (plus type and size of unit)—10 gal/year
5 Natural Gas (plus type and size of unit)—10 cu ft/year
6 Wood—tons/year
7 Other—please specify
C Industrial Fuel
1 Anthracite Coal (plus type and size of unit)—ton/year
2 Bituminous Coal (plus type and size of unit)—tons/year
3 Coke (plus type and size of unit)—tons/year
4 Distillate Oil (plus type and size of unit)—10 gal/year
5 Residual Oil (plus type and size of unit)—10 gal/year
6 Natural Gas (plus type and size of unit)—10 cu ft/year
7 Wood—tons/year
8 Other—please specify
II Process Losses (hydrocarbons only)
A Surface coating operations, dry cleaning, degreasing operations etc unless considered as point sources—appropriate basis for emission estimate
III Solid Waste Disposal
On site incineration (plus type of unit)—ton/year
1 Open burning—tons/year
Other—specify
IV Transportation
a Gasoline-powered motor vehicles—appropriate basis for emission estimate including hydrocarbon evaporative losses
b Diesel-powered motor vehicles—appropriate basis for emission estimate
c Off-highway fuel usage—10³ gal/year
d Aircraft—number of flights per year per type of aircraft
e Railroad—10³ gal diesel oil/year
f Vessel—10³ gal oil/year, tons of coal/year or tons of wood/year (includes sulfur and ash content of fuel if applicable)
G Gasoline handling evaporative losses—appropriate basis for hydrocarbon emission estimate from filling tank trucks service station tanks and automobile tanks
H Other—specify
V Miscellaneous
A Forest fires—appropriate basis for emission estimate
B Structural fires—appropriate basis for emission estimate
C Coal refuse burning—appropriate basis for emission estimate
D Agricultural burning—appropriate basis for emission estimate
L Other—specify

APPENDIX G—(POLLUTANT) EMISSIONS INVENTORY SUMMARY TONS/YR (REGIONS WHERE EMISSION LIMITATIONS ARE NOT DEVELOPED)

AIR QUALITY CONTROL REGION

DATA REPRESENTATIVE OF CALENDAR YEAR

Source category	State A			State B		
	County 1		County N	State region total	Ditto	Regional total
	a	b	a	a	Ditto	a
I Fuel combustion—Stationary sources						
A Area sources [c]						
B Point sources						
C Total						
II Process Losses						
A Area sources [c]						
B Point sources						
1 Chemical process industries						
2 Food and agricultural industries						
3 Metallurgical industries						
4 Mineral products industries						
5 Petroleum refining and petrochemical operations						
6 Wood processing						
7 Polymers and resins						
C Total						
III Solid waste disposal						
A Area sources [c]						
B Point sources						
C Total						
IV Transportation (Area sources only) [c]						
V Miscellaneous (Area sources only) [c]						
VI Grand Totals						
A Area sources						
B Point sources						
C Total						

[1] Indicate only if interstate region
[a] Enter emissions
[b] If no available does not need to be submitted for Priority III regions
[c] For hydrocarbons only would include emissions for surface coating operations, dry cleaning, degreasing operation, etc unless considered point sources
* For hydrocarbons would include vehicle evaporative losses and losses from filling tank trucks, service station tanks and automobile tanks

APPENDIX D—(POLLUTANT) EMISSIONS INVENTORY SUMMARY, TONS/YR (EXAMPLE REGIONS AND WHERE EMISSION LIMITATIONS ARE DEVELOPED)—Continued

Source category	State A						State B [1]					
	County 1				County N		State region total		Ditto		Region [2] total	
	II	III	II	III	II	III	II	III	Ditto		II	III
IV Transportation (area sources only)												
A Motor vehicles												
1 Gasoline powered [3]												
2 Diesel powered												
B Other (by fuel used)												
C Aircraft												
D Railroads												
E Ves												
F Gasoline handling evaporative losses [4]												
G Other (specify)												
H Total transportation												
V Miscellaneous (area sources only)												
A Forest fires												
B Structural fire												
C Control burning												
D Agricultural burning												
E Other (specify)												
F Total miscellaneous												
VI Grand total												
A Area sources												
B Point sources												
C Total												

[1] Include only if inter-state action

[2] Existing regions

[3] Emissions associated with control regulations or implementation plans. Must be submitted in example regions and where evaporative losses will be included.

[4] For example regions only would include emissions for surface coating operations, dry cleaning, degreasing operations etc. not considered point source

[5] For hydrocarbons would include vehicle evaporative losses

[6] For hydrocarbons would include losses from filling tank trucks, service station tanks, and automobile tanks.

APPENDIX E—POINT SOURCE DATA

(Does not need to be submitted with implementation plan but must be available for inspection by the Administrator, EPA)

I General source information
A Establishment name and address
B Person to contact on air pollution matters and telephone number
C Average number of employees
D Standard Industrial Classification (SIC) Codes
E Land area at plant location if available
F Operating Schedule
1 Percent of annual production by season
2 Days of week normally in operation
3 Shifts or hours of day normally in operation
4 Number of days per year in operation
G Year in which data are recorded
H Future activities if available (e.g., addition of new or expansion of existing facilities, changes in production rate, installation of control equipment, phasing out of equipment, fuel changes etc.)
I Map or general layout of large complex plant showing locations of various facilities if available
II Fuel Combustion
A Number of boilers
B Type of fuel burning equipment for each boiler
C Rated and/or maximum capacity of each boiler, 10^6 Btu/hr
D Type of fuel burned, quantities and characteristics
1 Type of each fuel used and place of origin
2 Maximum and average quantity per hour
3 Quantity per year
4 Sulfur content (as received), percent
5 Ash content (as received), percent
6 Heat content (as received), Btu/unit of fuel used
7 Type of future usage, if available
E Percent used for space heating and process heat
F Air pollution control equipment (existing and proposed)
1 Type
2 Collection efficiency (design and actual), percent
G Stack data
1 List stacks by boilers served
2 Location of stacks by grid coordinates (Universal Transverse Mercator, UTM, or equivalent) [1]
3 Stack height, ft
4 Stack diameter (inside, top), ft
5 Exit gas temperature °F
6 Exit gas velocity, fps
H Emission data
1 Based on emission factors
2 Estimate of emissions by the source
3 Results of any stack tests conducted
III Manufacturing Activities (Process Losses)
A Process name or description of each product
B Flow diagram of each process indicating equipment capacities
C Quantity of raw materials used and handled for each product, maximum quantity, per hour and average quantity per year
D Quantity of each product manufactured maximum quantity per hour, and average quantity per year
E Description of annual, seasonal, monthly, weekly, and daily operating cycle including downtime for maintenance and repairs
F Air pollution control equipment in use (existing and proposed)
1 Type
2 Collection efficiency (design and actual), percent
G Stack data
1 List of stacks by equipment served
2 Location of stacks by grid location (UTM or equivalent) [1]

[1] Required only when diffusion modeling is utilized

3 Stack height, ft
4 Stack diameter (inside, top), ft
5 Exit gas temperature, °F
6 Exit gas velocity, fps
H Emission data
1 Based on emission factors
2 Estimate of emissions by the source
3 Results of any stack tests conducted
IV Solid Waste Disposal
A Amount and description of solid waste generated quantity per year
B Percent of total that is combustible
C Method of disposal (on-site or off-site)
D Description of on-site disposal method, if applicable (incineration, open burning, landfill etc.) including maximum quantities disposed per hour and average quantities disposed per year and actual operating schedule
1 Location of the source by a grid system (UTM or equivalent) [1]
2 If method of disposal is by an incinerator include the following information
a Auxiliary fuel used
b Air pollution control equipment (existing and proposed)
(1) Type
(2) Collection efficiency (actual and design), percent
c Stack data
(1) List stacks by furnaces served
(2) Stack height, ft
(3) Stack diameter (inside, top), ft
(4) Exit gas temperature, °F
(5) Exit gas velocity, fps
(6) Exit gas moisture content, percent if available
3 Emission data
a Based on emission factors
b Estimate of emissions by the source
c Results of any stack tests conducted

APPENDIX I—AREA SOURCE DATA [1]

(Does not need to be submitted with implementation plan but must be available for inspection by the Administrator, EPA)

Grid Coordinate (lower left-hand corner) ——— UTM or equivalent [2]

Average Stack Height of Source ———— [3]

I Fuel Combustion—Stationary Sources (includes sulfur and ash content of fuels, if applicable)

A Residential Fuel

1 Anthracite Coal (plus type and size of unit) [4]—tons/year

2 Bituminous Coal (plus type and size of unit)—tons/year

3 Distillate Oil (plus type and size of unit)—10^3 gal/year

4 Residual Oil (plus type and size of unit)—10^3 gal/year

5 Natural Gas (plus type and size of unit)—10^6 cu ft/year

6 Wood—tons/year

7 Other—please specify

[1] Emissions data for all source categories and subcategories listed below would be summarized in the implementation plans as is in Appendix D or G

[2] Data would be required on a grid basis only when diffusion modeling is utilized. For proportional model technique data must be available only on a county basis

[3] Required only when diffusion modeling is utilized

[4] Average type and size for each category. This is used as the basis for selection of average emission factor

APPENDIX D—(POLLUTANT) EMISSIONS INVENTORY SUMMARY TONS/AR (EXAMPLE REGIONS AND WHERE EMISSION LIMITATIONS ARE DEVELOPED)

AIR QUALITY CONTROL REGION

DATA REPRESENTATIVE OF CALENDAR YEAR

Source category	State A						State B [1]				
	County 1		-	--	County N		State region total		Ditto	Region [1] total	
	II	III	II	III	II	III	II	III	Ditto	II	III
I Fuel combustion—stationary sources											
A Residential fuel											
1 Anthracite coal											
a Area sources											
b Point sources											
2 Bituminous coal											
a Area sources											
b Point sources											
3 Distillate oil											
a Area sources											
b Point sources											
4 Residual oil											
a Area sources											
b Point sources											
5 Natural gas											
a Area sources											
b Point sources											
6 Wood											
a Area sources											
b Point sources											
7 Other (specify)											
a Area sources											
b Point sources											
8 Total											
B Commercial and institutional fuel											
1 Anthracite coal											
a Area sources											
b Point sources											
2 Bituminous coal											
a Area sources											
b Point sources											
3 Distillate oil											
a Area sources											
b Point sources											
4 Residual oil											
a Area sources											
b Point sources											
5 Natural Gas											
a Area sources											
b Point sources											
6 Wood											
a Area sources											
b Point sources											
7 Other (specify)											
a Area sources											
b Point sources											
8 Total											
C Industrial fuel											
1 Anthracite coal											
a Area sources											
b Point sources											
2 Bituminous coal											
a Area sources											
b Point sources											
3 Coke											
a Area sources											
b Point sources											
4 Distillate oil											
a Area sources											
b Point sources											
5 Residual oil											
a Area sources											
b Point sources											

APPENDIX D—(POLLUTANT) EMISSIONS INVENTORY SUMMARY TONS/AR (EXAMPLE REGIONS AND WHERE EMISSION LIMITATIONS ARE DEVELOPED)—Continued

Source category	State A						State B [1]				
	County 1				County N		State region total		Ditto	Region [1] total	
	II	III	II	III	II	III	II	III	Ditto	II	III
I Fuel combustion—stationary source—Continued											
C Industrial fuel—Continued											
6 Natural gas											
a Area sources											
b Point sources											
7 Process gas											
a Area sources											
b Point sources											
8 Other (specify)											
a Area sources											
b Point sources											
9 Total											
D Steam electric power plant fuel (point sources only)											
1 Anthracite coal											
2 Bituminous coal											
3 Coke											
4 Distillate oil											
5 Residual oil											
6 Natural gas											
7 Process gas											
8 Other (specify)											
9 Total											
E Total stationary fuel combustion											
II Process losses											
A Area sources [2]											
B Point sources											
1 Chemical process industries											
2 Food and agricultural industries											
3 Metallurgical industries											
4 Mineral products industries											
5 Petroleum refining and petrochemical operations											
6 Wood processing											
7 Petroleum storage											
C Total process losses											
III Solid waste disposal											
A Incineration											
1 Other											
a Area sources											
b Point sources											
2 Municipal											
a Area sources											
b Point sources											
B Open burning											
1 On site											
a Area sources											
b Point sources											
2 Dumps											
a Area sources											
b Point sources											
C Other (specify)											
1 Area sources											
2 Point sources											
D Total solid waste disposal											

PROPOSED RULE MAKING

grant to this rule shall provide proper installation, maintenance, calibration, and operating records and shall operate and use control devices, as specified in the authority to construct or the permit to operate or as specified by the Director, for the appropriate times, pressures, rates of flow, or other operating conditions necessary to determine the degree and effectiveness of air pollution control.

5.6.8 Any person using organic solvents or any materials containing organic solvents shall supply the Director, upon request and in the manner and form prescribed by him, written evidence of the chemical composition, physical properties, and amount consumed for each organic solvent used.

5.6.9 The provisions of this rule shall not apply to:

(a) The manufacture of organic solvents, or the transportation or storage of organic solvents or materials containing organic solvents.

(b) The use of equipment for which other requirements are specified by 5.1, 5.2, 5.3 or which are exempt from air pollution control requirements by said rules.

(c) The spraying or other employment of insecticides, pesticides, or herbicides.

(d) The employment, operation, evaporation or drying of saturated halogenated hydrocarbons, or perchloroethylene.

5.6.10 For the purposes of this rule, organic solvents include diluents and thinners and are defined as organic materials which are liquids at standard conditions and which are used as dissolvers, viscosity reducers or cleaning agents.

5.6.11 For the purposes of this rule, a photochemically reactive solvent is any solvent with an aggregate of more than 20 percent of its total volume composed of the chemical compounds classified below or which exceeds any of the following individual percentage composition limitations, referred to the total volume of solvent:

(a) A combination of hydrocarbons, alcohols, aldehydes, esters, ethers or ketones having an olefinic or cyclo-olefinic type of unsaturation: 5 percent.

(b) A combination of aromatic compounds with either or more carbon atoms to the molecule except ethylbenzene: 8 percent.

(c) A combination of ethylbenzene, ketones having branched hydrocarbon structures, trichloroethylene or toluene: 20 percent.

Whenever any organic solvent or any constituent of an organic solvent may be classified from its chemical structure into more than one of the above groups of organic compounds, it shall be considered as a member of the most reactive chemical group, that is, that group having the least allowable percent of the total volume of solvents.

5.6.12 For the purposes of this rule organic materials are defined as chemical compounds of carbon excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides, metallic carbonates, and ammonium carbonate.

5.7 Architectural Coatings.

5.7.1 A person shall not sell or offer for sale for use in containers of 1-quart capacity or larger, any architectural coating containing photochemically reactive solvent, as defined in 5.6.11.

5.7.2 A person shall not employ, apply, evaporate, or dry any architectural coating, purchased in containers of 1-quart capacity or larger containing photochemically reactive solvent as defined, in 5.6.11.

5.7.3 A person shall not thin or dilute any architectural coating with a photochemically reactive solvent, as defined in 5.6.11.

5.7.4 For the purposes of this rule an architectural coating is defined as a coating used for residential or commercial buildings and their appurtenances, or industrial buildings.

5.8 Disposal and Evaporation of Solvents.

A person shall not during any one day dispose of a total of more than 1½ gallons of any photochemically reactive solvent, as defined in 5.6.11, or of any material containing more than 1½ gallons of any such photochemically reactive solvent by any means which will permit the evaporation of such solvent into the atmosphere.

NOTE: The various rules on hydrocarbon emission control cover the principal stationary source of hydrocarbon emissions. The type of rules needed in a particular region will depend on the nature of source distribution.

VI—CONTROL OF CARBON MONOXIDE EMISSIONS

6.1 Process Equipment.

No person shall emit the carbon monoxide gases generated during the operation of a gray iron cupola, blast furnace, or basic oxygen steel furnace unless they are burned at 1,300° F. for 0.3 second or greater in a direct flame afterburner or equivalent device equipped with an indicating pyrometer which is positioned in the working area at the operator's eye level.

6.2 No person shall emit carbon monoxide waste gas stream from any catalyst regeneration of a petroleum cracking system, petroleum fluid coker, or other petroleum process into the atmosphere unless the waste gas stream is burned at 1,300° F. for 0.3 seconds or greater in a direct-flame afterburner or boiler equipped with an indicating pyrometer which is positioned in the working area at the operator's eye level.

NOTE: Carbon monoxide emitted from open burning and incineration is controlled by other regulations.

VII—CONTROL OF NITROGEN OXIDES EMISSIONS

7.1 Combustion Sources.

7.1.1 No person shall cause or permit emissions of nitrogen oxides from an oil or gas-fired boiler with a capacity of 250 million B.t.u./hr. or more and completed before the effective date of this regulation in excess of 0.30 pounds per million B.t.u. of heat input per hour.

7.1.2 No person shall cause or permit emissions of nitrogen oxides from a coal-fired boiler with a capacity of 250 million B.t.u. per hour or more in excess of 0.9 pounds per million B.t.u. of heat input per hour.

NOTE: The proposed requirement for oil and gas-fired plants is about equivalent to 200 p.p.m. by volume at 3 percent oxygen. The requirement for coal-fired plants is about equivalent to 500 p.p.m. by volume. These levels are expected to be achieved by design and operation changes in firing boilers.

7.2 Nitric Acid Manufacture.

No person shall cause or permit the emission of nitrogen oxides from nitric acid manufacturing plants in excess of 5.8 pounds per ton of acid produced.

APPENDIX C—MAJOR POLLUTANT SOURCES

CHEMICAL PROCESS INDUSTRIES

Adipic acid
Ammonia
Ammonium nitrate
Carbon black [1]
Charcoal [1]
Chlorine
Detergent and soap [1]
Explosives (DNT and nitrocellulose) [1]
Hydrofluoric acid [1]
Nitric acid
Paint and varnish manufacturing [1]
Phosphoric acid [1]
Phthalic anhydride
Plastic manufacturing [1]
Printing ink manufacturing [1]
Sodium carbonate [1]
Sulfuric acid
Synthetic fiber
Synthetic rubber
Terephthalic acid

FOOD AND AGRICULTURAL INDUSTRIES

Alfalfa dehydrating [1]
Coffee roasting [1]
Cotton ginning [1]
Feed grain [1]
Fermentation processes
Fertilizers [1]
Fish meal processing
Meat smoke house [1]
Starch manufacturing [1]
Sugar cane processing [1]

METALLURGICAL INDUSTRIES

Ferrous metals industries
Aluminum ore reduction [1]
Copper smelters [1]
Ferroalloy production [1]
Iron and steel mills [1]
Lead smelters [1]
Metallurgical coke manufacturing [1]
Zinc [1]
Secondary metals industries
Aluminum operations [1]
Brass and bronze smelting [1]
Ferro alloys [1]
Gray iron foundries [1]
Lead smelting [1]
Magnesium smelting [1]
Steel foundries [1]
Zinc processes [1]

MINERAL PRODUCTS INDUSTRIES

Asphalt roofing [1]
Asphaltic concrete batching [1]
Brick and related clay refractories [1]
Calcium carbide [1]
Castable refractories [1]
Cement [1]
Ceramic and clay processes [1]
Clay and fly ash sintering [1]
Coal cleaning [1]
Concrete batching [1]
Fiberglass manufacturing [1]
Frit manufacturing [1]
Glass manufacturing [1]
Gypsum manufacturing [1]
Lime manufacturing [1]
Mineral wool manufacturing [1]
Paperboard manufacturing [1]
Perlite manufacturing [1]
Phosphate rock preparation [1]
Rock, gravel and sand quarrying and processing [1]

PETROLEUM REFINING AND PETROCHEMICAL OPERATIONS [1]

WOOD PROCESSING [1]

PETROLEUM STORAGE

(STORAGE TANKS AND BULK TERMINALS)

MISCELLANEOUS

Steam electric power plants [1]
Municipal or equivalent incinerators [1]
Open burning dumps [1]

[1] Major sources of sulfur oxides and/or particulate matter

1 1 3 No person shall cause or permit the emission or combustion of any refinery process gas stream or any other process gas stream which contains H2S in concentration greater than 10 grains per 100 cubic feet of gas without removal of the hydrogen sulfide in excess of the concentration

1 2 Sulfuric Acid Plant

4 2 1 No person should cause or permit sulfur dioxide tail gas emissions from sulfuric acid manufacturing plants to exceed 6 5 lb/ton of acid produced The tail gas acid mist emissions are not to exceed 0 5 lb/ton of acid produced and the sulfur dioxide emission rate not to exceed 6 5 lb/ton of acid produced

4 3 Sulfur Recovery Plants

4 3 1 No person shall cause or permit the sulfur dioxide emissions from a sulfur recovery plant to exceed 0 01 pounds per pound of sulfur processed

Note Processes are being offered commercially that are capable of meeting the above emission level for sulfur recovery plants Approximately 99 5 percent of the sulfur processed must be recovered to meet this regulation

1 4 Nonferrous Smelters

4 4 1 No person shall cause or permit emissions of sulfur oxides from primary nonferrous smelters to exceed that set forth according to the following equations

Copper smelters $Y=0.2X$
Zinc smelters $Y=0.564X^{0.85}$
Lead smelters $Y=0.98X^{0.7}$

Where X is the total sulfur fed to the smelter in lb/hr and Y is the allowable sulfur emissions in lb/hr

Note This rule in effect requires removal of about 90 percent of the input-sulfur to the smelter

4 5 Sulfite Pulp Mills

4 5 1 No person shall cause or permit the total sulfite pulp mill sulfur oxide emissions from blow pits washer vents storage tanks digester relief recovery system etc to exceed 9 0 lb per air-dried ton of pulp produced

Note This emission limit is being achieved with efficiently designed chemical recovery systems that are well integrated with the pulp mill and designed for maximum sulfur recovery

V—CONTROL OF HYDROCARBON EMISSIONS FROM STATIONARY SOURCES

5 1 Storage of Volatile Organic Materials

5 1 1 No person shall place store, or hold in any stationary tank reservoir or other container of more than 40 000 gallons capacity any volatile organic compounds unless such tank, reservoir or other container is a pressure tank capable of maintaining working pressures sufficient at all times to prevent vapor or gas loss to the atmosphere or is designed and equipped with one of the following vapor loss control devices

(a) A floating roof consisting of a pontoon type double deck type roof or internal floating cover which will rest on the surface of the liquid contents and be equipped with a closure seal or seals to close the space between the roof edge and tank wall This control equipment shall not be permitted if the volatile organic compounds have a vapor pressure of 11 0 pounds per square inch absolute or greater under actual storage conditions All tank gauging or sampling devices shall be gas-tight except when tank gauging or sampling is taking place

(b) A vapor recovery system consisting of a vapor gathering system capable of collecting the volatile organic compound vapors and gases discharged and a vapor disposal system capable of processing such volatile organic vapors and gases so as to prevent their emission to the atmosphere and with all tank gauging and sampling devices gas-tight except when gauging or sampling is taking place

(c) Other equipment or means of equal efficiency for purposes of air pollution control as may be approved by the Director

(d) No person shall place, store or hold in any stationary storage vessel more than 250-gallon capacity any volatile organic compound unless such vessel is equipped with a permanent submerged fill pipe or is a pressure tank as described in section 5 1 1 or is fitted with a vapor recovery system as described in section 5 1 1 (b)

5 2 Volatile Organic Materials Loading Facilities

5 2 1 No person shall load any volatile organic compounds into any tank, truck or trailer from any loading facility unless such loading facility is equipped with a vapor collection and disposal system or its equivalent properly installed, in good working order and in operation

5 2 2 No person shall load any volatile organic compounds into any tank truck or trailer unless such loading facility is equipped with a loading arm with a vapor collection adaptor pneumatic hydraulic, or other mechanical means shall be provided to force a vapor-tight seal between the adaptor and the hatch A means shall be provided to prevent liquid organic compounds drainage from the loading device when it is removed from the hatch of any tank, truck or trailer or to accomplish complete drainage before such removal When loading is effected through means other than hatches all loading and vapor lines shall be equipped with fittings which make vapor-tight connections and which close automatically when disconnected

5 3 Volatile Organic Compound Water Separation

5 3 1 No person shall use any compartment of any single or multiple compartment volatile organic compound water separation which compartment received effluent water containing 200 gallons a day or more of any equipment processing refining treating storing, or handling volatile organic compounds unless such compartment is equipped with one of the following vapor loss control devices, properly installed, in good working order, and in operation

(a) A container having all openings sealed and totally enclosing the liquid contents All gauging and sampling devices shall be gas-tight except when gauging or sampling is taking place

(b) A container equipped with a floating roof, consisting of a pontoon type, double deck type roof or internal floating cover, which will rest on the surface of the contents and be equipped with a closure seal or seals to close the space between the roof edge and container wall All gauging and sampling devices shall be gas-tight except when gauging or sampling is taking place

(c) A container equipped with a vapor recovery system consisting of a vapor gathering system capable of collecting the hydrocarbon vapors and gases discharged and a vapor disposal system capable of processing such hydrocarbon vapors and gases so as to prevent their emission to the atmosphere and with all container gauging and sampling devices gas-tight except when gauging or sampling is taking place

(d) A container having other equipment of equal efficiency for purposes of air pollution control as may be approved by the Director

5 4 Pumps and Compressors

All pumps and compressors handling volatile organic compounds shall have mechanical seals or other equipment of equal efficiency for purposes of air pollution control as may be approved by the Director

5 5 Waste Gas Disposal

5 5 1 No person shall emit a waste gas stream from any ethylene producing plant into the atmosphere unless the waste gas stream is properly burned at 1 300° for 0 3 seconds or greater in a direct-flame afterburner equipped with an indicating pyrometer which is positioned in the working area at the operator's eye level or an equally effective catalytic vapor incinerator also with pyrometer

5 5 2 No person shall emit hydrocarbon gases to the atmosphere from a vapor blowdown system unless these gases are burned by smokeless flare or an equally effective control device as approved by the Director

5 6 Organic Solvents

5 6 1 A person shall not discharge more than 15 pounds of organic materials into the atmosphere in any one day from any article machine equipment or other contrivance in which any organic solvent or any material containing organic solvent comes into contact with flame or is baked heated-cured or heat-polymerized in the presence of oxygen

5 6 2 A person shall not discharge more than 40 pounds of organic material into the atmosphere in any one day from an article, machine equipment or other contrivance used under conditions other than described in section 5 6 1 for employing applying, evaporating, or drying any photochemically reactive solvent as defined in section 5 6 11 or material containing such solvent unless all organic materials discharged from such article machine equipment or other contrivance have been reduced to not more than 40 pounds in any one day

5 6 3 Any series of articles machines equipment or other contrivances designed for processing a continuously moving sheet web, strip or wire which is subjected to any combination of operations described in section 5 6 1 or 5 6 2 involving any photochemically reactive solvent as defined in section 5 6 11, or material containing such solvent shall be subject to compliance with section 5 6 2 Where only nonphotochemically reactive solvents or material containing only nonphotochemically reactive solvents are employed or applied and where any portion or portions of said series of articles machines equipment, or other contrivances involves operations described in section 5 6 1 said portions shall be collectively subject to compliance with section 5 6 1

5 6 4 Emissions of organic materials to the atmosphere from the cleaning with photochemically reactive solvents as defined in section 5 6 11, of any article machine equipment or other contrivance described in section 5 6 1 5 6 2, or 5 6 3 shall be included with the other emissions of organic materials from that article machine equipment or other contrivance for determining compliance with this rule

5 6 5 Emissions of organic material to the atmosphere as a result of spontaneously continuing drying of products for the first 12 hours after their removal from any article machine equipment or other contrivance described in section 5 6 1 5 6 2 or 5 6 3, shall be included with other emissions of organic materials from that article, machine equipment or other contrivance, for determining compliance with this rule

5 6 6 Emissions of organic materials into the atmosphere required to be controlled by section 5 6 1, 5 6 2, or 5 6 3 shall be reduced by

(a) Incineration, provided that 90 percent or more of the carbon in the organic material being incinerated is oxidized to carbon dioxide or

(b) Adsorption or

(c) Processing in a manner determined by the Director to be not less than effective than (a) or (b) above

5 6 7 A person incinerating adsorbing, or otherwise processing organic materials pur-

reason for failure of an emission to meet the requirements of this regulation such a reason shall not apply

3.2 Fugitive Dust

3.2.1 No person shall cause suffer allow or permit any materials to be handled transported or stored or a building its appurtenances or a road to be used constructed altered repaired or demolished without taking reasonable precautions to prevent particulate matter from becoming airborne Such reasonable precautions shall include, but not be limited to, the following

(a) Use, where possible water or chemicals for control of dust in the demolition of existing buildings or structures construction operations the grading of roads or the clearing of land

(b) Application of asphalt oil water, or suitable chemicals on dirt roads materials stockpiles and other surfaces which can create airborne dusts

(c) Installation and use of hoods fans and fabric filters to enclose and vent the handling of dusty materials Adequate containment methods shall be employed during sandblasting or other similar operations,

(d) Covering, at all times when in motion open bodied trucks transporting materials likely to become airborne

(e) Conduct of agricultural practices such as tilling of land application of fertilizers etc in such manner as to not create a nuisance to others residing in the area

(f) The paving of roadways and their maintenance in a clean condition

(g) The prompt removal of earth or other material from paved streets which earth or other material has been transported thereto by trucking or earth moving equipment or erosion by water

3.2.2 No person shall cause or permit the discharge of visible emissions beyond the lot line of the property on which the emissions originate

3.2.3 When dust fumes, gases, mist odorous matter, vapors or any combination thereof escape from a building or equipment in such a manner and amount as to cause a nuisance or to violate any regulation, the Director may order that the building or equipment in which processing, handling and storage are done be tightly closed and ventilated in such a way that all air and gases and air or gas-borne material leaving the building or equipment are treated by removal or destruction of air contaminants before discharge to the open air

3.3 Incineration

3.3.1 No person shall cause or permit to be emitted into the open air from any incinerator particulate matter in the exhaust gases to exceed 0.10 pounds per 100 pounds of refuse burned

3.3.2 Emission tests shall be conducted at maximum burning capacity of the incinerator

3.3.3 The burning capacity of an incinerator shall be the manufacturers or designers guaranteed maximum rate or such other rate as may be determined by the Director in accordance with good engineering practices In case of conflict the determination made by the Director shall govern

3.3.4 For the purposes of this regulation the total of the capacities of all furnaces within one system shall be considered as the incinerator capacity

NOTE: This mass emission rate is about equivalent to a grain loading of 0.1 grains/SCF at 12 percent carbon dioxide More restrictive requirements are feasible for large incinerators

3.4 Fuel Burning Equipment

3.4.1 No person shall cause or permit emission to the atmosphere from fuel burning equipment burning solid fuel of particulate matter in excess of 0.10 pounds per million Btu per hour

3.4.2 No person shall cause or permit emission to the atmosphere from oil-fired fuel burning equipment rated greater than or equal to 250 million Btu per hour heat input of particulate matter in excess of 0.03 pounds per million Btu per hour

3.4.3 For purposes of this regulation the heat input shall be the aggregate heat content of all fuels whose products of combustion pass through a stack or stacks The heat input value used shall be the equipment manufacturer's or designer's guaranteed maximum input, whichever is greater The total heat input of all fuel burning units on a plant or premises shall be used for determining the maximum allowable amount of particulate matter which may be emitted

NOTE: Section 3.4.1 requires solid fuel burning equipment to remove about 99 percent of particulate matter generated by combustion of the average 10 percent ash coal Section 3.4.2 requires removal of about 80 percent of particulate generated from combustion of high-ash residual fuel oil in large boilers This can be accomplished by proper design and operation and use of small diameter cyclones and/or electrostatic precipitators or low-ash oil Additional regulations prohibiting the combustion of solid fuels and/or residual fuel oil in small units may be feasible in some areas and necessary to achieve national air quality standards for example, prohibition of hand-fired coal burning units is practiced in several areas

3.5 Process Industries—General

3.5.1 No person shall cause suffer, allow, or permit the emission of particulate matter in any one hour from any source in excess of the amount shown in Table IV for the process weight rate allocated to such source or in excess of 0.03 grains per standard cubic foot of exhaust gas

TABLE IV

Process weight rate (lb/hr)	Rate of emission (lb/hr)
100	0.551
200	0.877
400	1.40
600	1.85
800	2.22
1,000	2.58
1,500	3.38
2,000	4.10
2,500	4.76
3,000	5.38
3,500	5.96
4,000	6.52
5,000	7.58
6,000	8.56
7,000	9.49
8,000	10.4
9,000	11.2
12,000	13.6
16,000	16.5
18,000	17.9
20,000	19.2
30,000	25.2
40,000	30.5
50,000	35.4
60,000 or more	40.0

3.5.2 Interpolation of the data in this table for process weight rates up to 6,000 lb/hr shall be accomplished by use of the equation $E = 4.10P^{0.6}$, E=rate of emission in lb/hr and P=Process weight rate in tons/hr

3.5.3 Process weight per hour is the total weight of all materials introduced into any specific process that may cause any discharge of particulate matter Solid fuels charged will be considered part of the process weight, but liquid and gaseous fuels and combustion air will not For a cyclical or batch operation the process weight per hour will be derived by dividing the total process weight by the number of hours in one complete operation from the beginning of any given process to the completion thereof excluding any time during which the equipment is idle For a continuous operation the process weight per hour will be derived by dividing the process weight for a typical period of time

3.5.4 Where the nature of any process or operation or the design of any equipment is such as to permit more than one interpretation of this regulation, the interpretation that results in the minimum value for allowable emission shall apply

3.5.5 For purposes of the regulation, the total process weight from all similar process units at a plant or premises shall be used for determining the maximum allowable emission of particulate matter that passes through a stack or stacks

NOTE: Specific regulations for large industrial sources are encouraged in order to more closely require use of the latest available control techniques Consultation in developing such regulations is available from EPA upon request

IV—CONTROL OF SULFUR COMPOUND EMISSIONS

4.1 Fuel Combustion

4.1.1 No person shall burn, sell or make available for sale for burning in fuel burning equipment any fuel containing in excess of [illegible] sulfur by weight

NOTE: [illegible] is intended for application to small area sources where fuel substitution is the only practical control method

4.1.2 No person operating power and steam generating facilities having a power generating capacity in excess of 25 megawatts or a heat input greater than 250 million Btu/hr shall emit in excess of [illegible] pounds of sulfur per million Btu of heat input per hour

NOTE: This language is intended for application to large fuel combustion sources where installation of flue gas cleaning systems is feasible

[1] It is not possible to make universally applicable generalizations about attainable degrees of control of sulfur oxides emissions from combustion sources Availability of low-sulfur fuels varies from one area to another In some areas severe restrictions on the sulfur content of fuels could have a significant impact on fuel-supply patterns accordingly where such restrictions are necessary for attainment of national ambient air standards adoption of phased schedules of sulfur-in-fuel limitations is recommended Stack gas cleaning is feasible at large industrial combustion sources and steam electric power plants Technology now being demonstrated will allow 80 percent removal of sulfur oxides from combustion gases of most existing boilers It is reasonable to expect that these processes will be improved in the near future and thus permit attainment of 90 percent or greater collection efficiency for a wide range of boilers

Alternative means of meeting requirements for the control of sulfur oxides emissions from fuel combustion sources include Use of natural gas distillate oil low-sulfur coal and low-sulfur residual oil desulfurization of oil or coal stack gas desulfurization and restricted use shutdown or relocation of large existing sources

In many areas of the country regulations can be written requiring the following fuel characteristics Distillate oil—0.1 percent sulfur residual oil—0.3 percent sulfur bituminous coal—0.7 percent sulfur Because residual oil generally is obtained from overseas sources its use generally is restricted to areas accessible to water-borne transportation There are limited tonnages of 0.7 percent sulfur coal available at the present time but only in certain areas of the country

d Wholesale trade establishments Establishments of businesses primarily engaged in selling merchandise to retailers to industrial commercial institutional or professional users or to other wholesalers or acting as agents in buying merchandise for or selling merchandise to such persons or companies

e All offices of local county and State government including authorities joint meetings and other public bodies except those agencies which are determined by the chief administrative officer of local county or state government authorities joint meeting and other public bodies to be vital for public safety and welfare and the enforcement of the provisions of this order

f All retail trade establishments except pharmacies and stores primarily engaged in the sale of food

g Banks credit agencies other than banks securities and commodities brokers dealers exchanges and services offices of insurance carriers agents and brokers real estate offices

h Wholesale and retail laundries laundry service and cleaning and dyeing establishments photographic studios beauty shops barbershops shoe repair shops

i Advertising offices consumer credit reporting adjustment and collection agencies duplicating addressing blueprinting photocopying mailing list and stenographic services equipment rental service commercial testing laboratories

j Automobile repair automobile services garages

k Establishments rendering amusement and recreation services including motion picture theaters

l Elementary and secondary schools colleges universities professional schools junior colleges vocational schools and public and private libraries

4 All commercial and manufacturing establishments not included in this order will institute such actions as will result in maximum reduction of air contaminants from their operations by ceasing curtailing or postponing operations which emit air contaminants to the extent possible without causing injury to persons or damage to equipment

5 The use of motor vehicles is prohibited except in emergencies with the approval of local or State police

PART B—SOURCE CURTAILMENT

Any person responsible for the operation of a source of atmospheric contamination listed below shall take all required control actions for this Emergency Level

Source of air contamination	*Air pollution emergency*
1 Coal or oil-fired electric power generating facilities	a Maximum reduction by utilization of fuels having lowest ash and sulfur content b Maximum utilization of mid-day (12 m to 4 p m) atmospheric turbulence for boiler lancing or soot blowing c Maximum reduction by diverting electric power generation to facilities outside of Emergency Area
2 Coal and oil-fired process steam generating facilities	a Maximum reduction by reducing heat and steam demands to absolute necessities consistent with preventing equipment damage b Maximum utilization of mid-day (12 m to 4 p m) atmospheric turbulence for boiler lancing and soot blowing c Taking the action called for in the emergency plan
3 Manufacturing industries of the following classifications Primary Metals Industries Petroleum Refining Chemical Industries Mineral Processing Industries Grain Industry Paper and Allied Products	a Elimination of air contaminants from manufacturing operations by ceasing curtailing postponing or deferring production and allied operations to the extent possible without causing injury to persons or damage to equipment b Elimination of air contaminants from trade waste disposal processes which emit solid particles gases vapors or malodorous substances c Maximum reduction of heat load demands for processing d Maximum utilization of mid-day (12 m to 4 p m) atmospheric turbulence for boiler lancing or soot blowing

1 6 Prohibition of air pollution No person shall permit or cause air pollution, as defined in sect on 1 02 of this article

1 7 Compliance schedule Except as otherwise specified compliance with the provisions of these regulations shall be according to the following time schedule

1 7 1 New source All new sources shall comply as of going into operation

1 7 2 Existing sources All existing sources not in compliance as of the effective date of these regulations shall be in compliance within 6 months of the effective date of these regulations unless the owner or person responsible for the operation of the installation shall have submitted to the Director in a form and manner satisfactory to him a control plan and schedule for achieving compliance such plan and schedule to contain a date on or before which full compliance will be attained, and such other information as the Director may require If approved by the Director such date will be the date on which the person shall comply The Director may require persons submitting such a plan to submit subsequent periodic reports on progress in achieving compliance In no event shall the control plan and schedule exceed 3 years from the adopted date of these regulations

1 8 Circumvention No person shall cause or permit the installation or use of any device or any means which without resulting in reduction in the total amount of air contaminant emitted, conceals or dilutes in emission of air contaminant which would otherwise violate these regulations

1 9 Severability If any provision of these regulations or the application thereof to any person or circumstances is held to be invalid which invalidity shall not affect other provisions or applications of any other part of these regulations which can be given effect without the invalid provision or application and to this end the provisions of these regulations and the various applications thereof are declared to be severable

II—CONTROL OF OPEN BURNING AND INCINERATION

2 1 Open Burning No person shall ignite cause to be ignited permit to be ignited or maintain any open fire except as follows

2 1 1 Open fires for the cooking of food for human consumption on other than commercial premises

1 2 Fires for recreational or ceremonial purposes

2 1 3 Fires to abate a fire hazard providing hazard is so declared by the fire department or fire district having jurisdiction

2 1 4 Fires for prevention or control of disease or pests

2 1 5 Fires for training personnel in the methods of fighting fire

2 1 6 Fires for the disposal of dangerous materials where there is no alternate method of disposal and burning is approved by the Director

2 2 Incinerator Design and Operation

2 2 1 No residential or commercial single-chamber incinerator shall be used for the burning of refuse for a period in excess of eighteen (18) months after the adopted date of this regulations

2 2 2 All new incinerators and all existing incinerators within 18 month after adopted date of this regulation shall be multiple-chamber incinerators, provided that the Director may approve any other type of incinerator if it is demonstrated such design provides equivalent performance

2 2 3 No person shall operate or cause or permit the operation of any incinerator at any time other than between the hours of 10 a m and 4 p m This restriction shall not apply to incinerators having a refuse-burning capacity of five (5) tons per hour or more

2 2 4 Incinerators shall be designed and operated in such manner as is necessary to prevent the emission of objectionable odors

NOTE Additional regulations prohibiting all domestic and commercial incineration may be feasible in some areas and necessary for attainment of national air quality standards

III—CONTROL OF PARTICULATE EMISSIONS

3 1 Visible Emissions

3 1 1 Visible emissions restrictions for stationary sources

(a) No person shall discharge into the atmosphere from any single source of emission whatsoever any air contaminant of a shade or density equal to or darker than that designated as No 1 on the Ringelmann chart or 20 percent opacity

(b) A person may discharge into the atmosphere from any single source of emission for a period or periods aggregating not more than 3 minutes in any 60 minutes air contaminants of a shade of density not darker than No 3 on the Ringelmann chart or 60 percent capacity

3 1 2 Visible emission from motor vehicle

(a) No person shall cause or permit the emission of visible air contaminants from gasoline-powered motor vehicles for longer than 5 consecutive seconds

(b) No person shall cause or permit the emission of visible air contaminants from diesel-powered motor vehicles of a shade or density equal to or darker than that designated as No 1 on the Ringelmann chart or 20 percent opacity for longer than 5 consecutive seconds

3 1 3 Uncombined water Where the presence of uncombined water is the only

Table I—Abatement Strategies Emission Reduction Plans

Alert Level

PART A—GENERAL

1 There shall be no open burning by any persons of tree waste, vegetation, refuse, or debris in any form

2 The use of incinerators for the disposal of any form of solid waste shall be limited to the hours between 12 m and 4 p m

3 Persons operating fuel-burning equipment which requires boiler lancing or soot blowing shall perform such operations only between the hours of 12 m and 4 p m

4 Persons operating motor vehicles should eliminate all unnecessary operations

PART B—SOURCE CURTAILMENT

Any person responsible for the operation of a source of atmospheric contamination listed below shall take all required control actions for this Alert Level

Source of air contamination	*Air pollution alert*
1 Coal or oil-fired electric power generating facilities	a Substantial reduction by utilization of fuels having low ash and sulfur content b Maximum utilization of mid-day (12 m to 4 p m) atmospheric turbulence for boiler lancing and soot blowing c Substantial reduction by diverting electric power generation to facilities outside of Alert Area
2 Coal and oil-fired process steam generating facilities	a Substantial reduction by utilization of fuels having low ash and sulfur content b Maximum utilization of mid-day (12 m to 4 p m) atmospheric turbulence for boiler lancing and soot blowing c Substantial reduction of steam load demands consistent with continuing plant operations
3 Manufacturing industries of the following classifications Primary Metals Industry Petroleum Refining Operations Chemical Industries Mineral Processing Industries Paper and Allied Products Grain Industry	a Substantial reduction of air contaminants from manufacturing operations by curtailing, postponing or deferring production and all operations b Maximum reduction by deferring trade waste disposal operations which emit solid particles, gas vapors or malodorous substance c Maximum reduction of heat load demands for processing d Maximum utilization of mid-day (12 m to 4 p m) atmospheric turbulence for boiler lancing or soot blowing

Table II—Emission Reduction Plans

Warning Level

PART A—GENERAL

1 There shall be no open burning by any persons of tree waste, vegetation, refuse, or debris in any form

2 The use of incinerators for the disposal of any form of solid waste or liquid waste shall be prohibited.

3 Persons operating fuel-burning equipment which requires boiler lancing or soot blowing shall perform such operations only between the hours of 12 m and 4 p m

4 Persons operating motor vehicles must reduce operations by the use of car pools and increased use of public transportation and the elimination of unnecessary operation

PART B—SOURCE CURTAILMENT

Any person responsible for the operation of a source of atmospheric contamination listed below shall take all required control actions for this Warning Level

Source of air contamination	*Air pollution alert*
1 Coal or oil-fired electric power generating facilities	a Maximum reduction by utilization of fuels having lowest ash and sulfur content b Maximum utilization of mid-day (12 00 noon to 4 00 p m.) atmospheric turbulence for boiler lancing and soot blowing c Maximum reduction by diverting electric power generation to facilities outside of Warning Area
2 Oil and oil-fired process steam generating facilities	a Maximum reduction by utilization of fuels having the lowest available ash and sulfur content b Maximum utilization of mid-day (12 m to 4 p m) atmospheric turbulence for boiler lancing and soot blowing c Making ready for use a plan of action to be taken if an emergency develops
3 Manufacturing industries which require considerable lead time for shut-down including the following classifications Petroleum Refining Chemical Industries Primary Metals Industries Glass Industries Paper and Allied Products	a Maximum reduction of air contaminants from manufacturing operations by if necessary assuming reasonable economic hardships by postponing production and allied operation b Maximum reduction by deferring trade waste disposal operations which emit solid particles, gases vapors or malodorous substances c Maximum reduction of heat load demands for processing d Maximum utilization of mid-day (12 m to 4 p m) atmospheric turbulence for boiler lancing or soot blowing
4 Manufacturing industries require relatively short lead times for shut-down including the following classifications Primary Metals Industries Chemical Industries Mineral Processing Industries Grain Industry	a Elimination of air contaminants from manufacturing operations by ceasing curtailing, postponing or deferring production and allied operations to the extent possible without causing injury to persons or damage to equipment b Elimination of air contaminants from trade waste disposal processes which emit solid particles gases vapors, or malodorous substances c Maximum reduction of heat load demands for processing d Maximum utilization of mid-day (12 m to 4 p m) atmospheric turbulence for boiler lancing or soot blowing

Table III—Emission Reduction Plans

Emergency Level

PART A—GENERAL

1 There shall be no open burning by any persons of tree waste, vegetation, refuse, or debris in any form

2 The use of incinerators for the disposal of any form of solid or liquid waste shall be prohibited

3 All places of employment described below shall immediately cease operations:

a Mining and quarrying of nonmetallic minerals

b All construction work except that which must proceed to avoid imminent physical harm

c All manufacturing establishments except those required to have in force an air pollution emergency plan

(c) Emissions of particulate matter sulfur dioxide and oxides of nitrogen shall be expressed in pounds per hour and pounds per million BTU of heat input for fuel-burning equipment, in pounds per hour and pounds per 100 pounds of refuse burned for incinerators, and in pounds per hour and in pounds per hour of process weight or production rate in terms of some other easily measured and meaningful process unit specified by the Director.

(b) Sulfur dioxide and oxides of nitrogen emission data shall be recorded over a 24-hour period and shall be summarized monthly. Daily averages and monthly summaries shall be submitted to the Director biannually. Data should be calculated daily and available for inspection at any time.

(c) Particulate matter emissions shall be sampled and submitted biannually.

(d) Visible emissions shall be measured continuously and records kept indicating total minutes per day in which stack discharge effluent exceeds 20 percent opacity. Data should be summarized monthly and submitted monthly and submitted biannually. Current daily results shall be available for inspection at any time.

(e) The sulfur content of fuels as burned, except natural gas, shall be determined in accordance with current recognized ASTM procedures. Daily and monthly averages shall be submitted biannually. Daily records shall be kept current and be available for inspection.

1.2.3 The following sources are subject to the provisions of this regulation. (The appropriate State Agency should either classify each source by regulation or require reporting as a permit to operate condition.)

1.3 Sampling and Testing Methods.

1.3.1 All tests shall be made and the results calculated in accordance with test procedures approved by the Director. All tests shall be made under the direction of persons qualified by training and/or experience in the field of air pollution control.

1.3.2 The Director may conduct tests of emissions of air contaminants from any source. Upon request of the Department the person responsible for the source to be tested shall provide necessary holes in stacks or ducts and such other safe and proper sampling and testing facilities, exclusive of instruments and sensing devices as may be necessary for proper determination of the emission of air contaminants.

1.4 Malfunction of Equipment, Reporting.

1.4.1 In the case of shutdown of air pollution control equipment for necessary scheduled maintenance, the intent to shut down such equipment shall be reported to the Director at least twenty-four (24) hours prior to the planned shutdown. Such prior notice shall include, but is not limited to, the following:

(a) Identification of the specific facility to be taken out of service as well as its location and permit number.

(b) The expected length of time that the air pollution control equipment will be out of service.

(c) The nature and quantity of emissions of air contaminants likely to occur during the shutdown period.

(d) Measures such as the use of off-shift labor and equipment that will be taken to minimize the length of the shutdown period.

(e) The reasons that it would be impossible or impractical to shut down the source operation during the maintenance period.

1.4.2 In the event that any emission source, air pollution control equipment, or related facility breaks down in such a manner as to cause the emission of air contaminants in violation of this article, the person responsible for such equipment shall immediately notify the Director of such failure or breakdown and provide a statement giving all pertinent facts, including the estimated duration of the breakdown. The Director shall be notified when the condition causing the failure or breakdown has been corrected and the equipment is again in operation.

1.5 Air pollution emergencies. Notwithstanding any other provision of these air pollution control regulations, this episode regulation is declared to prevent the excessive buildup of air contaminants during air pollution episodes, thereby preventing the occurrence of an emergency due to the effects of these contaminants on the public health.

1.5.1 Episode criteria. Conditions justifying the proclamation of an air pollution alert, air pollution warning, or air pollution emergency shall be deemed to exist whenever the Director determines that the accumulation of air contaminants in any place is attaining or has attained levels which could, if such levels are sustained or exceeded, lead to a threat to the health of the public. In making this determination the Director will be guided by the following criteria:

(a) Air Pollution Forecast. An internal watch by the Department of Air Pollution Control shall be actuated by a National Weather Service advisory that Atmospheric Stagnation Advisory is in effect or the equivalent local forecast of stagnant atmospheric conditions.

(b) "Alert". The Alert level is that concentration of pollutants at which first stage control actions is to begin. An Alert will be declared when any one of the following levels is reached:

SO_2—0.3 p.p.m. 24-hour average.
Particulate—3.0 COHs 24-hour average.
SO and particulate combined—product of SO_2 p.p.m. 24-hour average and COHs equal to 0.2.
CO—15 p.p.m., 8-hour average.
O_X—0.1 p.p.m. 1-hour average.
NO_2—0.6 p.p.m. 1-hour average, 0.15 p.p.m., 24-hour average.

and meteorological conditions are such that this condition can be expected to continue for twelve (12) or more hours.

(c) "Warning". The warning level indicates that air quality is continuing to degrade and that additional abatement actions are necessary. A warning will be declared when any one of the following levels is reached:

SO—0.6 p.p.m. 24 hour average.
Particulate—6.0 COHs 24-hour average.
Combined SO and COHs, 24-hour average, SO and COHs equal to 1.0.
CO—30 p.p.m. 8-hour average.
O_X—0.4 p.p.m., 1-hour average.
NO—1.2 p.p.m. 1-hour average 0.3 p.p.m. 24-hour average.

and meteorological conditions are such that this condition can be expected to continue for twelve (12) or more hours.

(d) "Emergency". The emergency level is reached when the warning level for a pollutant has been exceeded and (1) the concentrations of the pollutant are continuing to increase, or (2) the Director determines that, because of meteorological or other factors, the concentrations will continue to increase.

(e) Termination. Once declared any status reached by application of these criteria will remain in effect until the criteria for that level are no longer met. At such time the next lower status will be assumed.

1.5.2 Emission Reduction Plans.

(a) Air Pollution Alert.—Any persons responsible for the operation of a source of air contamination as set forth in Table I shall take all Air Pollution Alert actions as required for such source of air contamination and shall particularly put into effect the preplanned strategy for an Air Pollution Alert.

(b) Air Pollution Warning. Any person responsible for the operation of a source of air contamination as set forth in Table II shall take all Air Pollution Warning actions as required for such source of air contamination and shall particularly put into effect the preplanned strategy for an Air Pollution Warning.

(c) Air Pollution Emergency.—Any person responsible for the operation of a source of air contamination as described in Table III shall take all Air Pollution Emergency actions as required for such source of air contamination and shall particularly put into effect the preplanned strategy for an Air Pollution Emergency.

1.5.3 Preplanned Abatement Strategies.

(a) Any person responsible for the operation of a source of air contamination as set forth in Table I shall prepare preplanned strategies, consistent with good industrial practice and safe operation procedures for reducing the emission of air contaminants into the outdoor atmosphere during periods of an Air Pollution Alert, Air Pollution Warning, and Air Pollution Emergency. Standby plans shall be designed to reduce or eliminate emissions of air contaminants into the outdoor atmosphere in accordance with the objectives set forth in Tables I–III which are made part of this section.

(b) Any person responsible for the operation of a source of air contamination not set forth under section 4.1 shall, when requested by the Director in writing, prepare preplanned strategies consistent with good industrial practice and safe operating procedures for reducing the emission of air contaminants into the outdoor atmosphere during periods of an Air Pollution Alert, Air Pollution Warning, and Air Pollution Emergency. Standby plans shall be designed to reduce or eliminate emissions of air contaminants into the outdoor atmosphere in accordance with the objectives set forth in Tables I–III.

(c) Preplanned strategies as required under sections 4.1 and 4.2 shall be in writing and show the source of air contamination, the approximate amount of reduction of contaminants, and a brief description of the manner in which the reduction will be achieved during an Air Pollution Alert, Air Pollution Warning, and Air Pollution Emergency.

(d) During a condition of Air Pollution Alert, Air Pollution Warning, and Air Pollution Emergency, preplanned strategies as required by this section shall be made available on the premises to any person authorized to enforce the provisions of the Air Pollution Control Regulations.

(e) Preplanned strategies as required by this section shall be submitted to the Director upon request within thirty (30) days of the receipt of such request. Such preplanned strategies shall be subject to review and approval by the Director. If in the opinion of the Director, such standby plans do not effectively carry out the objectives as set forth in Tables I–III, the Director may disapprove said preplanned strategies, state its reason for disapproval, and order the preparation of amended strategies within the time period specified in the order. Any person aggrieved by the order requiring the preparation of a revised strategy is entitled to a hearing. If the person responsible fails within the time period specified in the order to submit an amended preplanned strategy which in the opinion of the Director meets the said objectives, the Director may revise the standby plan to cause it to meet these objectives. Such revised strategies will thereafter be the preplanned strategy which the person responsible will put into effect upon the issuance of an appropriate order by the Director.

above the bottom of the tank or when applied to a tank which is joined from the side shall reach any full pipe the discharge opening of which is entirely submerged when the liquid level is at the time the fill pipe diameter 6 inches above the bottom of the tank

1 10 10 Effluent water separator any tank box sump, or other container in which any volatile organic compound floating on or entrained or contained in water entering such tank, box sump, or other container is physically separated and removed from such water prior to outfall drainage or recovery of such water

1 10 90 Volatile organic compounds any compound containing carbon and hydrogen or containing carbon and hydrogen in combination with any other element which has a vapor pressure of 1 5 pounds per square inch absolute or greater under actual storage conditions

1 1 Permits

1 1 1 General requirements

(a) No person shall cause or permit the construction or modification of any new source without first obtaining an authority to construct or modify from the Director as to the location and design of such new source to comply with applicable rules and regulations and ambient air quality standards

(b) The Director shall not approve such construction or modification unless the applicant demonstrates to the satisfaction of the Director that the new source can be expected to comply with the applicable rules and regulations

1 1 2 Applications

(a) Application for authority to construct or modify shall be made by the owner or operator of the new source on forms furnished by the Director If the applicant is a partnership or group other than a corporation, the application shall be made by one individual who is a member of the group If the applicant is a corporation the application shall be made by an officer of the corporation

(b) A separate application is required for each new source subject to rules and regulations To aid in evaluating the new source, additional applications may be required by the Director

(c) Each application shall be signed by the applicant The signature of the applicant shall constitute an agreement that the applicant will assume responsibility for the construction, modification or use of the new source concerned in accordance with the rules and regulations

1 1 3 Information required

(a) Each application for an authority to construct or modify, shall be accompanied by two copies of complete data setting information, plans descriptions specifications and drawings to show how the proposed new source is designed and in what manner it will be operated and controlled

(b) Any additional information, plans specifications evidence or documentation that the Director may require

1 1 4 Standards for granting authority to construct or modify No authority to construct or modify shall be granted unless the applicant shows to the satisfaction of the Director that

(a) The new source is designed and will be constructed or modified to operate without causing a violation of the applicable rules and regulations

(b) The new source is designed built and equipped in accordance with the latest available control technology so as to reduce emissions to a minimum

(c) The new source, as designed or modified does not endanger maintenance or attainment of any applicable ambient air quality standard

(d) The new source if required by the Director shall be provided with

(1) Sampling ports of a size number and location as the Director may require,

(2) Safe access to each port,

(3) Instrumentation to monitor and record emission data and

(4) Any other sampling and testing facilities the Director may require

1 1 5 Action on application

(a) The Director shall act within a reasonable time, on an application for an authority to construct or modify and shall notify the applicant in writing of his approval conditional approval or denial of the application

(b) If an application is denied the Director shall set forth his objections in the notice of denial

(c) The applicant may submit answer and comments in duplicate to the Directors objections to the application

(d) The Director will consider the applicants answers and comment to his objections, and shall notify the applicant in writing of his approval or denial of the application

(e) The Director shall not accept a further application unless the applicant has complied with the objections specified by the Director as his reasons for denial of the authority to construct or modify

1 1 6 Conditional authority to construct or modify The Director may grant a conditional authority to construct or modify if it appears likely from all of the information submitted that as a result of the condition the new source will satisfy the requirements of 1 1 4 above

1 1 7 Cancellation of authority to construct or modify

(a) The Director may cancel an authority to construct or modify if the construction or modification is not begun within 1 year from the date of issuance, or if the work involved in the construction or modification is suspended for 1 year or more from the date of issuance

(b) An applicant may secure an extension of the expiration date by written request to the Director stating the reasons for the request Extensions may be granted for a period of not more than 6 months

1 1 8 Permit to operate

(a) No person shall begin operation of a new source without notifying the Director at least 30 days prior to operation

(b) No person shall cause or permit the operation of a new source for more than a sixty (60) day period without applying for a permit to operate from the Director

(c) No person shall cause or permit the use or operation of existing sources of control apparatus without applying for a permit to operate from the Director within 6 months of the adopted date of these regulations or an approved control plan in accordance with section 1 7 of these regulations

(d) No owner or operator shall cause or permit the operation of a new or existing source if the Director denies or revokes a permit to operate

1 1 9 Applications Applications for a permit to operate shall be made in accordance with 1 1 2 of this part

1 1 10 Standards for granting permits No permit to operate shall be granted unless the applicant shows to the satisfaction of the Director that the new source satisfied the requirements of the applicable rules and regulations and has been constructed installed or modified in accordance with the requirements and conditions contained in the authority to construct or modify

1 1 11 Performance testing Before a permit to operate is granted, the applicant, if required by the Director, shall conduct performance tests, in accordance with methods approved by the Director with the tests being made at the expense of the applicant The Director may monitor performance to be conducted by the applicant and may also conduct performance tests

1 1 12 Action on application

(a) Before acting on an application for a permit to operate the Director may require the applicant to furnish additional information plans or specification

(b) The Director shall act within a 60-day period on an application for a permit to operate and shall notify the applicant in writing of his approval conditional approval or denial of the application

(c) If an application is denied the procedures of 1 1 5 of this part shall apply

1 1 13 Conditional permit The holder of a permit to operate shall comply with the conditions contained in his permit as well as all applicable provisions of rules and regulations

1 1 14 Suspension or revocation of permit

(a) The Director may suspend or revoke a permit to operate for willful or continued violation of rules and regulations

(b) Suspension or revocation of a permit to operate shall become final 10 days after service of notice on the holder of the certificate

(c) A permit to operate which has been revoked pursuant to these regulations shall be surrendered forthwith to the Director

1 1 15 Transfer of permit Any purported or attempted transfer of a permit to operate from one owner or from one location to another or from one new source to another shall void the permit

1 1 16 Reporting information Nothing herein shall cause or permit the operation of any new source without furnishing such performance tests results information and records as may be required by the Director in the applicable rules and regulations

1 1 17 Exemptions An authority to construct and a permit to operate shall not be required for

(a) The installation or alteration of an air contaminant detector air contaminant recorder, combustion controller or combustion shutoff

(b) Air conditioning or ventilating systems not designed to remove air contaminant generated by or released from equipment

(c) Fuel burning equipment other than smoke house generators which uses gas as a fuel for space heating air conditioning or heating water, or is used in a private dwelling or has a B t u input of not more than 350 000 B t u per hour or is used for space heating other than boilers and hot air furnaces

(d) Internal combustion engines

(e) Laboratory equipment used exclusively for chemical or physical analyses

(f) Other sources of minor significance specified by Director

NOTE This suggested regulation specifies a complete permit system for application to new and existing sources For existing sources, a simple registration is adequate although not as effective for enforcement purposes

1 2 Monitoring Records Reporting

1 2 1 The Director may require the owner or operator of any air contaminant source to install, use and maintain such monitoring equipment sample such emissions in accordance with methods as the Director shall prescribe, establish and maintain such records and make such periodic emission reports as required in section 1 2 2

1 2 2 Records and reports as the Director shall prescribe on air contaminants or fuel shall be recorded compiled, and submitted on forms furnished by the Director The procedures below are examples requirements)

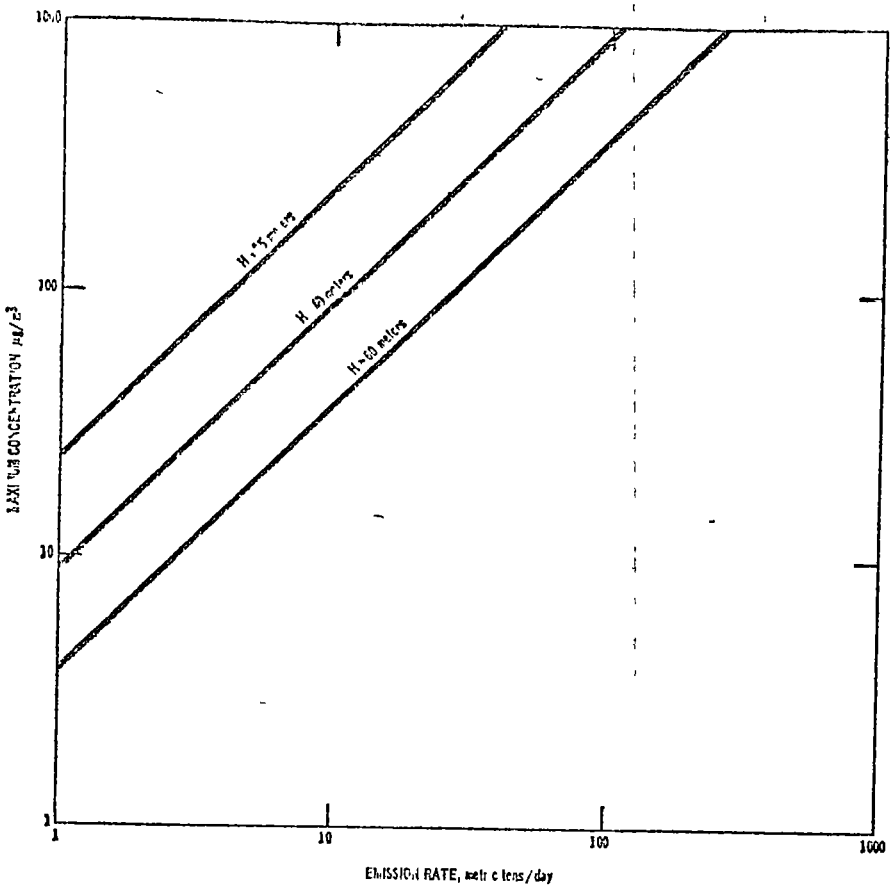

Figure 2 Relationship of emission rate, stack height, and estimated ground level concentration

APPENDIX B—AIR POLLUTION CONTROL REGULATIONS

These air pollution control regulations include examples of the administrative provisions and pollutant emission limitations a State may need for an approvable implementation plan. Part I contains general provisions regarding permits for new construction, emission monitoring, recordkeeping, and reporting, prevention of air pollution emergencies, and timetables for compliance. Parts II through VII contain emission limitations applicable to sources of particulate matter, sulfur oxides, hydrocarbons, carbon monoxide, and nitrogen oxides.

Although these emission limitations contained herein are relatively stringent, they have, with some modification, been applied by various State and local jurisdictions. Notes have been added, where necessary, to explain the basis or application of the regulations. These emission limitations do not necessarily represent the ultimate in emission control.

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I—GENERAL PROVISIONS

1.0 Definitions.

1.0.1 "Air contaminant" shall mean dust, fumes, mist, smoke, other particulate matter, vapor, gas, or any combination thereof.

1.0.2 "Air pollution" shall mean the presence in the outdoor atmosphere of one or more air contaminants in such quantities and duration as is or tends to be injurious to human health or welfare, animal or plant life, or property or interferes with the enjoyment of life or property.

1.0.3 "Director" shall mean the Director of the State Air Pollution Control Agency.

1.0.4 "Existing source" shall mean all equipment, machines, devices, article, contrivance, or installations which are in being on the effective date of these regulations, except that any existing equipment, machine, device, article, contrivance, or installation which is altered, replaced, or rebuilt after the effective date of these regulations shall be reclassified as "new source".

1.0.5 "Fuel-burning equipment" shall mean any furnace, boiler, apparatus, stack, and all appurtenances thereto, used in the process of burning fuel for the primary purpose of producing heat or power by indirect heat transfer.

1.0.6 "Fugitive dust" shall mean solid air-borne particulate matter emitted from any source other than a flue or stack.

1.0.7 "Multiple-chamber incinerator" shall mean any article, machine, equipment, contrivance, structure or part of a structure, used to dispose of combustible refuse by burning, consisting of three or more refractory lined combustion furnaces in series, physically separated by refractory walls, interconnected by gas passage ports or ducts and employing adequate design parameters necessary for maximum combustion of the material to be burned.

1.0.8 "New source" shall mean equipment, machines, devices, articles, contrivances, or installations built or installed on or after the effective date of these regulations, and installations existing at said stated time which are later altered, repaired, or rebuilt. Any equipment moved to another premise involving a change of address or purchased and to be operated by a new owner or when a new lessee desires to operate such equipment after the effective date of these regulations shall be considered a new source.

1.0.9 "Opacity" shall mean a state which renders material partially or wholly impervious to rays of light and causes obstruction of an observer's view.

1.0.10 "Open burning" shall mean the burning of any matter in such a manner that the products of combustion resulting from the burning are emitted directly into the ambient air without passing through an adequate stack, duct, or chimney.

1.0.11 "Particulate matter" shall mean any material except water in uncombined form that is or has been airborne and exists as a liquid or a solid at standard conditions.

1.0.12 "Person" shall mean any individual, corporation, partnership, firm, association, trust, estate, public or private institution, group, agency, political subdivision of this State, any other State or political subdivision or agency thereof, or any legal successor, representative, agent, or agency of the foregoing.

1.0.13 "Ringelmann chart" shall mean the chart published and described in the U.S. Bureau of Mines Information Circular 8333.

1.0.14 "Soiling index." A measure of the soiling properties of suspended particles in air, determined by drawing a measured volume of air through a known area of Whatman No. 4 filter paper for a measured period of time, expressed as COH's/1,000 linear feet.

1.0.15 "Source" shall mean any property, real or personal, or person contributing to air pollution.

1.0.16 "Stack or chimney" shall mean any flue, conduit, or duct arranged to conduct emissions.

1.0.17 "Standard conditions" shall mean a dry gas temperature of 70° Fahrenheit and a gas pressure of 14.7 pounds per square inch absolute.

1.0.18 "Submerged fill pipe" any fill pipe the discharge opening of which is entirely submerged when the liquid level is 6 inches

§ 430.32 Request for one or postponement.

(a) Pursuant to section 110(f) of the Act the Governor of a State may request, with respect to any stationary source or class of moving sources, a postponement for not more than 1 year of the applicability of any requirement prescribed in a State plan approved by the Administrator under this part.

(b) Any such request regarding sources located in an interstate region shall show that the Governor of each State in the region has been notified of such request.

(c) Any such request shall clearly identify the source(s) and requirement(s) which are the subject of such request.

(d) A public hearing will be held, before the Administrator or his designee, on any such request. No such hearing will be held earlier than 1 year in advance of the prescribed date for compliance with any such requirement(s).

(e) No such request shall operate to stay the applicability of the requirement(s) covered by such request.

(f) A State's determination to defer the applicability of any requirement of a plan with respect to such source(s) will not necessitate a request for postponement under this section unless such deferral will prevent attainment or maintenance of a national standard within the time prescribed by the Act or such additional time prescribed by the Administrator under § 420.30. *Provided, however,* That any such determination would constitute revision of an applicable State plan under § 420.07.

APPENDIX A—AIR QUALITY ESTIMATION

Ambient pollutant levels may be estimated through the application of atmospheric diffusion models. These estimates are based primarily upon the emission densities, meteorology and topography that prevail within a region. Two types of diffusion models may be used: (1) A model developed by Holzworth,[1] and subsequently modified, which estimates annual average concentrations on the basis of emissions uniformly distributed throughout a region, and (2) a diffusion model which predicts concentration resulting from point sources during particularly unfavorable meteorological conditions.

Holzworth model. This model requires estimates of a region's average emission density, the size of the region, and the wind speed through the atmospheric mixing layer. Emission densities have been computed for all of the Standard Metropolitan Statistical Areas (SMSA) for both particulate matter and sulfur dioxide (SO_2) and can be readily estimated for other urbanized areas. Values of the wind speed in the mixing layer have been determined and published by Holzworth. The basic assumption and technical modifications of Holzworth's procedures are found elsewhere; however, a summary and description of how to use the procedure are presented here.

Let, for discussion purposes, let:

X_μ = Limited concentration, micrograms/cubic meter ($\mu g/m^3$).

μ = Wind speed through mixing layer, meters/second (m/s).

Q = Emission density, micrograms/square meter-second ($\mu g/m^2$-s).

C = Urban size = $\frac{1}{2}\sqrt{\text{urban area}}$, kilometers (km).

Figure 1 is a plot of normalized concentration[2] $\left(\frac{X_\mu}{Q}\right)$ as a function of urban size and is defined to be the product of predicted concentration and wind speed divided by emission density. Concentrations are an increasing function of urban size and are directly proportional to emission density. The wind serves as a diluting agent and reduces expected pollutant concentrations.

As an example, the SMSA of Chicago is used to compute the expected concentration of SO_2 from 1967 emissions in the Chicago area. The urban area of Chicago for computational purposes is 2,500 square km. The urban size, as defined, is consequently 25 km and thus from Figure 1

$$\frac{X_\mu}{Q} = 230$$

For Chicago

$$Q = 17.8 \frac{\mu g/sec}{meter^2}$$

$$\mu = 7.3 \text{ meters/sec}$$

and hence

$$X_\mu = \frac{(230)\ (17.8)}{7.3} = 561\ \mu g/m^3$$

Using this procedure concentrations estimates for both SO_2 and particulate matter can be made on a regional basis. These predicted air quality concentrations may be used to establish region classifications.

Point source model. A short-term diffusion model[3] will be used to estimate the maximum ambient concentrations due to point source emissions. The model is composed of two portions and describes the maximum concentration which may occur under two separate types of meteorological condition.

The first portion is stack height dependent and describes concentrations that may occur using a generalized atmospheric diffusion model.[4] The second portion of the model is one in which ambient concentrations are estimated on the basis of emissions from "all stacks" during periods of low wind speeds and severe limitations on vertical mixing.

A joint consideration of these two models indicates that expected maximum concentrations are constant for physical stack heights which exceed 60 meters. A plot of 24-hour maximum concentration expected for various stack heights and emissions is given in Table 2.

For example, at stack heights of 60 meters SO_2 emission rates from a point source must exceed 100 metric tons/day for the primary standard for sulfur oxides to be exceeded. Mass emission rates are available for all significant sources of sulfur oxides and particulate matter in the country and will be used to aid in the regional classification for each pollutant.

[1] Holzworth, George C., "Meteorological Potential for Urban Pollution in the Contiguous United States", Paper No. ME-206 presented at the Second International Clean Air Congress, Washington, D.C., December 1970.

[2] Fensterstock, et al., "The Development and Utilization of an Air Quality Index", APCA paper 69-73 presented at annual meeting of APCA, New York, N.Y., June 1969.

[3] Carpenter, S. B. et al., "Multiple Point Source Dispersion Models—[illegible]", APCA Paper No. 70-149 presented at annual meeting of APCA, St. Louis, Mo., June 1970.

[4] Gifford, Frank A., "The Problem of Forecasting Dispersion in the Lower Atmosphere", USAEC, Division of Technical Information Extension, Oak Ridge, Tenn., July 1961.

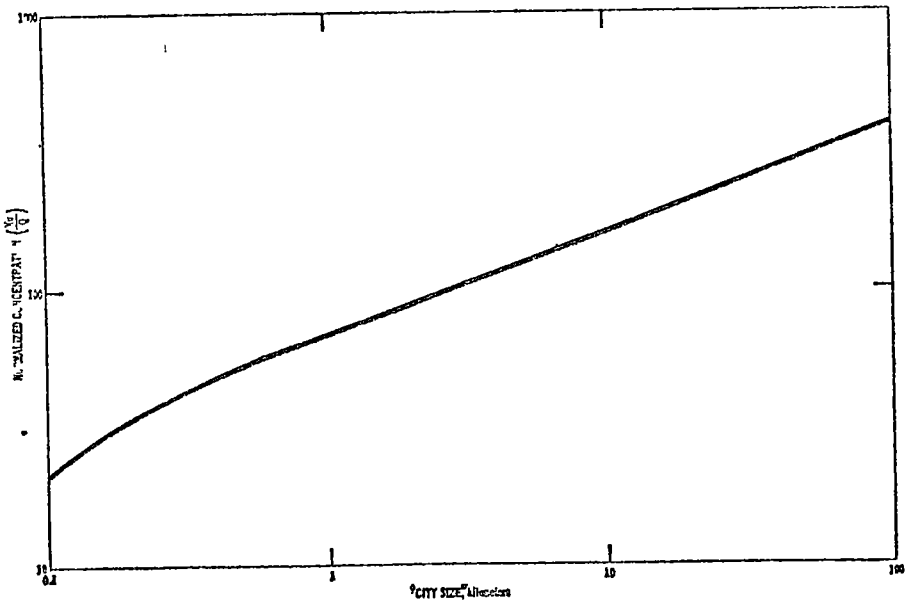

Figure 1. Relationship of normalized pollutant concentration and city size.

(c) The plan shall provide that information regarding the establishment and operation of the network and the data resulting from its use will be available to the Administrator upon request.

(d) The plan shall provide for monitoring of air quality during emergency episodes. The stations selected for use during episodes must be capable of providing real-time validated air quality data.

§ 420.18 Review of new sources and modifications.

(a) Each plan shall include a description of the procedures that will be used to implement the authority described in § 420.11(a)(4), which procedure shall be adequate to enable the State agency to determine that construction and modification of stationary sources does not result in violations of applicable emission limitations or other regulations and does not interfere with attainment or maintenance of a national standard. Procedures such as those described in section 1.1 of Appendix B to this part will be deemed to fulfill this requirement.

(b) Such procedures shall provide for the submission, by the owner or operator of a new stationary source or existing source which is to be modified, of such information on location, design, construction, and operation of such source as may be necessary to permit the State agency to make the determination referred to in paragraph (a) of this section.

(c) Such procedures shall also include means of disapproving such construction or modification if it will result in a violation of applicable emission limitations or other regulations or will interfere with attainment or maintenance of a national standard.

(d) Such procedure shall provide that approval of any construction or modification shall not affect the responsibility of the owner or operator to comply with applicable emission limitations or other regulations.

§ 420.19 Source registration.

Each plan shall contain a description of the procedures that will be used for registration of significant existing sources of pollutants for which there are national standards. Such procedure shall provide for the submission and periodic updating, by the owners or operators of such sources, of information on the nature and amount of emissions from such sources and such other information as may be necessary to enable the State agency to determine whether such sources are in compliance with applicable emission limitations or other regulations. Procedures derived from those described in section 1.1 of Appendix B to this part will be deemed to fulfill this requirement.

§ 420.20 Emissions surveillance.

Each plan shall include a description of the procedures that will be used to monitor compliance with emission limitations and other regulations applicable to emission sources. Such procedures shall include:

(a) Periodic inspection of stationary sources at intervals not exceeding 2 years.

(b) A field investigation system for:

(1) Detecting, and initiating any necessary action to abate, emissions from sources not otherwise known to the State agency.

(2) Investigating and taking any necessary action with respect to complaints.

(3) Enforcing regulations applicable to visible emissions.

(4) Conducting emission tests on point sources.

§ 420.21 Resources.

The plan shall include a description of the resources available to the State agency and local agencies at the date of submission of the plan and of any additional resources needed to carry out the plan during the 5-year period following its submission. Such description, which shall be provided in a form similar to that in Appendix K to this part, shall include projections of the extent to which resources will be acquired at 1-, 3-, and 5-year intervals.

§ 420.22 Intergovernmental cooperation.

(a) For the purpose of assisting the development of a plan for any interstate region, the State agency responsible for implementing national standards in any portion of such an interstate region shall furnish any available data on emissions, air quality, and control strategy development, upon request to any other State or local agency having such responsibility in any other portion of such interstate region.

(b) Each plan shall identify, by official title, local air pollution control agencies involved in the development of the plan as well as those which will participate in the implementation of the plan.

(c) Each plan shall provide that the State agency having primary responsibility for implementing national standards in any region, or portion thereof, will promptly transmit, to other State agencies having such responsibility in the same or other States, information on factors (e.g., construction of new industrial plants) which may significantly affect air quality in any other portion of such region or in any adjoining region.

Subpart C—Extensions

§ 420.30 Request for 2-year extension.

(a) The Governor of a State may, at the time of submission of a plan to implement a primary standard in a Priority I region, request the Administrator to extend, for a period not exceeding 2 years, the 3-year period for attainment of the primary standard in such region.

(b) Any such request regarding an interstate region shall be submitted jointly with the requests of Governors of all States in the region, or shall show that the Governor of each State in the region has been notified of such request.

(c) Any such request regarding attainment of a primary standard shall be submitted together with a plan providing for attainment of such primary standard not later than 5 years after the date of the Administrator's approval of such plan and shall show that it is more reasonable to provide for attainment of such primary standard within such 5-year period than within a 3-year period. Any plan so submitted shall reflect consideration of the emission reductions which can be achieved through application of measures such as those described in Appendix B to this part and in § 420.14(c).

(d) Any showing pursuant to paragraph (c) of this section shall include:

(1) A clear identification of emission sources or classes of moving sources which will be unable to comply with the requirements of such plan within a 3-year period because the necessary technology or alternative methods of compliance will not be available soon enough to permit such compliance.

(2) A clear identification and justification of any assumptions made with respect to the time at which such needed technology or alternative methods of compliance will be available.

(3) A clear identification of the alternative means of attainment of such primary standard which were considered and an explanation of why such alternatives were rejected as not being reasonably available.

(4) A showing that emission sources or classes of moving sources other than those referred to in subparagraph (1) of this paragraph will be required to comply, within such 3-year period, with any applicable requirements of such plan.

(5) A clear identification of the interim control measures provided for in such plan with respect to emissions from such source(s).

§ 420.31 Request for 18 month extension.

(a) Upon request of the State agency made in accordance with this section, the Administrator may, whenever he determines necessary, extend for a period not to exceed 18 months the deadline for submitting that portion of a plan that implements a secondary standard.

(b) Requests for such extensions will be given consideration only in the case of Priority I and Priority II regions.

(c) Requests for extensions of the deadline shall show that attainment of the secondary standards will require emission reductions exceeding those which can be achieved through the application of emission limitations identical or equivalent to those described in Appendix B to this part.

(d) In addition to satisfying the other requirements of this subpart, a request for extension of the deadline with respect to any portion of an interstate region shall be submitted jointly with requests for such extensions from all other States within the region or shall show that all such States have been notified of such request.

(e) A request for extension of the deadline shall be submitted sufficiently early to permit development of a plan prior to the deadline in the event that such request is denied. Any such request shall contain the information necessary to permit the Administrator to determine whether such request satisfies the requirements of this section.

Pollutant	Sampling methods	Number of sites per region	Frequency of sampling
Carbon monoxide	Nondispersive infrared or equivalent[1]	One	Continuous
Nitrogen dioxide	24-hour sampling period (Jacobs-Hochheiser) or equivalent[2]	do	One 24 hour sample, once every 3 days
Photochemical oxidants	Neutral buffered potassium iodide (KI) or equivalent	do	Continuous if equipment is available, otherwise, four 1 hour samples between 11 a.m. and 3 p.m. each day for 5 days per week

[1] Equivalent methods are gas chromatographic and mercury replacement.
[2] Equivalent methods are ultraviolet fluorescence and colorimetric.
[3] Equivalent methods are ultraviolet fluorescence and colorimetric.

(2) For Priority I regions, only a single air quality data for hydrocarbons must be submitted.

(3) For Priority III regions, no air quality data for carbon monoxide, hydrocarbons, nitrogen oxides, and photochemical oxidants need be submitted.

(4) Air quality data required by this subparagraph shall be submitted in the form similar to that shown in Appendix H to this part.

§ 420.15 Emergency action criteria and procedures.

Plans for Priority I and Priority II regions shall include criteria and procedures for implementing emission control actions commensurate with the severity of air pollution conditions in an emergency episode situation in accordance with the requirements of this section.

(a) Plans for Priority I and Priority II regions shall specify as episode criteria ambient pollutant concentrations at which control actions will be taken to reduce or prohibit emissions and shall provide for such actions to be taken when the specified concentrations are reached at any one monitoring site in the region. The control actions to be taken shall be identified by episode criteria level. Acceptable episode criteria and control actions are set forth in Appendix B to this part.

(b) Plans for Priority I regions shall include the following elements:

(1) Episode surveillance system.

(i) The air quality surveillance system in each such region shall include one or more air monitoring stations capable of providing data sufficiently rapidly to permit prompt identification of situations in which pollutant concentrations have reached, or are increasing toward, applicable episode criteria levels.

(ii) Each plan shall provide for daily acquisition of forecasts of atmospheric stagnation conditions and shall further provide that, during periods of atmospheric stagnation or any episode stage, such forecasts shall be updated at least every 12 hours.

(iii) Each plan shall provide for inspection of sources to ascertain compliance with applicable emission reduction requirements.

(2) Each plan shall include an emission reduction plan which shall include prescribed action for reduction of pollutant emissions at each episode criteria level. Such emission reduction plan shall include specific emission reduction action plans for each major source of pollution (100 tons per year or more). An acceptable episode control regulation is set forth in Appendix B to this part.

(3) Each plan shall provide for communications procedures for transmitting status reports and orders as to control actions to be taken during any episode stage, including procedures for contact with public officials, major emissions sources, public safety and emergency agencies and news media. Such communications procedures shall be set forth in a manual which shall specify, in detail, how contacts are made and received at each episode criteria level.

(c) In the event that procedures meeting the requirements of paragraph (b) of this section have not been fully implemented by the prescribed date for submitting a plan, a description of procedures under consideration and a timetable for their implementation shall be submitted with the plan. Such timetable shall provide for full implementation of such procedures within 1 year after such prescribed date. A description of actions that will be taken to reduce emissions during episodes which occur during such 1 year period shall be included.

§ 420.16 Control regulations.

The control strategy included in the plan shall be adopted in the form of control regulations and copies shall be submitted with the plan, together with timetables for implementation and enforcement of such regulations. A plan containing proposed control regulations does not satisfy requirements for plan content nor will it be construed a timely submission.

§ 420.17 Air quality surveillance.

(a) (1) The plan shall provide for the establishment of an air quality surveillance system meeting, at a minimum, the following requirements:

Classification of region	Pollutant	Sampling method	Minimum number of air quality monitoring sites	Minimum frequency of sampling
I	Suspended particulates	NASN high volume	One per 50,000 population up to 10 sites	One 24-hour sample every 6 days
		Tape sampler	One per 100,000 population up to 5 sites	Continuous
	Sulfur dioxide	Modified pararosaniline or equivalent[4]	One per 100,000 population up to 10 sites and	One 3-hour sample every 6 days (peak basis)[5]
			One per 250,000 population up to 5 sites	Continuous
	Carbon monoxide	Nondispersive infrared or equivalent[6]	One per 200,000 population up to 5 sites	Continuous
	Nitrogen dioxide	24-hour sampling method (Jacobs-Hochheiser method) or equivalent[4]	One per 100,000 population up to 10 sites and One per 250,000 population up to 5 sites	One 24-hour sample every 6 days (peak basis)[5]
				Continuous
	Oxidants	Neutral buffered potassium iodide colorimetric or equivalent[4]	One per 250,000 population up to 5 sites	Continuous
II	Suspended particulates	NASN high volume	3	One 24-hour sample every 6 days[7]
	Sulfur dioxide	Modified pararosaniline	3	One 24-hour sample every 6 days (peak basis)[5]
III	Suspended particulates	NASN high volume	1	One 24-hour sample every 6 days[7]
	Sulfur dioxide	Modified pararosaniline	1	One 24-hour sample every 6 days (peak basis)[5]

[4] Equivalent methods are continuous ultraviolet fluorescence, continuous colorimetric, or manual methods.
[5] Equivalent methods are continuous gas chromatographic and continuous coulometric.
[6] Equivalent methods are continuous electrochemical and continuous gas filter correlation.
[7] Manual methods are the Jacobs-Hochheiser and continuous.
[8] Equivalent methods are the continuous and manual methods.
[9] Equivalent to 1 hour sample per day.

(2) At least one sampling site must be located in the area of estimated maximum pollutant concentrations.

(b) The plan shall contain a description of the existing and proposed system which shall set forth:

(1) The basis for the design of the surveillance system, selection of samplers, and sampling sites.

(2) The locations of the samplers by Universal Transverse Mercator (UTM) grid coordinate or the equivalent. Any National Air Sampling Network sampling site may be designated as a sampler location.

(3) The sampling schedules.

(4) The methods of sampling and analysis.

(5) The method of data handling and analysis procedures.

(6) The timetable for the installation of any additional equipment needed to complete the system.

sented either in tabular form or as an isopleth map showing maximum pollutant concentrations and expected concentration gradient. Computer printouts of the input and output data associated with use of a diffusion model shall be retained and made available for inspection by the Administrator.

(4) Appendix B to this part contains examples of emission limitations and other measures directly applicable or adaptable to point sources and area sources. This subpart shall not be construed to require that such limitations or measures be applied solely to area sources or solely to point sources.

(e) Emissions data.

(1) Each plan shall include the following data on emissions of sulfur oxides and particulate matter:

(i) For each example region in the State a detailed inventory of emissions from point sources and area sources in each county shall be summarized in a form similar to that shown in Appendix D to this part, and the data described in Appendices E and F to this part shall be retained and made available for inspection by the Administrator.

(ii) For all other regions, point-source and area-source data shall be submitted in summary form as shown in Appendix G, except that for regions classified as Priority III, only point-source data and any existing area-source data shall be submitted. Data shown in Appendices E and F to this part shall be retained and made available for inspection by the Administrator.

(2) As used in this section, a "point source" is:

(i) Any stationary source causing emissions in excess of twenty-five (25) tons per year of any pollutant for which there is a national standard, or

(ii) Without regard to quantity of emissions, any source listed in Appendix C to this part.

(3) As used in this section, an "area source" is any small residential, government, institutional, commercial, or industrial fuel combustion operation, onsite waste disposal facility, motor vehicles, aircraft, vessels or other transportation facilities, or other miscellaneous sources such as those listed in Appendix D to this part, as identified through inventory techniques similar to those described in "A Rapid Survey Technique for Estimating Community Air Pollution Emissions," Public Health Service Publication No. 999-AP-29, October 1966.

(f) Air quality data. Data showing existing air quality with respect to sulfur oxides and particulate matter shall be submitted for each example region. Actual measurements shall be used where available. If actual measurements are not available and cannot be made in time to be employed in the development of the control strategy, air quality may be estimated by the procedure described in Appendix A to this part. Air quality data, whether measured or estimated, shall be submitted in the form shown in Appendix H to this part.

§ 420.14 Control strategy: Carbon monoxide, hydrocarbons, photochemical oxidants, and nitrogen dioxide.

(a) *Priority I Regions.* (1) Each plan for a region classified as Priority I shall include a control strategy which shall provide for the degree of emission reduction necessary for attainment and maintenance of the national standards after consideration of the emission reductions that will result from the application of Federal motor vehicle emission standards promulgated by the Administrator pursuant to section 202 of the Act.

(2) Unless specific data are available for a region, a State shall assume that such Federal motor vehicle emission standards will result in the emission reductions shown in Appendix I to this part. If specific data are used such data must be submitted in the plan for such region.

(b) *Priority III Regions.* For a region classified as Priority III, a control strategy need include only procedures for preventing ambient levels of a pollutant from exceeding the applicable primary standard. Regulations such as those described in section 1.1 of Appendix B to this part will be deemed to fulfill this requirement.

(c) *Control strategy development.* In a region in which attainment and maintenance of a national standard will require emission reductions in addition to those which will result from application of the Federal motor vehicle emission standards, the control strategy shall provide for application of such emission limitations or other measures as may be necessary for attainment and maintenance of such national standard, including, but not limited to the following:

(1) Emission limitations or other measures such as those described in Appendix B to this part.

(2) Emission limitations necessitating installation of emission control devices or systems on in-use motor vehicles, which limitations may be assumed to be capable of producing the emission reductions shown in Appendix I to this part.

(3) Emission limitations necessitating conversion of motor vehicle fleets, including commercial and governmental fleets, to use liquified natural gas or liquified petroleum gas or other low-emission fuels or engines.

(4) Measures to reduce motor vehicle traffic, particularly rush-hour traffic, including measures such as commuter taxes, gasoline rationing, parking limitations, staggered working hours, or restrictions on motor vehicle idling time.

(5) Expansion or promotion of the use of mass transportation facilities through measures such as increases in frequency, convenience, and passenger-carrying capacity of mass transportation systems, subsidization of the costs of operating such systems, providing for special bus lanes on major streets and highways, or other incentives to efficient operation and use of such systems.

(6) At such time as they are determined by the Administrator to be feasible and practicable, programs for periodic inspection and testing of motor vehicle emission control systems.

(d) *Adequacy of control strategy.* (1) The plan shall demonstrate that the control strategy included in such plan for a region classified as Priority I is adequate for attainment and maintenance of the national standard(s) to which such control strategy applies, by means of a proportional model or diffusion/photochemical model.

(i) With respect to control of carbon monoxide and nitrogen oxides, the proportional model to be used for purposes of this paragraph is described in § 420.13(d)(2), provided, with respect to the national standards for nitrogen dioxide, that the degree of air quality improvement indicated to be necessary by the proportional model will be achieved by a corresponding degree of reduction of total nitrogen oxides emissions from stationary and mobile sources.

(ii) With respect to control of hydrocarbons and photochemical oxidants, it may be assumed that the degree of total hydrocarbon emission reduction necessary for attainment and maintenance of the primary standards for photochemical oxidants will also be adequate for attainment of the primary standard for hydrocarbons. The proportional model to be used to determine the necessary reduction is set forth in Appendix J to this part.

(2) The plan shall show that the control strategy will result in the degree of emission reduction indicated to be necessary by the proportional model. The plan shall contain a summary of the computations used to determine the emission reductions that will result from application of the control strategy to each point source and each group of area sources. Such summary shall be included in a table similar to that presented in Appendix D to this part. The detailed computations shall be retained by the State and made available for inspection by the Administrator.

(3) If a diffusion/photochemical model is used, the plan shall include a description of such model.

(e) *Emission data.* Emission data on carbon monoxide, hydrocarbons, photochemical oxidants, and nitrogen oxides shall be submitted in accordance with the requirements in § 420.13(e).

(f) *Air quality data.* Data showing existing air quality levels shall be presented in accordance with this section.

(1) For Priority I regions, data on carbon monoxide, nitrogen dioxide, and photochemical oxidants shall, as a minimum, include the results of measurements made during the period July 1, 1971, through September 30, 1971, in accordance with the following procedures:

ards (which emission limitations and other measures, together with timetables for implementing such limitations and other measures, shall be referred to hereinafter as the "control strategy")

(3) The adequacy of the control strategy

(4) Existing air quality and source emissions

(5) Systems to be used for surveillance of air quality and emissions

(6) Procedures and criteria for emergency action

(7) The resources which are and will be made available for implementation of such plan

(8) Provisions for intergovernmental cooperation in the formulation and implementation of such plan

§ 120.11 Legal authority.

(a) The plan shall show that the State agency or agencies directly responsible for implementing the plan have legal authority to implement the plan, including authority to

(1) Adopt emission standards and limitations and any other measures required by the plan as necessary for attainment and maintenance of national ambient air quality standards

(2) Enforce applicable laws, regulations, and standards including authority to seek injunctive relief

(3) Abate pollutant emissions on an emergency basis to prevent substantial endangerment to public health, i.e. authority comparable to that available to the Environmental Protection Agency under section 303 of the Clean Air Act, as amended

(4) Establish and operate a statewide system under which permits would be required for the construction and operation of new stationary sources of air pollution and the construction and operation of modifications to existing sources, including authority to prevent such construction, modification, or operation and any other necessary land use control authority required by the plan

(5) Obtain information necessary to determine whether air pollution sources are in compliance with applicable laws, regulations, and standards including authority to require recordkeeping and to make inspections and conduct tests of air pollution sources

(6) Require owners or operators of stationary sources to install, maintain, and use emission monitoring devices and to make periodic reports to the State on the nature and amounts of emissions from such stationary sources and to make such data available to the public as reported and as correlated with any applicable emission standards

(7) Carry out a program of inspection and testing of motor vehicles to enforce compliance with applicable emission standards when necessary and practicable and to impose other necessary controls on transportation provided for in the plan

(b) The provisions of law or regulation which the State determines provide the authority required under this section shall be specifically identified, and copies of such laws or regulations shall be submitted with the plan.

(c) The plan shall show that the legal authorities specified in this section are available to the State agency or agencies directly responsible for implementing the plan at the time of submission of the plan.

§ 120.12 Control strategy: General.

(a) In any region where measured or estimated ambient levels of a pollutant are above the levels specified by an applicable national standard the plan shall include a control strategy which shall be shown to provide for the degree of emission reduction necessary for attainment and maintenance of such national standard reflecting the degree of emission reduction necessary to offset emission increases that can reasonably be expected to result from projected growth of population industrial activity, motor vehicle traffic or other factors that may cause or contribute to increased emissions.

(b) In any region where measured or estimated ambient levels of a pollutant are identical to, or below, the levels specified by an applicable secondary standard, the control strategy shall include procedures for preventing such ambient levels from exceeding such secondary standard. Regulations such as those described in section 11 of Appendix B to this part will be deemed to fulfill this requirement.

§ 120.13 Control strategy: Sulfur oxides and particulate matter.

(a) In any region where emission reductions are necessary for attainment and maintenance of a primary standard the control strategy shall provide for the application of such emission limitations or other measures as may be necessary to achieve such emission reductions including but not limited to, emission limitations or other measures such as those described in Appendix B to this part.

(b) (1) In any region where application of emission limitations or other measures which are not more stringent than those described in Appendix B to this part will result in attainment and maintenance of a secondary standard, "reasonable time" shall be 3 years or less, unless the State shows good cause why the application of such emission limitations or other measures should be postponed.

(2) Nothing in this subpart shall be construed as requiring or encouraging the adoption or enforcement of emission limitations or other measures which will necessitate restrictions on the use or composition of fuel in stationary sources, except as necessary for attainment of primary standards.

(c) Example region.

(1) A control strategy which provides for the attainment and maintenance of a national standard in one region in a State will be deemed by the Administrator to be adequate for attainment and maintenance of such standard in any or all other regions of the State in which measured or estimated levels of the pollutant are lower than those in the region for which the control strategy was formulated provided that such control strategy is sufficiently comprehensive to include adequate controls on sulfur oxides and particulate emissions from sources listed in Appendix C to this part. Any region (i) for which the State formulates a control strategy which is applied to other regions or (ii) for which a control strategy is developed, without regard to whether such strategy is applied outside of the region is referred to hereinafter as an "example region."

(2) The State shall obtain through the Regional Director the concurrence of the Administrator in the election of an example region.

(d) Adequacy of control strategy.

(1) The plan shall demonstrate that the control strategy for each national standard is adequate for attainment and maintenance of such standard in the example region(s) to which it applies. The adequacy of a control strategy shall be demonstrated by means of a proportional model or diffusion model.

(2) The proportional model shall be one in which the following equation is employed to calculate the degree of improvement in air quality needed for attainment of a national standard:

$$R = \frac{A - C}{A - B} \times 100 = \text{percent reduction needed}$$

where

R = Reduction needed

A = Air quality at the location having the highest measured or estimated concentration in the region

B = Background concentration

C = National standard

The plan shall show that application of the control strategy will result in a degree of emission reduction indicated to be necessary by the above calculation. The plan shall contain a summary of the computations used to determine the emission reductions that will result from application of the control strategy to each point source and group of area sources. Such summary shall be included in a table similar to that presented in Appendix D to this part. The detailed computations shall be retained and be made available for inspection by the Administrator.

(3) (i) If a diffusion model is used it shall be identified and described, provided however, that if either of the two diffusion models described in the following publications is used, it need only be identified.

Air Quality Implementation Planning Program (IPP) Volume I Operators Manual National Air Pollution Control Administration Environment Protection Agency Washington D.C., November 1970.

Air Quality Display Model (AQDM) National Air Pollution Control Administration Department of Health, Education and Welfare Washington, D.C. November 1969.

(ii) The plan shall contain a summary of emission levels expected to result from application of the control strategy, which summary shall be included in a table similar to that presented in Appendix D to this part.

(iii) The plan shall also show the air quality levels expected to result from application of the control strategy, pre-

(ii) The more restrictive classification will be chosen where there is a difference between the 24-hour maximum value and the annual average, e.g., if a region is Priority I with respect to an annual average and Priority II with respect to a 24-hour maximum value, the classification will be Priority I.

(2) The procedures which will be used to estimate air quality in regions where no measured data or inadequate data exist are described in Appendix A to this part.

(b) For carbon monoxide, nitrogen dioxide, and photochemical oxidants, each region will be classified into one of two categories, defined as Priority I or Priority III.

(1) Ambient concentration limits which define the classification system are:

(i) Carbon monoxide: Priority I: Equal to or above 21 milligrams per cubic meter, 1-hour maximum, or 14 milligrams per cubic meter, 8-hour maximum. Priority III: Below both of such values.

(ii) Nitrogen dioxide: Priority I: Equal to or above either of the primary standards. Priority III: Below both of the primary standards.

(iii) Photochemical oxidants: Priority I: Equal to or above 170 micrograms per cubic meter, 1-hour maximum. Priority III: Below such value.

(2) In the absence of measured data to the contrary, classification with respect to carbon monoxide, photochemical oxidants and nitrogen dioxide will be based on the following estimate of the relationship between these pollutants and population: Any region containing a metropolitan area whose 1970 "urban place" population, as defined by the U.S. Bureau of Census, exceeds 200,000 will be classified as Priority I. All other regions will be classified as Priority III.

(3) Classifications with respect to hydrocarbons will be the same as the classifications with respect to photochemical oxidants.

§ 120.03 Public hearings.

(a) Each State shall, prior to adoption of a plan and after reasonable notice thereof, conduct one or more public hearings on the plan. Separate hearings may be held for plans to implement primary and secondary standards.

(b) For purposes of this part, "reasonable notice" shall be considered to be notice given at least 21 days prior to the date of the hearings. In the case of an interstate region, "reasonable notice" shall be considered to include notice to the State agency of any other State a portion of which is included in the region and to any local agencies in such other State's portion of the region.

(c) States shall prepare and retain, for submission to the Administrator upon his request, a record of the hearing(s). The record shall contain, as a minimum, a list of witnesses together with a summary of each presentation.

(d) Each State shall submit with its plan (1) a copy of the notice required by this section, and (2) a certification that the hearing was held in accordance with the notice.

§ 420.04 Submission of plans, preliminary review of plans.

(a) Submission to the Administrator shall be accomplished by delivering five copies of the plan to the appropriate Regional Director and a letter to the Administrator notifying him of such action. Plans shall be adopted by each State and submitted to the Administrator by the Governor as follows:

(1) For any primary standard, within 9 months after promulgation of such standard.

(2) For any secondary standard within 9 months after promulgation of such secondary standard or by such later date prescribed by the Administrator pursuant to Subpart C of this part.

(b) Upon request of a State agency, the Administrator will provide preliminary review of a plan or portion thereof submitted in advance of the date such plan is due. Such request shall be made in writing to the appropriate Regional Director, and shall be accompanied by five copies of the material for which review is sought. Such requests shall be made no later than 90 days prior to the date on which a plan is required to be submitted. Requests for preliminary review shall not operate to relieve a State from the responsibility of adopting and submitting plans in accordance with prescribed due dates.

§ 120.05 Revisions.

(a) The plan shall provide for its revision from time to time as may be necessary to take account of:

(1) Revisions of national standards,

(2) The availability of improved or more expeditious methods of achieving such standards, or

(3) A finding by the Administrator that the plan is substantially inadequate to achieve or maintain the national standard which it implements.

(b) The plan shall be revised within 60 days following notification by the Administrator under paragraph (a) of this section, or by such later date prescribed by the Administrator after consultation with the State. Where required by the Administrator or the laws of the State, such revisions shall be adopted after reasonable notice and public hearings.

§ 120.06 Reports.

(a) For the 3-month period commencing with the approval of a plan by the Administrator and for each 3-month period thereafter, the State shall submit to the Administrator (through the Regional Director) a report on air quality data that includes data on pollutant concentrations, sampler types, sampling period, time intervals and frequency of sampling, methods of collection and analysis, sampler locations, and elevation and height of sampling stations.

(b) For the 6-month period commencing with the approval of a plan by the Administrator, and for each 6-month period thereafter the State shall submit to the Administrator (through the Regional Director) reports on progress toward carrying out the plan. Such reports shall include information on: Compliance with time schedules and emission limitations included in the plan; enforcement activities; implementation of permit and registration systems; source tests and monitoring programs; emergency episode regulations; actions taken with respect to variances; progress in acquiring the resources provided for in the plan; and any difficulties which have delayed or may delay the State in carrying out the approved plan.

(c) The reports required by this section shall be submitted within 30 days after the end of the reporting period on forms which shall be prescribed by the Administrator.

§ 120.07 Approval of plans, applicable State plans.

The Administrator shall approve any plan or portion thereof, or any revision of such plan or portion thereof, if he determines that it meets the requirements of the Act. The approved plan or any portion thereof shall be the applicable State plan for purposes of the Clean Air Act. Changes or revisions in such plan shall not be considered part of the applicable State plan until such changes or revisions have been approved by the Administrator in accordance with this part.

Subpart B—Plan Content and Requirements

§ 120.10 General requirements.

(a) Each plan shall include such emission limitations and other measures as are necessary for attainment and maintenance of the national standards in each region within the State to which such plan applies. Plans for different regions within a State may be submitted in a single document or in separate documents.

(b) Plans implementing a primary standard shall provide for the attainment of such standard as expeditiously as practicable, but in no case, except as otherwise provided by Subpart C of this part, later than 3 years after the date of the Administrator's approval of such plan.

(c) Plans implementing a secondary standard shall provide for the attainment of such standard within a reasonable time after the date of the Administrator's approval of such plan.

(d) The plan for each region shall have adequate provisions to insure that pollutant emissions within such region will not interfere with attainment and maintenance of the national standards in any portion of such region or in any other region.

(e) Each plan shall include in accordance with the requirements more specifically set forth in this subpart, separate sections setting forth:

(1) The legal authority to implement such plan.

(2) The emission limitations and other measures to be implemented in order to attain and maintain the national stand-

ENVIRONMENTAL PROTECTION AGENCY

[42 CFR Part 420]

NATIONAL AMBIENT AIR QUALITY STANDARDS

Preparation, Adoption, and Submittal of Implementation Plans

On or about April 30, 1971 pursuant to section 109 of the Clean Air Act, as amended, the Administrator will promulgate national ambient air quality standards for sulfur oxides, particulate matter, carbon monoxide, photochemical oxidants, hydrocarbons and nitrogen oxides. Within 9 months thereafter each State is required by section 110 of the Act to adopt and submit to the Administrator a plan which provides for the implementation, maintenance, and enforcement of such national ambient air quality standards within each air quality control region (or portion thereof) within the State. An additional period of no longer than 18 months may be allowed for adoption and submittal of that portion of a plan relating to implementation of secondary ambient air quality standards. State plans must provide for attainment of national primary ambient air quality standards within 3 years after the date of the Administrator's approval of such plans, except that a 2-year extension of this deadline may be granted by the Administrator upon application by a Governor if the application satisfies the requirements set forth in section 110(e) of the Act. State plans must provide for attainment of national secondary ambient air quality standards within a reasonable time. Within 4 months from the date on which State plans are required to be submitted, the Administrator must either approve or disapprove such plans or portions thereof. The regulations proposed herein contain the requirements to be met in preparing, adopting, and submitting implementation plans and in requesting extensions of the time deadlines set forth in the Act. The proposal also sets forth the factors which the Administrator will take into consideration in reviewing State plans and evaluating requests for extensions.

It is recognized that States will require assistance from the Environmental Protection Agency in preparing implementation plans conforming to the requirements proposed herein. The Agency will furnish such assistance through its Regional Air Pollution Control Directors.

Interested persons may submit written comments on the proposed [illegible] in triplicate to the Office of the Associate Commissioner, Air Pollution Control Office, Environmental Protection Agency, 411 West Chapel Hill St., Durham, NC 27701. All relevant comments postmarked not later than 21 days after publication of this notice will be considered. The regulations, modified as the Administrator deems appropriate after consideration of comments, will be effective upon the date of their republication in the FEDERAL REGISTER.

This notice of proposed rule making is issued under the authority of section 301(a) of the Clean Air Act (42 U.S.C. 1857g(a)), as amended by section 15(c)(2) of Pub. Law 91-604, 84 Stat. 1713.

Dated: March 30, 1971.

WILLIAM D. RUCKELSHAUS,
Administrator,
Environmental Protection Agency.

A new Part 420 would be added to Chapter IV, Title 42, Code of Federal Regulations, as follows:

PART 420—REQUIREMENTS FOR PREPARATION, ADOPTION, AND SUBMISSION OF PLANS

Subpart A—General Provisions

Sec.
420.01 Definitions.
420.02 Classification of regions.
420.03 Public hearings.
420.04 Submission of plans; preliminary review of plans.
420.05 Revisions.
420.06 Reports.
420.07 Approval of plans; applicable State plans.

Subpart B—Plan Content and Requirements

420.10 General requirements.
420.11 Legal authority.
420.12 Control strategy: General.
420.13 Control strategy: Sulfur oxides and particulate matter.
420.14 Control strategy: Carbon monoxide, hydrocarbons, photochemical oxidants, and nitrogen dioxide.
420.15 Emergency episode criteria and procedures.
420.16 Control regulations.
420.17 Air quality surveillance.
420.18 Review of new sources and modifications.
420.19 Source registration.
420.20 Emissions surveillance.
420.21 Resources.
420.22 Intergovernmental cooperation.

Subpart C—Extensions

420.30 Request for 2-year extension.
420.31 Request for 18-month extension.
420.32 Request for 1-year postponement.
Appendix A—Air Quality Estimation.
Appendix B—Air Pollution Control Regulations.
Appendix C—Major Pollutant Sources.
Appendix D—Emissions Inventory Summary (Example Regions).
Appendix E—Point Source Data.
Appendix F—Area Source Data.
Appendix G—Emissions Inventory Summary (Other Regions).
Appendix H—Air Quality Data Summary.
Appendix I—Projected Motor Vehicle Emissio[illegible]
Appendix J—[illegible] Hydrocarbon Emission [illegible] of Oxidant [illegible]
Appendix K—[illegible] Regulations.

Subpart A—General Provisions

§ 420.01 Definitions.

As used in this part, all terms not defined herein shall have the meaning given them in the Act.

(a) "Act" means the Clean Air Act (42 U.S.C. 1857–1857l), as amended by Public Law 91-604, 84 Stat. 1676).

(b) "Administrator" means the Administrator of the Environmental Protection Agency.

(c) "Primary standard" means a national primary ambient air quality standard promulgated pursuant to section 109 of the Act.

(d) "Secondary standard" means a national secondary ambient air quality promulgated pursuant to section 109 of the Act.

(e) "National standard" means either a primary or a secondary standard.

(f) "Plan" means an implementation plan under section 110 of the Act to attain and maintain a national standard.

(g) "Regional Director" means a Regional air pollution control Director of the Environmental Protection Agency.

(h) "State agency" means the air pollution control agency primarily responsible for development and implementation of a plan under the Act.

(i) "Local agency" means any air pollution control agency, other than a State agency, which is charged with responsibility for carrying out part of a plan.

(j) "Region" means (1) an air quality control region designated by the Secretary of Health, Education, and Welfare or the Administrator, (2) an area designated by a State as an air quality control region under subparagraph (1) or (2) of this paragraph.

§ 420.02 Classification of region.

This section establishes a classification system to categorize regions for purposes of plan development and evaluation. The requirements of this part vary according to the classification of each region in order that the time and resources to be expended in developing the plan for that region, as well as the substantive content of that plan, will be commensurate with the complexity of the air pollution problem. The classification will be based upon measured ambient air pollutant where known, or, where not known will be estimated air quality in the area or the maximum pollutant concentration all regions will be classified by the Administrator after consultation with State governments. Each region will be classified separately with respect to each of the following pollutants: sulfur oxides, particulate matter, carbon monoxide, nitrogen dioxide, and photochemical oxidants.

(a) For sulfur oxides and particulate matter each region will be classified into one of three categories, defined as Priority I, Priority II, or Priority III.

(1) (i) Ambient concentration limits (expressed as micrograms per cubic meter) which define the classification system for sulfur oxides and particulate matter are:

Pollutant	Priority I	Priority II	Priority III
	Greater than	*From - To*	*Less than*
Sulfur oxides:			
Annual arithmetic mean	100	60-100	60
24 hour maximum	455	260-455	260
Particulate matter:			
Annual geometric mean	95	60-95	60
24 hour maximum	325	150-325	150

FEDERAL REGISTER

VOLUME 36 • NUMBER 67

Wednesday, April 7, 1971 • Washington, D.C.

PART II

ENVIRONMENTAL PROTECTION AGENCY

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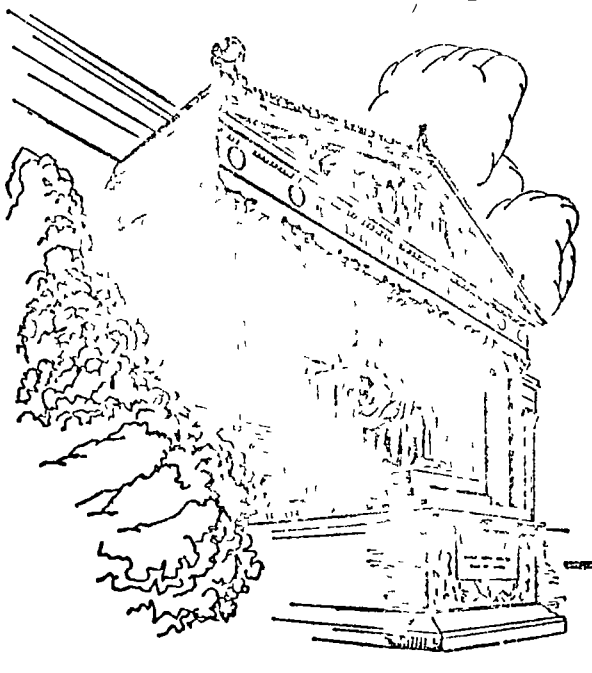
NATIONAL AMBIENT AIR QUALITY STANDARDS

Notice of Proposed Regulations for Preparation, Adoption, and Submittal of Implementation Plans



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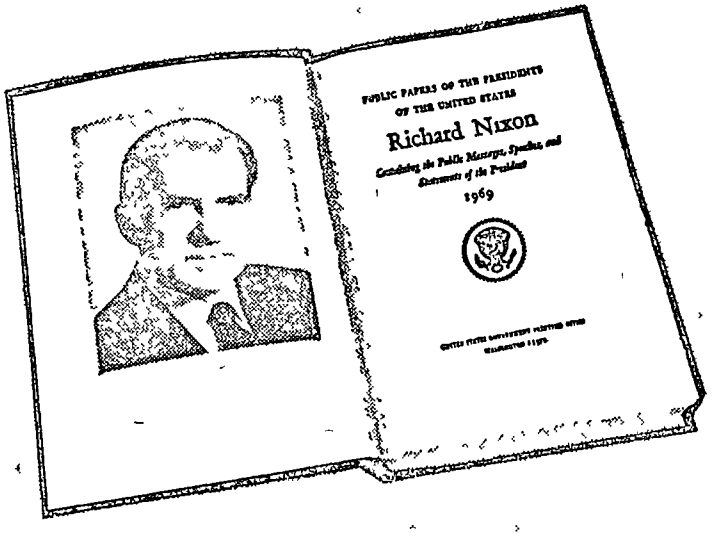

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k Establishments rendering amusement and recreational services including motion picture theaters

l Elementary and secondary schools, colleges, universities, professional schools, junior colleges, vocational schools, and public and private libraries

4 All commercial and manufacturing establishments not included in this order will institute such actions as will result in maximum reduction of air pollutants from their operation by ceasing, curtailing, or postponing operations which emit air pollutants to the extent possible without causing injury to persons or damage to equipment

5 The use of motor vehicles is prohibited except in emergencies with the approval of local or State police

Part B Source curtailment

Any person responsible for the operation of a source of air pollutants listed below shall take all required control actions for this Emergency Level

Source of air pollution	*Control action*
1 Coal or oil-fired electric power generating facilities	a Maximum reduction by utilization of fuels having lowest ash and sulfur content b Maximum utilization of mid-day (12 m. to 4 p.m.) atmospheric turbulence for boiler lancing or soot blowing c Maximum reduction by diverting electric power generation to facilities outside of Emergency Area
2 Coal and oil-fired process steam generating facilities	a Maximum reduction by reducing heat and steam demands to absolute necessities consistent with preventing equipment damage b Maximum utilization of mid-day (12 m. to 4 p m) atmospheric turbulence for boiler lancing and soot blowing c Taking the action called for in the emergency plan
3 Manufacturing industries of the following classifications Primary Metals Industries. Petroleum Refining Chemical Industries Mineral Processing Industries Grain Industry Paper and Allied Products	a Elimination of air pollutants from manufacturing operations by ceasing, curtailing, postponing or deferring production and allied operations to the extent possible without causing injury to persons or damage to equipment b Elimination of air pollutants from trade waste disposal processes which emit solid particles, gases, vapors or malodorous substances c Maximum reduction of heat load demands for processing d. Maximum utilization of mid-day (12 m. to 4 p.m.) atmospheric turbulence for boiler lancing or soot blowing

[FR Doc 71-11387 Filed 8-13-71,8 45 am]

4 Persons operating motor vehicles must reduce operations by the use of car pools and increased use of public transportation and elimination of unnecessary operation

Part B Source curtailment

Any person responsible for the operation of a source of air pollutants listed below shall take all required control actions for this Warning Level

Source of air pollution	*Control action*
1 Coal or oil-fired electric power generating facilities	a Maximum reduction by utilization of fuels having lowest ash and sulfur content b Maximum utilization of mid-day (12 m to 4 p.m.) atmospheric turbulence for boiler lancing and soot blowing c Maximum reduction by diverting electric power generation to facilities outside of Warning Area
2 Oil and oil-fired process steam generating facilities	a Maximum reduction by utilization of fuels having the lowest available ash and sulfur content b Maximum utilization of mid-day (12 m to 4 p m) atmospheric turbulence for boiler lancing and soot blowing c Making ready for use a plan of action to be taken if an emergency develops
3 Manufacturing industries which require considerable lead time for shut-down including the following classifications Petroleum Refining Chemical Industries Primary Metals Industries Glass Industries Paper and Allied Products	a Maximum reduction of air contaminants from manufacturing operations by, if necessary, assuming reasonable economic hardships by postponing production and allied operation b Maximum reduction by deferring trade waste disposal operations which emit solid particles, gases, vapors or malodorous substances c Maximum reduction of heat load demands for processing d Maximum utilization of mid-day (12 m to 4 p m) atmospheric turbulence for boiler lancing or soot blowing
4. Manufacturing industries require relatively short lead times for shut-down including the following classifications Primary Metals Industries Chemical Industries Mineral Processing Industries Grain Industry	a Elimination of air pollutants from manufacturing operations by ceasing, curtailing postponing or deferring production and allied operations to the extent possible without causing injury to persons or damage to equipment b Elimination of air pollutants from trade waste disposal processes which emit solid particles, gases, vapors or malodorous substances c Maximum reduction of heat load demands for processing d Maximum utilization of mid-day (12 m to 4 p m) atmospheric turbulence for boiler lancing or soot blowing

TABLE III—EMISSION REDUCTION PLANS

EMERGENCY LEVEL

Part A General

1 There shall be no open burning by any persons of tree waste, vegetation, refuse, or debris in any form

2 The use of incinerators for the disposal of any form of solid or liquid waste shall be prohibited

3 All places of employment described below shall immediately cease operations

a Mining and quarrying of nonmetallic minerals

b All construction work except that which must proceed to avoid emergent physical harm

c All manufacturing establishments except those required to have in force an air pollution emergency plan

d All wholesale trade establishments, i e, places of business primarily engaged in selling merchandise to retailers, or industrial, commercial, institutional or [illegible] users, or to other wholesale agents in buying merchandise for merchandise to [illegible] except those engaged in the sale of drugs, surgical supplies and food

e All offices of local, county and State government including authorities, joint meetings, and other public bodies excepting such agencies which are determined by the chief administrative officer of local, county, or State government, authorities, joint meetings and other public bodies to be vital for public safety and welfare and the enforcement of the provisions of this order

f All retail trade establishments except pharmacies, surgical supply distributors and stores primarily engaged in the sale of food

g Banks, credit agencies other than banks, securities and commodities brokers dealers exchanges and services, offices of insurance carriers, agents and brokers, real estate offices

h Wholesale and retail laundries laundry services and cleaning and dyeing establishments, photographic studios beauty shops, barber shops, shoe repair shops

i Advertising offices, consumer credit reporting, adjustment and collection agencies duplicating, addressing, blueprinting mailing, mailing list and [illegible] equipment rental services [illegible] laboratories [illegible] automobile services, garages

an Air Pollution Alert, any person responsible for the operation of a source of air pollutants as set forth in Table I shall take all Air Pollution Alert actions as required for such source of air pollutants and shall put into effect the preplanned abatement strategy for an Air Pollution Alert

(b) Air Pollution Warning—When the Director declares an Air Pollution Warning, any person responsible for the operation of a source of air pollutants as set forth in Table II shall take all Air Pollution Warning actions as required for such source of air pollutants and shall put into effect the preplanned abatement strategy for an Air Pollution Warning

(c) Air Pollution Emergency—When the Director declares an Air Pollution Emergency, any person responsible for the operation of a source of air pollutants as described in Table III shall take all Air Pollution Emergency actions as required for such source of air pollutants and shall put into effect the preplanned abatement strategy for an Air Pollution Emergency

(d) When the Director determines that a specified criteria level has been reached at one or more monitoring sites solely because of emissions from a limited number of sources, he shall notify such source(s) that the preplanned abatement strategies of Tables, I, II, and III or the standby plans are required, insofar as it applies to such source(s), and shall be put into effect until the criteria of the specified level are no longer met

1 5 3 *Preplanned abatement strategies* (a) Any person responsible for the operation of a source of air pollutants as set forth in Tables I–III shall prepare standby plans for reducing the emission of air pollutants during periods of an Air Pollution Alert, Air Pollution Warning, and Air Pollution Emergency Standby plans shall be designed to reduce or eliminate emissions of air pollutants in accordance with the objectives set forth in Tables I–III which are made a part of this section

(b) Any person responsible for the operation of a source of air pollutants not set forth under section 1 5 3(a) shall, when requested by the Director in writing, prepare standby plans for reducing the emission of air pollutants during periods of an Air Pollution Alert, Air Pollution Warning, and Air Pollution Emergency Standby plans shall be designed to reduce or eliminate emissions of air pollutants in accordance with the objectives set forth in Tables I–III

(c) Standby plans as required under sections 1 5 3(a) and 1 5 3(b) shall be in writing and identify the sources of air pollutants, the approximate amount of reduction of pollutants and a brief description of the manner in which the reduction will be achieved during an Air Pollution Alert, Air Pollution Warning, and Air Pollution Emergency

(d) During a condition of Air Pollution Alert, Air Pollution Warning, and Air Pollution Emergency, standby plans as required by this section shall be made available on the premises to any person authorized to enforce the provisions of applicable rules and regulations

(e) Standby plans as required by this section shall be submitted to the Director upon request within thirty (30) days of the receipt of such request, such standby plans shall be subject to review and approval by the Director If, in the opinion of the Director, a standby plan does not effectively carry out the objectives as set forth in Table I–III, the Director may disapprove it, state his reason for disapproval and order the preparation of an amended standby plan within the time period specified in the order

1 6 *Prohibition of air pollution* No person shall permit or cause air pollution, as defined in section 1 02 of this part

1 7 *Compliance schedule* Except as otherwise specified, compliance with the provisions of applicable rules and regulations shall be according to the following schedule

1 7 1 *Existing sources* All existing sources not in compliance with applicable rules and regulations on the date of adoption of such rules and regulations shall be in compliance within 6 months of the date of adoption unless the owner or person responsible for the operation of the source shall have submitted to the Director a control plan and schedule for achieving compliance, such plan and schedule to contain a date on or before which compliance will be attained, and such other information as the Director may require If approved by the Director, such date will be the date on which the person shall comply The Director may require persons submitting such a plan to submit subsequent periodic reports on progress in achieving compliance In no event shall the control plan and schedule prescribe a compliance date later than 3 years from the date of adoption of applicable rules and regulations

1 8 *Circumvention* No person shall install or cause the installation or use of any device or any means which, without resulting in reduction in the total amount of air pollutant emitted, conceals or dilutes an emission of air pollutant which would otherwise violate applicable rules and regulations

1 9 *Severability* If any provisions of these regulations or the application thereof to any person or circumstances is held to be invalid, such invalidity shall not affect other provisions or application of any other part of these regulations which can be given effect without the invalid provisions or application, and to this end the provisions of these regulations and the various applications thereof are declared to be severable

NOTE These example administrative procedures do not include examples for an administrative appeal procedure or for judicial review of decisions of the Director regarding permits and compliance schedules since such procedures ordinarily are dependent on generally applicable provisions of State law

TABLE I—ABATEMENT STRATEGIES EMISSION REDUCTION PLANS

ALERT LEVEL

Part A General

1 There shall be no open burning by any persons of tree waste, vegetation, refuse, or debris in any form

2 The use of incinerators for the disposal of any form of solid waste shall be limited to the hours between 12 m and 4 p m

3 Persons operating fuel-burning equipment which required boiler lancing or soot blowing shall perform such operations only between the hours of 12 m and 4 p m

4 Persons operating motor vehicles should eliminate all unnecessary operations

Part B Source curtailment

Any person responsible for the operation of a source of air pollutants listed below shall take all required control actions for this Alert Level

Source of air pollution	*Control action*
1 Coal or oil-fired electric power generating facilities	a Substantial reduction by utilization of fuels having low ash and sulfur content b Maximum utilization of mid-day (12 m to 4 p.m.) atmospheric turbulence for boiler lancing and soot blowing c Substantial reduction by diverting electric power generation to facilities outside of Alert Area
2 Coal and oil-fired process steam generating facilities	a Substantial reduction by utilization of fuels having low ash and sulfur content b Maximum utilization of mid-day (12 m to 4 p.m.) atmospheric turbulence for boiler lancing and soot blowing c Substantial reduction of steam demands consistent with continuity of operations
3 Manufacturing industries of the following classifications Primary Metals Industry Petroleum Refining Operations Chemical Industries Mineral Processing Industries Paper and Allied Products Grain Industry	a Substantial reduction of air pollutants from manufacturing operations by curtailing, postponing, or deferring production and all operations b Maximum reduction by deferring trade waste disposal operations which emit solid particles, gas vapors or malodorous substances c Maximum reduction of heat load demands for processing d Maximum utilization of mid-day (12 m to 4 p m) atmospheric turbulence for boiler lancing or soot blowing

TABLE II—EMISSION REDUCTION PLANS

WARNING LEVEL

Part A General

1 There shall be no open burning by any persons of tree waste, vegetation, refuse, or debris in any form

2 The use of incinerators for the disposal of any form of solid waste or liquid waste shall be prohibited

3 Persons operating fuel-burning equipment which requires boiler lancing or soot blowing shall perform such operations only between the hours of 12 m and 4 p.m.

APPENDIX K—CONTROL AGENCY FUNCTIONS

Man-year estimates by function for State of ---------- portion of ---- ------ AQCR

Function	Year							
	Present							
	State agency	Local agencies	State agency	Local agencies	State agency	Local agencies	State agency	Local agencies
Enforcement services (Subtotal)								
Scheduled inspections								
Complaints and field patrol								
Engineering services (Subtotal)								
Permit system								
Emission estimates								
Source testing								
Reports new legislation, etc								
Technical services (Subtotal)								
Operation of monitoring network								
Special studies								
Instrument Calibration and Maintenance								
Laboratory operations								
Data processing								
Management services (Subtotal)								
Policy P/R, Strategies, etc								
Staff training								
Administrative and clerical support								
Totals								

Fund estimates by function for State of ---------- portion of ---------- AQCR

Function	Year							
	Present							
	State agency	Local agencies	State agency	Local agencies	State agency	Local agencies	State agency	Local agencies
Enforcement services								
Operating funds								
Capital funds								
Contract funds								
Engineering services								
Operating funds								
Capital funds								
Contract funds								
Technical services								
Operating funds								
Capital funds								
Contract funds								
Management services								
Operating funds								
Capital funds								
Contract funds								
Total operating funds								
Total capital funds								
Total contract funds								
Total funds								

NOTE Report funds as $1,000

APPENDIX L—EXAMPLE REGULATIONS FOR PREVENTION OF AIR POLLUTION EMERGENCY EPISODES

The example regulations presented herein reflect generally recognized ways of preventing air pollution from reaching levels that would cause imminent and substantial endangerment to the health of persons States are required to have emergency episode plans for Priority I regions, but they are not required to adopt the regulations presented herein.

1 5 *Air pollution emergency* This regulation is designed to prevent the excessive buildup of air pollutants during air pollution episodes, thereby preventing the occurrence of an emergency due to the effects of these pollutants on the health of persons.

1 5 1 *Episode criteria* Conditions justifying the proclamation of an air pollution alert, air pollution warning or air pollution emergency shall be deemed to exist whenever the Director determines that the accumulation of air pollutants in any place is attaining or has attained levels which could, if such levels are sustained or exceeded, lead to a substantial threat to the health of persons In making this determination, the Director will be guided by the following criteria

(a) "Air Pollution Forecast" An internal watch by the Department of Air Pollution Control shall be actuated by a National Weather Service advisory that Atmospheric Stagnation Advisory is in effect or the equivalent local forecast of stagnant atmospheric condition

(b) "Alert" The Alert level is that concentration of pollutants at which first stage control actions is to begin An Alert will be declared when any one of the following levels is reached at any monitoring site

SO_2—800 $\mu g/m^3$ (0 3 p p m), 24-hour average

Particulate—3 0 COHs or 375 $\mu g/m^3$, 24-hour average

SO_2 and particulate combined—product of SO_2 p p m, 24-hour average, and COHs equal to 0 2 or product of SO_2 — $\mu g/m^3$, 24-hour average and particulate $\mu g/m^3$, 24-hour average equal to 65×10^3

CO—17 mg/m^3 (15 p p m) 8-hour average

Oxidant (O_3)—200 $\mu g/m^3$ (0 1 p p m)—1-hour average

NO_2—1130 $\mu g/m^3$ (0 6 p p m) 1-hour average, 282 $\mu g/m^3$ (0 15 p p m) 24-hour average

and meteorological conditions are such the pollutant concentrations can be expected to remain at the above levels for twelve (12) or more hours or increase unless control actions are taken

(c) 'Warning' The warning level indicates that air quality is continuing to degrade and that addition control actions are necessary A warning will be declared when any one of the following levels is reached at any monitoring site

SO_2—1,000 $\mu g/m^3$ (0 6 p p m) 24-hour average

Particulate—6 0 COHs or 750 $\mu g/m^3$, 24-hour average

SO_2 and particulate combined—product of SO p p m 24-hour average and COHs equal to 1 0 or product of SO_2 $\mu g/m^3$, 24-hour average and particulate $\mu g/m^3$, 24-hour average equal to 327×10^3

CO (30 p p m), 8-hour

Oxidant (O_3)—800 $\mu g/m^3$ (0 4 p p m) 1-hour average

NO_2—2,260 $\mu g/m^3$ (1 2 p p m)—1-hour average 565 $\mu g/m^3$ (0 3 p p m) 24-hour average

and meteorological conditions are such that pollutant concentrations can be expected to remain at the above levels for twelve (12) or more hours or increase unless control actions are taken

(d) Emergency The emergency level indicates that air quality is continuing to degrade to a level that should never be reached and that the most stringent control actions are necessary An emergency will be declared when any one of the following levels is reached at any monitoring site

SO —2 100 $\mu g/m^3$ (0 8 p p m) 24-hour average

Particulate—8 0 COHs or 1 000 $\mu g/m^3$ 24-hour average

SO_2 and particulate combined—product of SO p p m 24-hour average and COHs equal to 2 0 or product of SO_2 $\mu g/m^3$ 24-hour average and particulate $\mu g/m^3$ 24-hour average equal to 650×10^3

CO—46 mg/m^3 (40 p p m) 8-hour average

Oxidant (O_3)—1,200 $\mu g/m^3$ (0 6 p p m), 1-hour average

NO_2—3 000 $\mu g/m^3$ (1 6 p p m), 1-hour average 750 $\mu g/m^3$ (0 4 p p m), 24-hour average

and meteorological conditions are such that this condition can be expected to continue for twelve (12) or more hours

(e) 'Termination' Once declared, any status reached by application of these criteria will remain in effect until the criteria for that level are no longer met At such time, the next lower status will be assumed

1 5 2 *Emission reduction plans* (a) Air Pollution Alert—When the Director declares

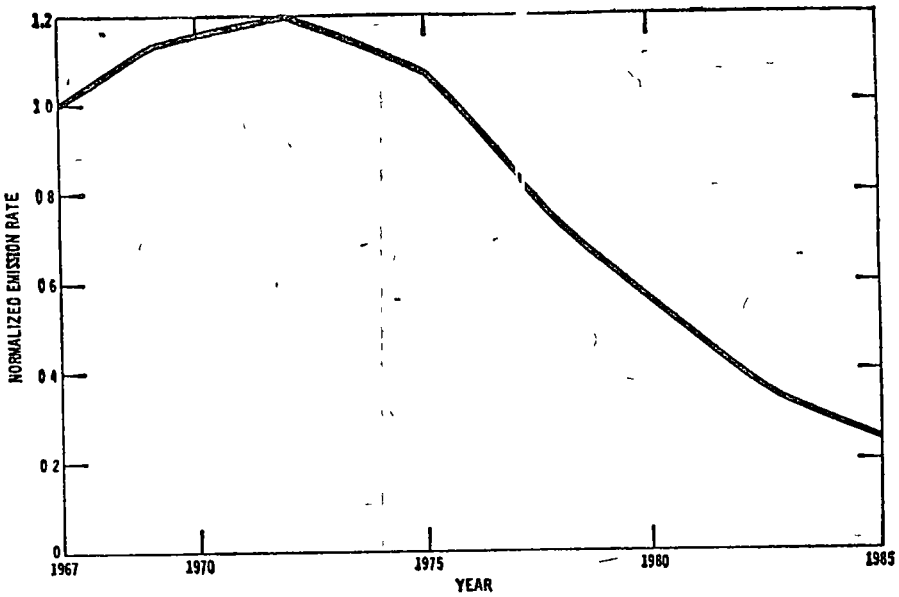

Figure 3. Nitrogen oxides emission rates from urban vehicles in United States - projected from 1967 base of 1.

APPENDIX J

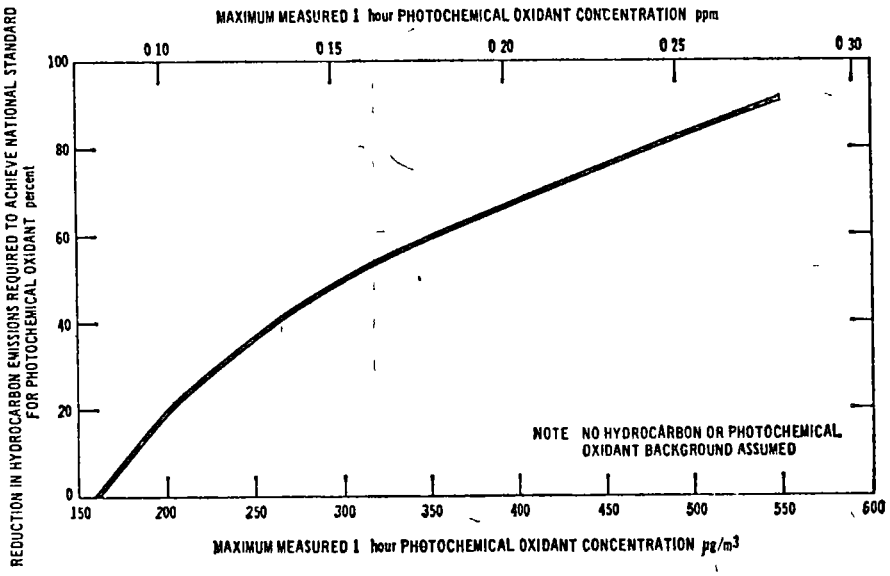

Figure 1. Required hydrocarbon emission control as a function of photochemical oxidant concentration. (Reference: Air Quality Criteria for Nitrogen Oxides, AP-84, Environmental Protection Agency, Washington, D C , January 1971)

AQ = Air quality (measured or estimated) in region
E = Normalized emissions from Figures 1–3
F = Ratio of motor vehicle emissions to total emissions of each pollutant in region
GF = Growth factor for emission increases from stationary sources

This equation can be applied directly for carbon monoxide, nitrogen dioxide (if all nitrogen oxides emissions are assumed to be measured as nitrogen dioxide), and nonmethane hydrocarbons (assumes reduction in total hydrocarbon emissions will result in a proportion reduction of measured nonmethane hydrocarbons) The equation cannot directly be applied to determine the reduction in photochemical oxidant levels resulting from reductions in hydrocarbon emissions The percent reduction in hydrocarbon emissions expected from the Federal Motor Vehicle Control Program can be estimated using that portion of the equation in brackets [ ] By using Appendix J, it can be determined if this is sufficient to achieve the national standard for photochemical oxidants and if stationary source and/or transportation controls are required

REFERENCES

1 FEDERAL REGISTER, Vol 35, No 219 Part II No. 10, 1970

2 Exhaust Emissions from Privately Owned 1966–1970 California Automobiles—A Statistical Evaluation of Surveillance Data," Supplement to Progress Report No 22 by Arthur J Hooker, California Air Resources Board Los Angeles, Calif , Apr 19, 1971

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4 'Automotive News—1968 Almanac Issue' Slocum Publishing, Detroit, Mich , Apr 29, 1969

5 Bostich, T A , and Greenbalgh, H J , "Relationship of Passenger Car Age and other Factors to Miles Driven," U S Department of Commerce, Bureau of Public Roads, Washington, D C , Jan 1967

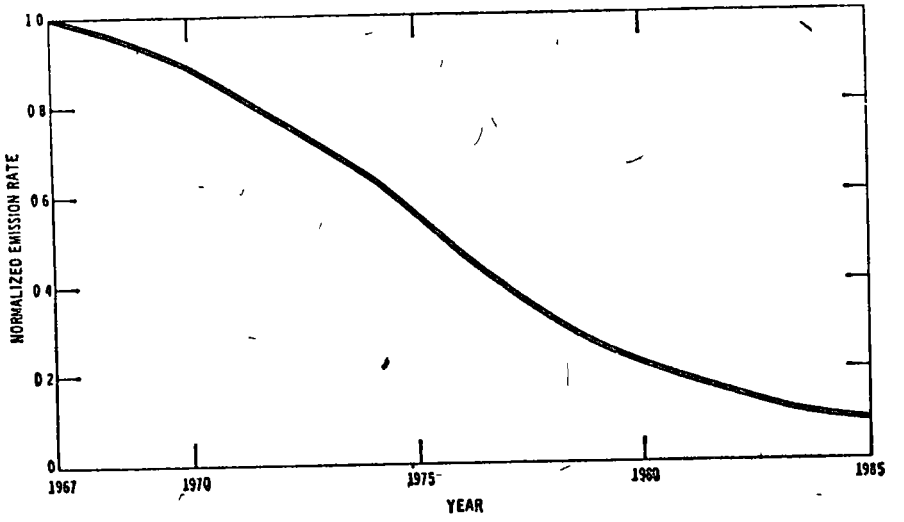

Figure 1. Hydrocarbon emission rates from urban vehicles in United States - projected from 1967 base of 1.

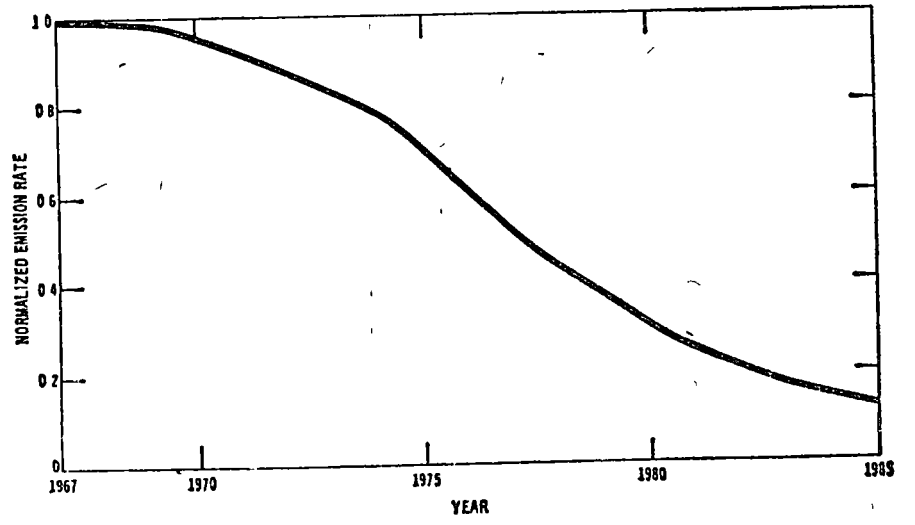

Figure 2. Carbon monoxide emission rates from urban vehicles in United States - projected from 1967 base of 1.

4 Residual Oil (plus type size of unit)—10^3 gal /year or 10^3 liters/year
5 Natural Gas (plus type and size of unit)—10^6 cu -ft /year or 10^6 cu -meters/year
6 Wood—tons/years or metric tons/year
7 Other—please specify
B Commercial and Institutional Fuel
1 Anthracite Coal (plus type and size of unit)—tons/year or metric tons/year
2 Bituminous Coal (plus type and size of unit)—tons/year or metric tons/year
3 Distillate Oil (plus type and size of unit)—10^3 gal /year or 10^3 liters/year
4 Residual Oil (plus type and size of unit)—10^3 gal /year or 10^3 liters/year
5 Natural Gas (plus type and size of unit)—10^6 cu -ft /year or 10^6 cu -meters/year
6 Wood—tons/year or metric tons/year
7 Other—please specify
C Industrial Fuel
1 Anthracite Coal (plus type and size of unit)—tons/year or metric tons/year
2 Bituminous coal (plus type and size of unit)—tons/year or metric tons/year
3 Coke (plus type and size of unit)—tons/year or metric tons/year
4 Distillate Oil (plus type and size of unit)—10^3 gal /year or 10^3 liters/year
5 Residual Oil (plus type and size of unit)—10^3 gal /year or 10^3 liters/year
6 Natural Gas (plus type and size of unit)—10^6 cu -ft /year or 10^6 cu -meters/year
7 Wood—tons/year or metric tons/year
8 Other—please specify

II PROCESS LOSSES (HYDROCARBONS ONLY)

A Surface coating operations, dry cleaning, degreasing operations, etc, unless considered as point sources—appropriate basis for emission estimate

III SOLID WASTE DISPOSAL

A On-site incineration (plus type of unit)—tons/year or metric tons/year
B Open burning—tons/year or metric tons/year
C Other—please specify

IV TRANSPORTATION

A Gasoline-powered motor vehicles—appropriate basis for emission estimate, including hydrocarbon evaporative losses
B Diesel-powered motor vehicles—appropriate basis for emission estimate
C Off-highway fuel usage—10^3 gal /year or 10^3 liters/year
D Aircraft—number of flights per year per type of aircraft
E Railroad—10^3 gal diesel oil/year or 10^3 liters/year
F Vessels—10^3 gal or 10^3 liters of oil/year, tons or metric tons of coal/year, or tons or metric tons of wood/year
G Gasoline handling evaporative losses—appropriate basis for hydrocarbon emission estimate from filling tank trucks, service station tanks, and automobile tanks
H Other—please specify

V MISCELLANEOUS

A Forest fires—appropriate basis for emission estimate
B Structural fires—appropriate basis for emission estimate
C Coal refuse burning—appropriate basis for emission estimate
D Agricultural burning—appropriate basis for emission estimate
E Other—please specify

APPENDIX G—(POLLUTANT) EMISSIONS INVENTORY SUMMARY TONS/YR (OR METRIC TONS/YR) (REGIONS WHERE EMISSION LIMITATIONS ARE NOT DEVELOPED)

_ _ __ _ _ AIR QUALITY CONTROL REGION

DATA REPRESENTATIVE OF CALENDAR YEAR __

Source category	State A			State B[1]		
	County 1	____ __	County N	State region total	Ditto	Regional[1] total
	"	"	"	"	Ditto	"
I Fuel combustion—Stationary sources						
A Area sources [iii]						
B Point sources						
C Total						
II Process losses						
A Area sources [iii] [iv]						
B Point sources						
1 Chemical process industries						
2 Food and agricultural industries						
3 Metallurgical industries						
4 Mineral products industries						
5 Petroleum refining and petrochemical operations						
6 Wood processing						
7 Petroleum storage						
C Total						
III Solid waste disposal						
A Area sources [iii]						
B Point sources						
C Total						
IV Transportation (Area Sources only) [iii] [v]						
V Miscellaneous (Area Sources only) [iii]						
VI Grand totals						
A Area sources [iii]						
B Point sources						
C Total						

[1] Included only if interstate region
[ii] Existing Emissions
[iii] If not available, does not need to be submitted for Priority III regions
[iv] For hydrocarbons only, would include emissions for surface coating operations, dry cleaning, degreasing operations, etc, unless considered point sources
[v] For hydrocarbons would include vehicle evaporative losses and losses from filling trucks, service station tanks, and automobile tanks

APPENDIX H—AIR QUALITY DATA SUMMARY

Pollutant	Sampling site location[1]	Sampling interval (months)	Start date	End date	Number of samples	Maximum 1-hour	Maximum 3 hours, 6-9 a m	Maximum 8 hours	Maximum 24 hours	Annual arith mean	Std dev	Annual geo mean	Geo std dev
Particulate matter	X	X	X	X	X				X	X	X	X	X
Sulfur oxides (as SO_2)	X	X	X	X	X				X	X	X		X
Nitrogen dioxide	X	X	X	X	X					X	X		X
Photo chemical oxidants	X	X	X	X	X	X				X	X		X
Carbon monoxide	X	X	X	X	X	X		X		X	X		X

X = Date or information required
[1] UTM Grid coordinate or equivalent

APPENDIX I—PROJECTED MOTOR VEHICLE EMISSIONS

The assumptions listed below were made in calculating the projected national urban emissions from motor vehicles as shown in Figures 1–3

a Emission factors are based on the new Federal test procedure (1), which has an average route speed of 18 miles per hour (29 kilometers per hour).

b Emission control devices are assumed to just meet present and proposed standards when new, but deteriorate with age Deterioration factors are adapted from data given in Reference 2

c Urban vehicle-mile projections adapted from Reference 3

d Distribution of automobiles by age from Reference 4

e Relative miles of travel fo[illegible] (i e, new cars are driv[illegible] ones) from Reference [illegible]

Figures 1–3 can be used to approximate air quality levels resulting from the Federal Motor Vehicle Control Program. The following equation calculates the expected air quality concentration for any given year

$$A\,Q_1 = A\,Q_0\left[\frac{E_1}{E_0}\,F_0 + (1-F_0)\,(GF)\right]$$

[illegible] and 1 denote the base year [illegible]erest, respectively.

APPENDIX D—(POLLUTANT) EMISSIONS INVENTORY SUMMARY, TONS/YR. (EXAMPLE REGIONS AND WHERE EMISSION LIMITATIONS ARE DEVELOPED)—Continued

Source category	State A						State B [1]				
	County 1		------	------	County N		State region total		Ditto	Region [1] total	
	[ii]	[iii]	[ii]	[iii]	[ii]	[iii]	[ii]	[iii]	Ditto	[ii]	[iii]
IV Transportation (area sources only)											
A Motor vehicles											
1 Gasoline powered [v]											
2 Diesel powered											
B Off-highway fuel usage											
C Aircraft											
D Railroads											
E Vessels											
F Gasoline handling evaporative losses [vi]											
G Other (specify)											
H Total transportation											
V Miscellaneous (area sources only)											
A Forest fires											
B Structural fires											
C Coal refuse burning											
D Agricultural burning											
E Other (specify)											
F Total miscellaneous											
VI Grand totals											
A Area sources											
B Point sources											
C Total											

[1] Included only if interstate region
[ii] "Existing Emissions"
[iii] "Emissions Achieved" with control regulations of implementation plans Must be submitted in example regions
[iv] For hydrocarbons only, would include emissions or surface coating operations, dry cleaning, degreasing operations etc, unless considered point sources
[v] For hydrocarbons, would include vehicle evaporative losses
[vi] For hydrocarbons only, would include losses from filling tank trucks, service station tanks, and automobile tanks

APPENDIX E—POINT SOURCE DATA

(The following information is not required to be submitted with an implementation plan but must be available for inspection by the Administrator, EPA)

I GENERAL SOURCE INFORMATION

A Establishment name and address
B Person to contact on air pollution matters and telephone number
C Operating schedule
1 Percent of annual production by season
2 Days of week normally in operation
3 Shifts or hours of day normally in operation
4 Number of days per year in operation
D Year in which data are recorded
E Future activities, if available (e g, addition of new or expansion of existing facilities, changes in production rate, installation of control equipment, phasing out of equipment, fuel change, etc)
F Map or general layout of large complex plants showing locations of various facilities, if available [1]

II FUEL COMBUSTION

A Number of boilers
B Type of fuel burning equipment for each boiler
C Rated and/or maximum capacity of each boiler 10^6 B t u /hr or kcal/hr.
D Types of fuel burned, quantities, and characteristics
1 Type of each fuel used and place of origin
2 Maximum and average quantity per hour
3 Quantity per year
4 Sulfur content (as received), percent
5 Ash content (as received), percent
6 Heat content (as received), B t u or kcal/unit of measure
7 Estimate of future usage, if available
E Percent used for space heating and process heat
F Air pollution control equipment (existing and proposed)
1 Type
2 Collection efficiency (design and actual), percent
G Stack data
1 List stacks by boilers served
2 Location of stacks by grid coordinates (Universal Transverse Mercator, UTM, or equivalent) [1]
3 Stack height feet or meters
4 Stack diameter (inside, top), feet or meters
5 Exit gas temperature, °F or °C
6 Exit gas velocity, feet/sec or meters/sec
H Emission data
1 Based on emission factors
2 Estimate of emissions by the source
3 Results of any stack tests conducted

III MANUFACTURING ACTIVITIES (PROCESS LOSSES)

A Process name or description of each product
B Quantity of raw materials used and handled for each product, maximum quantity per hour, and average quantity per year
C Quantity of each product manufactured, maximum quantity per hour, and average quantity per year
D Description of annual, seasonal, monthly, weekly, and daily operating cycle including downtime for maintenance and repairs
E Air pollution control equipment in use (existing and proposed)
E Air pollution control equipment in use (existing and proposed)
1 Type
2 Collection efficiency (design and actual), percent
F Stack data
1 List of stacks by equipment served
2 Location of stacks by grid location (UTM or equivalent) [1]
3 Stack height, feet or meters
4 Stack diameter (inside, top), feet or meters
5 Exit gas temperature, °F or °C
6 Exit gas velocity, feet/sec or meters/sec
G Emission data
1 Based on emission factors
2 Estimate of emissions by the source
3 Results of any stack tests conducted

IV SOLID WASTE DISPOSAL

A Amount and description of solid waste generated, quantity per year
B Percent of total that is combustible
C Method of disposal (on-site or off-site)
D Description of on-site disposal method, if applicable (incineration, open burning, landfill, etc) including maximum quantities disposed per hour and average quantities disposed per year and actual operating schedule
1 Location of the source by a grid system (UTM or equivalent) [1]
2 If method of disposal is by an incinerator, include the following information
a Auxiliary fuel used
b Air pollution control equipment (existing and proposed)
(1) Type
(2) Collection efficiency (actual and design) percent
c Stack data
(1) List stacks by furnaces served.
(2) Stack height, feet or meters
(3) Stack diameter (inside, top), feet or meters
(4) Exit gas temperature, °F or °C
(5) Exit gas velocity, feet/sec or meters/sec
(6) Exit gas moisture content, percent, if available
3 Emission data
a Based on emission factors
b Estimate of emissions by the source
c Results of any stack tests conducted

APPENDIX F—AREA SOURCE DATA

(The following information is not required to be submitted with an implementation plan but must be available for inspection by the Administrator, EPA)

Grid Coordinate (lower left-hand corner) ------, UTM or equivalent [2]
Average Stack Height of Sources— ------ [3]

I FUEL COMBUSTION—STATIONARY SOURCES

Includes sulfur and ash content of fuels, if applicable)
A Residential Fuel
1 Anthracite Coal (plus type and size of unit) [4]—tons/year or metric tons/year
2 Bituminous Coal (plus type unit)—tons/year or metric tons/year
3 Distillate Oil (plus type and size unit)—10^3 gal /year or 10^3 liters/year

[1] Required only when diffusion modeling is utilized
[1] Emissions data for all source categories and subcategories should be summarized in the implementation plans as is in Appendix D or G
[2] Data is required on a grid basis only when diffusion modeling is utilized For proportional model technique, data must be available on a county basis
[3] Required only when diffusion modeling is utilized
[4] Average type and size for each category This is used as the basis for selection of average emission factor

APPENDIX D—(POLLUTANT) EMISSIONS INVENTORY SUMMARY TONS/YR (OR METRIC TONS/YR) (EXAMPLE REGIONS)

. . . . . AIR QUALITY CONTROL REGION

DATA REPRESENTATIVE OF CALENDAR YEAR .

Source category	County 1		State A		County N		State B [1] State region total		Ditto		Region [1] total	
	II	III	II	III	II	III	II	III	Ditto		II	III
I. Fuel combustion—stationary sources												
A Residential fuel												
1 Anthracite coal												
a. Area sources												
b Point sources												
2 Bituminous coal												
a. Area sources												
b Point sources												
3 Distillate oil												
a Area sources												
b Point sources												
4 Residual oil												
a Area sources												
b Point sources												
5 Natural gas												
a Area sources												
b Point sources												
6 Wood												
a. Area sources												
b Point sources												
7 Other (specify)												
a. Area sources												
b Point sources												
8 Total												
B Commercial and institutional fuel												
1 Anthracite coal												
a. Area sources												
b Point sources												
2 Bituminous coal												
a Area sources												
b Point sources												
3 Distillate oil												
a Area sources												
b Point sources												
4. Residual oil												
a Area sources												
b Point sources												
5. Natural Gas												
a Area sources												
b Point sources												
6 Wood												
a. Area sources												
b Point sources												
7 Other (specify)												
a. Area sources												
b Point sources												
8 Total												
C Industrial fuel												
1 Anthracite coal												
a Area sources												
b Point sources												
2 Bituminous coal												
a. Area sources												
b Point sources												
3 Coke												
a. Area sources												
b Point sources												
4 Distillate oil												
a Area sources												
b Point sources												
5 Residual oil												
a. Area sources												
b Point sources												

See footnotes at end

APPENDIX D—(POLLUTANT) EMISSIONS INVENTORY SUMMARY TONS/YR (EXAMPLE REGIONS AND WHERE EMISSION LIMITATIONS ARE DEVELOPED)—Continued

Source category	County 1		State A		County N		State B [1] State region total		Ditto		Region [1] total	
	II	III	II	III	II	III	II	III	Ditto		II	III
Fuel combustion—stationary sources—Continued												
C Industrial fuel—Continued												
6 Natural gas												
a. Area sources												
b Point sources												
7 Process gas												
a. Area sources												
b Point sources												
8 Other (specify)												
a Area sources												
b Point sources												
9 Total												
D Steam-electric power plant fuel (point sources only)												
1 Anthracite coal												
2 Bituminous coal												
3 Coke												
4 Distillate oil												
5 Residual oil												
6 Natural gas												
7 Process gas												
8 Other (specify)												
9 Total												
E Total stationary fuel combustion												
II Process losses												
A. Area sources [1]												
B Point sources												
1 Chemical process industries												
2 Food and agricultural industries												
3 Metallurgical industries												
4 Mineral products industries												
5 Petroleum refining and petrochemical operations												
6 Wood processing												
7 Petroleum storage												
C Total process losses												
III Solid waste disposal												
A Incineration												
1. On-site												
a Area sources												
b Point sources												
2. Municipal, etc												
a. Area sources												
b Point sources												
B Open burning												
1 On-site												
a. Area sources												
b Point sources												
2. Dumps												
a. Area sources												
b Point sources												
C Other (specify)												
1 Area sources												
2. Point sources												
D Total solid waste disposal												

plish complete drainage before the removal When loading is effected through means other than hatches, all loading and vapor lines can be equipped with fittings which make vapor-tight connections and which close automatically when disconnected This emission limitation will result in 55 to 60 percent reduction in volatile organic emissions from uncontrolled sources in gasoline marketing and other organic transfer operations

4 3 *Volatile organic compounds water separation* Single or multiple compartment volatile organic compounds water separators which receive effluent water containing 200 gallons (760 liters) a day or more of any volatile organic compound from any equipment processing, refining treating, storing or handling volatile organic compounds having a Reid vapor pressure of 0 5 pound or greater can be equipped with one of the following vapor loss control devices, properly installed in good working order and in operation

(a) A container having all openings sealed and totally enclosing the liquid contents All gauging and sampling devices can be gas-tight except when gauging or sampling is taking place

(b) A container equipped with a floating roof, consisting of a pontoon type, double deck type roof, or internal floating cover, which will rest on the surface of the contents and be equipped with a closure seal or seals to close the space between the roof edge and container wall All gauging and sampling devices can be gas-tight except when gauging or sampling is taking place

(c) A container equipped with a vapor recovery system consisting of a vapor gathering system capable of collecting the organic vapors and gases discharged and a vapor disposal system capable of processing such organic vapors and gases so as to prevent their emission to the atmosphere and with all container gauging and sampling devices gas-tight except when gauging or sampling is taking place This emission limitation will reduce organic compound emissions from uncontrolled waste water separator units approximately 95 to 100 percent

4 4 *Pumps and compressors* All pumps and compressors handling volatile organic compounds can be equipped with mechanical seals or other equipment of equal efficiency

4 5 *Waste gas disposal* Any waste gas stream containing organic compounds from any ethylene producing plant or other ethylene emission source can be burned at 1 300° F (704° C) for 0 3 second or greater in a direct-flame afterburner or an equally effective device This does not apply to emergency reliefs and vapor blowdown systems The emission of organic compounds from a vapor blowdown system or emergency relief can be burned by smokeless flares, or an equally effective control device This emission limitation will reduce organic compound emissions approximately 98 percent

4 6 *Organic solvents* The emission of organic compounds of more than 3 pounds (1 3 kg) per hour or 15 pounds (6 8 kg) per day from any equipment can be reduced by at least 85 percent This can be accomplished by

(a) Incineration, provided that 90 percent or more of the carbon in the organic compounds being incinerated is oxidized to carbon dioxide, or

(b) Carbon adsorption This limitation can be applied to a variety of solvent users including industrial surface coatings, dry cleaning degreasing and printing operations Surface coating operations may appropriately be exempted from this limitation when the coating's solvent makeup is water-based and does not exceed 20 percent of organic compounds by volume Organic solvents which have been shown to be virtually unreactive in the formation of oxidants, e g , saturated halogenated hydrocarbons, perchloroethylene, benzene, acetone, and C_1-C_5 n-paraffins also may be considered for exemption Other compounds which hav been shown to have low reactivity include cyclohexanone, ethyl acetate, diethylamine, isobutyl acetate, isopropyl alcohol, methyl benzoate, 2-nitropropane phenyl aceta e and triethylamine This emission limitation may impose an economic burden upon some paint spray booth installations If such sources are not major contributors to hydrocarbon pollution levels, they may appropriately be considered for exemption

4 7 *Architectural coatings for buildings* The emission of organic compounds from architectural coatings can be reduced by requiring the use of water-base or other coatings having an organic solvent content of less than 20 percent by volume The effectiveness of the limitations set forth in §§ 4 6 and 4 7 will vary, depending on the nature and amounts of emissions in an area, a rough estimate based on Los Angeles emission data indicates that application of the limitation would result in a 70 percent reduction in organic solvent emissions In estimating the effectiveness, it should be assumed that all organic emissions are reactive, use of exempt solvents as substitutes for regulated solvents may be considered 100 percent effective in reducing reactive organic solvent emissions

5 0 CONTROL OF CARBON MONOXIDE EMISSIONS

The emissions of carbon monoxide can be limited by requiring complete secondary combustion of waste gas generated in such operations as a grey iron cupola, blast furnace, basic oxygen steel furnace, catalyst regeneration of a petroleum cracking system, petroleum fluid coker or other petroleum process

6 0 CONTROL OF NITROGEN OXIDES EMISSIONS

6 1 *Fuel burning equipment* The emission of nitrogen oxides calculated as nitrogen dioxide from gas-fired fuel burning equipment can be limited to 0 2 pound per million B t u (0 36 gm/10^6 gm-cal) of heat input This emission limitation is about equivalent to a nitrogen dioxide concentration of 175 p p m , by volume, on a dry basis at 3 percent oxygen and represents about a 50 percent reduction in nitrogen oxide emissions from uncontrolled gas-fired equipment

The emission of nitrogen oxides, calculated as nitrogen dioxide, from oil-fired fuel burning equipment can be limited to 0 30 pound per million B t u (0 54 gm/10^6 gm-cal) of heat input This emission limitation is about equivalent to a nitrogen dioxide concentration of 230 p p m , by volume, on a dry basis, at 3 percent oxygen and represents about a 50 percent reduction in nitrogen oxide emissions from uncontrolled oil-fired fuel burning equipment

6 2 *Nitric acid manufacture* The emission of nitrogen oxides, calculated as nitrogen dioxide, from nitric acid manufacturing plants can be limited to 5 5 pounds per ton (2 8 kg /metric ton) of 100 percent acid produced This emission limitation is about equivalent to a nitrogen dioxide concentration of 400 p p m , by volume

APPENDIX C—MAJOR POLLUTANT SOURCES

CHEMICAL PROCESS INDUSTRIES

Adipic acid
Ammonia
Ammonium nitrate
Carbon black [1]
Charcoal [1]
Chlorine
Detergent and soap [1]
Explosives (TNT and nitrocellulose) [1]
Hydrofluoric acid [1]
Nitric acid
Paint and varnish manufacturing [1]
Phosphoric acid [1]
Phthalic anhydride
Plastics manufacturing [1]
Printing ink manufacturing [1]
Sodium carbonate [1]
Sulfuric acid [1]
Synthetic fibers
Synthetic rubber
Terephthalic acid

FOOD AND AGRICULTURAL INDUSTRIES

Alfalfa dehydrating [1]
Ammonium nitrate
Coffee roasting [1]
Cotton ginning [1]
Feed and grain [1]
Fermentation processes
Fertilizers [1]
Fish meal processing
Meat smoke houses [1]
Starch manufacturing [1]
Sugar cane processing [1]

METALLURGICAL INDUSTRIES

Primary metals industries
- Aluminum ore reduction [1]
- Copper Smelters [1]
- Ferroalloy production [1]
- Iron and steel mills [1]
- Lead smelters [1]
- Metallurgical coke manufacturing [1]
- Zinc [1]

Secondary metals industries
- Aluminum operations [1]
- Brass and bronze smelting [1]
- Ferroalloys [1]
- Gray iron foundries [1]
- Lead smelting [1]
- Magnesium smelting [1]
- Steel foundries [1]
- Zinc processes [1]

MINERAL PRODUCTS INDUSTRIES

Asphalt roofing [1]
Asphaltic concrete batching [1]
Bricks and related clay refractories [1]
Calcium carbide [1]
Castable refractories [1]
Cement [1]
Ceramic and clay processes [1]
Clay and fly ash sintering [1]
Coal cleaning [1]
Concrete batching [1]
Fiberglass manufacturing [1]
Frit manufacturing [1]
Glass manufacturing [1]
Gypsum manufacturing [1]
Lime manufacturing [1]
Mineral wool manufacturing [1]
Paperboard manufacturing [1]
Perlite manufacturing [1]
Phosphate rock preparation [1]
Rock, gravel, and sand quarrying and processing [1]

PETROLEUM REFINING AND PETROCHEMICAL OPERATIONS [1]

WOOD PROCESSING [1]

PETROLEUM STORAGE (Storage tanks and bulk terminals)

MISCELLANEOUS

Fossil fuel steam electric powerplants.[1]
Municipal or equivalent incinerators [1]
Open burning dumps [1]

[1] Major sources of sulfur oxides and/or particulate matter

TABLE I

Process weight rate (lbs /hr)	Emission rate (lbs /hr)
50	0 03
100	0 55
500	1 53
1 000	2 25
5,000	6 34
10,000	9 73
20 000	14 99
60,000	29 60
80 000	31 19
120,000	33 28
160 000	34 85
200 000	36 11
400 000	40 35
1 000,000	46 72

Interpolation of the data in table I for the process weight rates up to 60,000 lbs /hr shall be accomplished by the use of the equation

$$E = 3\ 59\ P^{0\ 62} \quad P \leq 30 \text{ tons/hr}$$

and interpolation and extrapolation of the data for process weight rates in excess of 60,000 lbs /hr shall be accomplished by use of the equation

$$E = 17\ 31\ P^{0\ 16} \quad P \geq 30 \text{ tons/hr}$$

Where E = Emissions in pounds per hour
P = Process weight rate in tons per hour

Application of mass emission limitations on the basis of all similar units at a plant is recommended in order to avoid unequal application of this type of limitation to plants with the same total emission potential but different size units

3 0 CONTROL OF SULFUR COMPOUND EMISSIONS

3 1 *Fuel combustion* It is not possible to make nationally applicable generalizations about attainable degrees of control of sulfur oxides emissions from combustion sources Availability of low-sulfur fuels varies from one area to another In some areas, severe restrictions on the sulfur content of fuels could have a significant impact on fuel-supply patterns, accordingly where such restrictions are necessary for attainment of national ambient air quality standards, adoption of phased schedules of sulfur-in-fuel limitations is recommended Stack gas cleaning is feasible at large industrial combustion sources and steam electric power plants Technology has been demonstrated which will allow 70 percent removal of sulfur oxides from combustion gases of most existing fuel burning units

Alternative means of meeting requirements for the control of sulfur oxides emissions from fuel combustion sources include Use of natural gas, distillate oil, low-sulfur coal, and low-sulfur residual oil, desulfurization of oil or coal, stack gas desulfurization, and restricted use, shutdown, or relocation of large existing sources

It is technically feasible to produce or desulfurize fuels to meet the following specifications Distillate oil—0 1 percent sulfur (though it should be noted that distillate oil containing less than 0 2 percent sulfur is not generally available at this time) residual oil—0 3 percent sulfur, bituminous coal—0 7 percent sulfur Availability of significant quantities of such low-sulfur fuels in any region where they do not naturally occur or have not been imported from other domestic or foreign sources will require planning for the timely development of new sources of such fuels Because residual oil generally is obtained from overseas sources, its use ordinarily is restricted to areas accessible to waterborne transportation There are limited tonnages of 0 7 percent sulfur coal produced at the present time, primarily in the western United States, large reserves of such coal exist but are not now being mined

The flaring or combustion of any refinery process gas stream or any other process gas stream that contains sulfur compounds measured as hydrogen sulfide can be limited to a concentration of 10 grains per 100 standard cubic feet (23 gm/100scm) of gas This limitation on combustion of process gas relates to the control of sulfur oxide emissions that would result from burning untreated process gas from refinery operations or coke ovens containing hydrogen sulfide and other sulfur compounds Hydrogen sulfide emissions can be controlled by requiring incineration or other equally effective means for all process units Approximately 95 to 99 percent of the sulfur compounds must be removed from the process gas stream to meet this emission limitation It may be appropriate to consider exemption of very small units which economically may not be able to achieve this level of control

3 2 *Sulfuric acid plants* The emissions of sulfur dioxide from sulfuric acid plants can be limited to 6 5 pounds per ton (3 25 kg /metric ton) of 100 percent acid produced This emission limitation is equivalent to an overall SO_2 to SO_3 conversion efficiency of 99 5 percent or a stack gas concentation of about 250 to 550 p p m of sulfur dioxide, by volume, depending on the strength of the feed gas

3 3 *Sulfur recovery plants* The emission of sulfur oxides, calculated as sulfur dioxide, from a sulfur recovery plant can be limited to 0 01 pound (kg) per pound (kg) of sulfur processed Approximately 99 5 percent of the sulfur processed must be recovered to meet this limitation. Existing plants typically recover 90 to 97 percent of the sulfur This emission limitation corresponds to a sulfur dioxide concentration of about 1,300 p p m , by volume

3 4 *Nonferrous smelters* Technology is available to limit emission of sulfur oxides, calculated as sulfur dioxide, from primary nonferrous smelters according to the following equations

Copper smelters $Y = 0\ 2X$
Zinc smelters $Y = 0\ 564X^{0\ 85}$
Lead smelters $Y = 0\ 98X^{0\ 77}$

Where

X = Total sulfur fed to smelter (lb /hr)
Y = Sulfur Dioxide Emissions (lb /hr)

These emission limitations are equivalent to removal of about 90 percent of the input-sulfur to the smelter for most copper smelters and somewhat higher for most lead and zinc smelters Technology capable of achieving such emission limitations may not be applicable to all existing smelters In such cases, less restrictive control can be coupled with restricted operations to achieve air quality standards

3 5 *Sulfite pulp mills* The total sulfite pulp mill emissions of sulfur oxides, calculated as sulfur dioxide, from blow pits, washer vents, storage tanks, digester relief, and recovery system, can be reduced to 9 pounds per air-dried ton (4 5 kg /metric ton) of pulp produced This emission limitation has application only to those sulfite mills that install waste liquor recovery systems for water pollution control or other purposes The installation of a recovery system can result in significant sulfur oxides emissions if not properly designed For sulfite mills with existing recovery systems, a sulfur oxides emission limitation of 20 pounds per air-dried ton (9 kg /metric ton) of pulp may be more reasonable due to economic considerations

4 0 CONTROL OF ORGANIC COMPOUNDS EMISSIONS

The following emission limitations are applicable to the principal stationary source of organic compound emissions Reducing total organic compound emissions will reduce photochemical oxidant formation Such control of organic compound emissions may appropriately be considered in areas where application of the Federal motor vehicle emission standards will not produce the emission reductions necessary for attainment and maintenance of the national ambient air quality standards for photochemical oxidants These emission limitations emphasize reduction of total organic compound emissions, rather than substitution of "nonreactive" or "less reactive" organic compounds for those already in use, because there is evidence that very few organic compounds are photochemically nonreactive Substitution may be useful, however, where it would result in a clearly evident decrease in reactivity and thus tend to reduce photochemical oxidant formation The extent to which application of these emission limitations would reduce photochemical oxidant formation in a given air quality control region will depend on the "mix" of emission sources in the region These limitations are separable, i e , one or more portions can be considered, as necessary

4 1 *Storage of volatile organic compounds* The storage of volatile organic compounds in any stationary tank, reservoir or other container of more than 40,000 gallons (150 000 liters) can be in a pressure tank capable of maintaining working pressures sufficient at all times to prevent vapor or gas loss to the atmosphere If this cannot be done, the tank can be equipped with a vapor loss control device such as

(a) A floating roof, consisting of a pontoon type, double deck type roof or internal floating cover, which will rest on the surface of the liquid contents and be equipped with a closure seal or seals to close the space between the roof edge and tank wall This control equipment may not be appropriate if the volatile organic compounds have a vapor pressure of 11 pounds per square inch absolute (568 mm Hg) or greater under actual storage conditions All tank gauging or sampling devices can be gas-tight except when tank gauging or sampling is taking place

(b) A vapor recovery system, consisting of a vapor gathering system capable of collecting the volatile organic compound vapors and gases discharged, and a vapor disposal system capable of processing such volatile organic vapors and gases so as to prevent their emission to the atmosphere and all tank gauging and sampling devices can be gas-tight except when gauging or sampling is taking place

The storage of any volatile organic compound in any stationary storage vessel more than 250-gallon (950 liter) capacity c... in a vessel equipped with a permanent ... merged fill pipe or fitted with a vapor recovery system This emission limitation will reduce volatile organic emissions 90 to 100 percent from uncontrolled sources of storage in vessels 40,000 gallon capacity or greater and approximately 40 percent from uncontrolled sources of storage in vessels 250 gallon capacity or greater

4 2 *Volatile organic compounds loading facilities* The loading of volatile organic compounds into any tank, truck or trailer having a capacity in excess of 200 gallons (760 liters) can be from a loading facility equipped with a vapor collection and disposal system Also, the loading facility can be equipped with a loading arm with a vapor collection adaptor, pneumatic, hydraulic or other mechanical means to force a vapor-tight seal between the adaptor and the hatch A means can be provided to prevent drainage of liquid organic compounds from the loading device when it is removed from the hatch of any tank, truck, or trailer, or to accom-

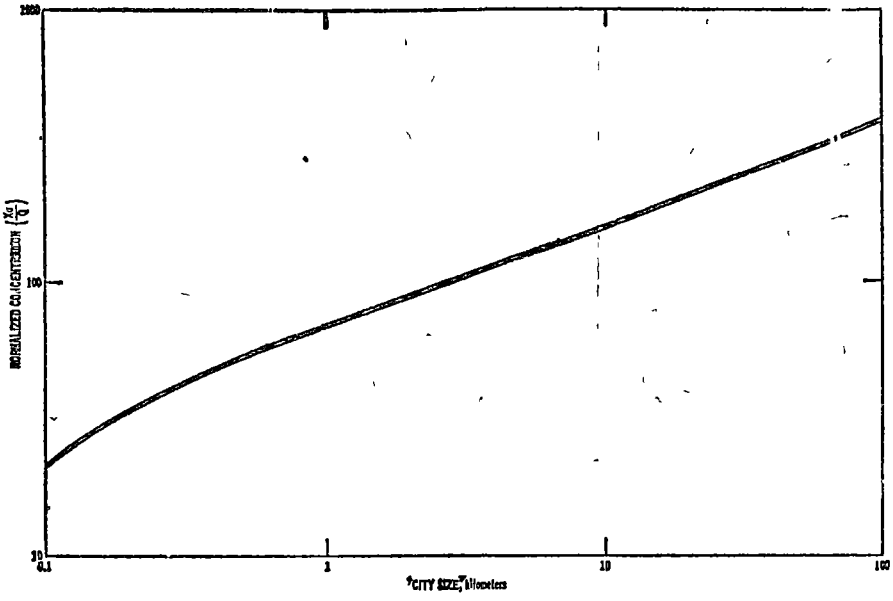

Figure 1 Relationship of normalized pollutant concentration and city size

APPENDIX B—EXAMPLES OF EMISSION LIMITATIONS ATTAINABLE WITH REASONABLY AVAILABLE TECHNOLOGY

This appendix sets forth emission limitations which, in the Administrator's judgment, are attainable through the application of reasonable available emission control technology The statements presented herein are not intended, and should not be construed, to require or encourage State agencies to adopt such emission limitations without consideration of (1) the necessity of imposing such emission limitations in order to attain and maintain a national standard, (2) the social and economic impact of such emission limitations, and (3) alternative means of providing for attainment and maintenance of a national standard Failure of a State agency to adopt any or all of the emission limitations set forth herein will not be grounds for rejecting a State implementation plan if that implementation plan provides for attainment and maintenance of the National Ambient Air Quality Standards within the time prescribed by the Clean Air Act Nor will State adoption of any or all of these emission limitations be grounds for approval of an implementation plan that does not provide for timely attainment and maintenance of the national standards In preparing implementation plans, State agencies should tailor their control strategies to deal with the particular problems and meet the particular needs of their own States

1 0 DFFINITIONS

Air pollutant" means dust, fumes, mist, smoke, other particulate matter, vapor, gas, odorous substances, or any combination thereof

"Effluent water separator" means any tank, box, sump, or other container in which any volatile organic compound floating on or entrained or contained in water entering such tank, box, sump or other container is physically separated and removed from such water prior to outfall, drainage, or recovery of such water

"Emission" means the act of releasing or discharging air pollutants into the ambient air from any source

"Fuel-burning equipment" means any furnace, boiler, apparatus, stack, and all appurtenances thereto, used in the process of burning fuel for the primary purpose of producing heat or power by indirect heat transfer

'Fugitive dust" means solid, airborne particulate matter emitted from any source other than through a stack

'Opacity" means a state which renders material partially or wholly impervious to rays of light and causes obstruction of an observer's view

"Particulate matter" means any material, except water in uncombined form, that is or has been airborne and exists as a liquid or a solid at standard conditions

"Ringelmann chart" means the chart published and described in the U S Bureau of Mines Information Circular 8333

'Source" means any property, real or personal, which emits or may emit any air pollutant

"Stack" means any chimney, flue, conduit, or duct arranged to conduct emissions to the ambient air

"Standard conditions" mean a dry gas temperature of 70° Fahrenheit and a gas pressure of 14 7 pounds per square inch absolute

"Submerged fill pipe" means any fill pipe the discharge opening of which is entirely submerged when the liquid level is 6 inches (15 cm) above the bottom of the tank or when applied to a tank which is loaded from the side, means any fill pipe the discharge opening of which is entirely submerged when the liquid level is 18 inches (45 cm) above the bottom of the tank

'Volatile organic compounds' means any compound containing carbon and hydrogen or containing carbon and hydrogen in combination with any other element which has a vapor pressure of 1 5 pounds per square inch absolute (77 6 mm Hg) or greater under actual storage conditions

2 0 CONTROL OF PARTICULATE EMISSIONS

2 1 *Visible emissions* The emission of visible air pollutants can be limited to a shade or density equal to but not darker than that designated as No 1 on the Ringelmann chart or 20 percent opacity except for brief periods during such operations as soot blowing and startup This limitation would generally eliminate visible pollutant emissions from stationary sources

The emission of visible air pollutants from gasoline-powered motor vehicles can be eliminated except for periods not exceeding 5 consecutive seconds The emission of visible air pollutants from diesel-powered motor vehicles can be limited to a shade or density equal to but not darker than that designated as No 1 on the Ringelmann chart or 20 percent opacity except for periods not exceeding 5 consecutive seconds.

2 2 *Fugitive dust* Reasonable precautions can be taken to prevent particulate matter from becoming airborne Some of these reasonable precautions include the following

(a) Use, where possible, of water or chemicals for control of dust in the demolition of existing buildings or structures, construction operations, the grading of roads or the clearing of land,

(b) Application of asphalt, oil, water, or suitable chemicals on dirt roads, materials stockpiles, and other surfaces which can give rise to airborne dusts,

(c) Installation and use of hoods, fans, and fabric filters to enclose and vent the handling of dusty materials Adequate containment methods can be employed during sandblasting or other similar operations,

(d) Covering, at all times when in motion, open bodied trucks, transporting materials likely to give rise to airborne dusts,

(e) Conduct of agricultural practices such as tilling of land, application of fertilizers, etc , in such manner as to prevent dust from becoming airborne,

(f) The paving of roadways and their maintenance in a clean condition,

(g) The prompt removal of earth or other material from paved streets onto which earth or other material has been transported by trucking or earth moving equipment, erosion by water, or other means

2 3 *Incineration* The emission of particulate matter from any incinerator can be limited to 0 20 pound per 100 pounds (2 gm/kg) of refuse charged This emission limitation is based on the source test method for stationary sources of particulate emissions which will be published by the Administrator This method includes both a dry filter and wet impingers and represents particulate matter of 70° F and 1 0 atmosphere pressure

2 4 *Fuel burning equipment* The emission of particulate matter from fuel burning equipment burning solid fuel can be limited to 0 30 pound per million B t u (0 54 gm/10^6 gm-cal) of heat input This emission limitation is based on the source test method for stationary sources of particulate emissions which will be published by the Administrator This method includes both a dry filter and wet impingers and represents particulate matter of 70° F and 1 0 atmosphere pressure

2 5 *Process industries—general* The emission of particulate matter for any process source can be limited in a manner such as in table I Process weight per hour means the total weight of all materials introduced into any specific process that may cause any emission of particulate matter Solid fuels charged are considered as part of the process weight, but liquid and gaseous fuels and combustion air are not For a cyclical or batch operation, the process weight per hour is derived by dividing the total process weight by the number of hours in one complete operation from the beginning of any given process to the completion thereof, excluding any time during which the equipment is idle For a continuous operation, the process weight per hour is derived by dividing the process weight for a typical period of time

the respect to the time at which the necessary technology or alternatives will be available

(3) A clear identification of any alternative means of attainment of such primary standard which were considered and rejected

(4) A showing that stationary emission sources or classes of moving sources other than those identified pursuant to subparagraph (1) of this paragraph will be required to comply, within such 3-year period, with any applicable portions of such control strategy

(5) A showing that reasonable interim control measures are provided for in such plan with respect to emissions from the source(s) identified pursuant to subparagraph (1) of this paragraph

§ 420 31 Request for 18-month extension

(a) Upon request of the State made in accordance with this section, the Administrator may, whenever he determines necessary, extend, for a period not to exceed 18 months, the deadline for submitting that portion of a plan that implements a secondary standard

(b) Any such request will be given consideration only in the case of Priority I and Priority II regions

(c) Any such request shall show that attainment of the secondary standards will require emission reductions exceeding those which can be achieved through the application of reasonably available control technology

(d) Any such request for extension of the deadline with respect to any State's portion of an interstate region shall be submitted jointly with requests for such extensions from all other States within the region or shall show that all such States have been notified of such request

(e) Any such request shall be submitted sufficiently early to permit development of a plan prior to the deadline in the event that such request is denied

§ 420 32 Request for 1-year postponement

(a) Pursuant to section 110(f) of the Act, the Governor of a State may request, with respect to any stationary source or class of moving sources, a postponement for not more than 1 year of the applicability of any portion of the control strategy

(b) Any such request regarding sources located in an interstate region shall show that the Governor of each State in the region has been notified of such request

(c) Any such request shall clearly identify the source(s) and portion(s) of the control strategy which are the subject of such request and shall include information relevant to the determinations required by section 110(f) of the Act

(d) A public hearing will be held, before the Administrator or his designee, on any such request No such hearing will be held earlier than 1 year in advance of the prescribed date for compliance with any such portion(s) of the control strategy

(e) No such request shall operate to stay the applicability of the portion(s) of the control strategy covered by such request

(f) A State's determination to defer the applicability of any portion(s) of the control strategy with respect to such source(s) will not necessitate a request for postponement under this section unless such deferral will prevent attainment or maintenance of a national standard within the time specified in such plan *Provided, however,* That any such determination will be deemed a revision of an applicable plan under § 420 6

Appendix A—Air Quality Estimation

Ambient pollutant levels may be estimated through the application of atmospheric diffusion models These estimates are based primarily upon the pollutant emissions meteorology, and topography that prevails within a region Several procedures are available for estimating air quality based on atmospheric dispersion The complexity and sophistication of these procedures range from a few simple calculations that may be made manually to thousands of calculations that require a computer The procedures presented here are simple and require a minimum of calculations The two procedures presented are referred to as an area model and a point model The area model was used to classify regions not having air quality data where the air quality levels are the result of several pollutant sources distributed throughout the region The point model was used where the air quality results from a single point source of pollutant

Area model The relationship presented in figure 1 is based on the concepts of the model developed by Miller and Holzworth [1] This model requires estimates of a region's average emission density, the "size" of the region, and the wind speed through the atmospheric mixing layer A summary and description of how to use the procedure are presented here

For discussion purposes let

X = Estimate concentration, micrograms/cubic meter ($\mu g/m^3$)

μ = Wind speed through mixing layer, meters/second (m/s)

Q = Emission density, micrograms/square meter-second ($\mu g/m^2$-s)

C = Urban size = $\frac{1}{2}\sqrt{\text{urban area}}$ kilometers (km)

Figure 1 is a plot of "normalized concentration" ( ) as a function of urban size and is defined to be the product of predicted concentration and wind speed divided by emission density Concentrations are an increasing function of urban size and are directly proportional to emission density The wind serves as a diluting agent and reduces expected pollutant concentrations

As an example, the Standard Metropolitan Statistical Area (SMSA) of Chicago is used to compute the expected concentration of SO_2 from 1967 emissions in the Chicago area The urban area of Chicago for computational purposes is 2,500 square km The urban size, as defined is consequently 25 km. and thus from figure 1

$$\frac{X_\mu}{Q} = 230$$

For Chicago

$$Q = 17\,8 \ \frac{\mu g/sec}{meter^2}$$

$$\mu = 7\,3 \text{ meters/sec}$$

and hence

$$X = \frac{(230)(17\,8)}{7\,3} = 561 \ \mu g/m^3$$

Using this procedure concentration estimates for both SO_2 and particulate matter may be made on a regional basis These predicted air quality concentrations may be used to establish region classification

Point Model The ambient air quality concentrations that result from the emissions of a single point source have a large degree of variability depending upon the meteorological conditions Because of this, the short-term air quality concentrations are of more concern than the long-term In many cases, the short-term maximum concentrations occur when the plume is trapped in a mixing layer of limited depth In these cases, the 1-hour ground level concentration from a single point source may be estimated from the following equation [2]

$$X = \frac{Q}{\sqrt{2\pi}\sigma_y L u} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

where

X = concentration, gm/meter^3

Q = source emission rate gm/sec

σ_y = the standard deviation in the cross-wind direction of the plume concentration distribution, meters

L = height of the mixing layer meters

u = wind speed, meters/sec

y = cross wind distance, meters

The values of the meteorological parameters must be based on the meteorological conditions in the vicinity of the source Multiplying the estimated maximum 1-hour concentration by 0 25 may be used to estimate a maximum 24-hour concentration This factor is deemed appropriate for the meteorological conditions to which the above equation applies The factor implies that the meteorological conditions persist 6 hours of a 24-hour period During the remaining 18 hours, wind direction and other meteorological parameters are such that the source has no impact upon the location subjected to contamination during the 6-hour period The estimated maximum 24-hour concentration may be compared to the maximum 24-hour national standards This procedure may be used in Priority 1A regions to estimate the existing air quality levels for developing a control strategy

Under certain source and meteorological conditions, the above equation may not be appropriate, however, other equations [2] are available that may be used

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[1] Miller, M E, and Holzworth, G C, "An Atmospheric Diffusion Model for Metropolitan Areas", Jour Air Poll Cont Assoc, 17 46–50, Jan 1967

[2] Turner, D B, 'Workbook of Atmospheric Dispersion Estimates", Public Health Service Publication No 999–AP–26, U S Department of Health, Education, and Welfare, Public Health Service, Consumer Protection and Environmental Health Service, National Air Pollution Control Administration, Cincinnati, Ohio Revised 1969

(2) At least one sampling site must be located in the area of estimated maximum pollutant concentrations

(b) The plan shall include a description of the existing and proposed air quality surveillance system, which shall set forth

(1) The basis for the design of the surveillance system, selection of samplers, and sampling sites

(2) The locations of the samplers by Universal Transverse Mercator (UTM) grid coordinates or the equivalent Any EPA monitoring station may be designated as a sampler location

(3) The sampling schedules

(4) The methods of sampling and analysis

(5) The method of data handling and analysis procedures

(6) The timetable for the installation of any additional equipment needed to complete the system

(c) The plan shall provide for monitoring of air quality during any air pollution emergency episode stage. The stations selected for use during such periods must be in operation within 1 year after the date of the Administrator's approval of the plan and be capable of indicating when pollutant concentrations have reached, or are approaching, any episode criteria established pursuant to § 420 16.

§ 420 18 Review of new sources and modifications.

(a) Each plan shall set forth legally enforceable procedures that will be used to implement the authority described in § 420 11(a) (4), which procedures shall be adequate to enable the State to determine whether construction or modification of stationary sources will result in violations of applicable portions of the control strategy or will interfere with attainment or maintenance of a national standard

(b) Such procedures shall provide for the submission, by the owner or operator of a new stationary source, or existing source which is to be modified, of such information on the nature and amounts of emissions, locations, design, construction, and operation of such sources as may be necessary to permit the State agency to make the determination referred to in paragraph (a) of this section.

(c) Such procedures shall also include means of disapproving such construction or modification if it will result in a violation of applicable portions of the control strategy or will interfere with attainment or maintenance of a national standard

(d) Such procedures shall provide that approval of any construction or modification shall not affect the responsibility of the owner or operator to comply with applicable portions of the control strategy.

§ 420 19 Source surveillance.

(a) Each plan shall provide for monitoring the status of compliance with any rules and regulations which set forth any portion of the control strategy Specifically, each plan shall as a minimum, provide for

(1) Legally enforceable procedures for requiring owners or operators of stationary sources to maintain records of, and periodically report to the State information on, the nature and amount of emissions from such stationary sources and/or such other information as may be necessary to enable the State to determine whether such sources are in compliance with applicable portions of the control strategy

(2) Periodic testing and inspection of stationary sources

(3) Establishment of a system for detecting violations of any rules and regulations through the enforcement of appropriate visible emission limitations and for investigating complaints.

(b) As used in this section, "stationary sources" means sources of a class or category which, for purposes of construction or modification, would be subject to procedures established pursuant to § 420 18

§ 420.20 Resources.

Each plan shall include a description of the resources available to the State and local agencies at the date of submission of the plan and of any additional resources needed to carry out the plan during the 5-year period following its submission Such description, which shall be provided in a form similar to that in Appendix K to this part, shall include projections of the extent to which resources will be acquired at 1-, 3-, and 5-year intervals

§ 420 21 Intergovernmental cooperation.

(a) For the purpose of assisting in the development of a plan for any interstate region, the State agency responsible for implementing national standards in any portion of such an interstate region shall furnish any available data on emissions, air quality, and control strategy development, upon request, to any other State or local agency having such responsibility in any other portion of such interstate region.

(b) Each plan shall identify

(1) The local agencies, by official title, which will participate in carrying out the plan

(2) The responsibilities of such local agencies and the responsibilities of any State governmental agency involved in carrying out any portion of the plan

(c) Each plan shall provide assurances that the State agency having primary responsibility for implementing national standards in any region, or portion thereof, will promptly transmit to other State agencies having similar or related responsibility in the same or other States, information on factors (e g , construction of new industrial plants) which may significantly affect air quality in any portion of such region or in any adjoining region

§ 420 22 Rules and regulations

Emission limitations and other measures necessary for attainment and maintenance of any national standard, including any measures necessary to implement the requirements of § 420 11, shall be adopted as rules and regulations enforceable by the State agency Copies of all such rules and regulations shall be submitted with the plan Except as otherwise provided by § 420 11(b), submittal of a plan setting forth proposed rules and regulations will not satisfy the requirements of this section nor will it be considered a timely submittal.

Subpart C—Extensions

§ 420 30 Request for 2-year extension.

(a) The Governor of a State may, at the time of submission of a plan to implement a primary standard in a Priority I region, request the Administrator to extend, for a period not exceeding 2 years, the 3-year period prescribed by the Act for attainment of the primary standard in such region

(b) Any such request regarding an interstate region shall be submitted jointly with the requests of Governors of all States in the region, or shall show that the Governor of each State in the region has been notified of such a request

(c) Any such request regarding attainment of a primary standard shall be submitted together with a plan which shall

(1) Set forth a control strategy adequate for attainment of such primary standard

(2) Show that the necessary technology or alternatives will not be available soon enough to permit full implementation of such control strategy within such 3-year period, i e , one or more emission sources or classes of sources will be unable to comply with applicable portions of the control strategy

(3) Provide for attainment of such primary standard as expeditiously as practicable, but in no case later than 5 years after the date of the Administrator's approval of such plan

(d) Any showing pursuant to paragraph (c) of this section shall include

(1) A clear identification of stationary emission sources or classes of moving sources which will be unable to comply with the applicable portions of such control strategy within a 3-year period because the necessary technology or alternatives will not be available soon enough to permit such compliance

(2) A clear identification and justification of any assumptions made with

(1) Daily acquisition of forecasts of atmospheric stagnation conditions or during any episode stage and updating of such forecasts at least every 12 hours

(2) Inspection of sources to ascertain compliance with applicable emission control action requirements

(3) Communications procedures for transmitting status reports and orders as to emission control actions to be taken during an episode stage, including procedures for contact with public officials, major emission sources, public health, safety, and emergency agencies and news media

(f) In the event that the requirements of paragraphs (c) and (e) of this section have not been fully met by the prescribed date for submitting a plan, a description of the steps under consideration and a timetable for their completion shall be submitted with the plan. Such timetable shall provide for meeting all requirements of paragraphs (c) and (e) of this section within 1 year after such prescribed date. A description of interim actions that will be taken to control emissions during any episode stage which occurs during such 1-year period shall be included.

(g) Each plan for a Priority II region shall include a contingency plan meeting, as a minimum, the requirements of subparagraphs (1) and (2) of paragraph (b) of this section.

§ 420.17 Air quality surveillance.

(a) (1) The plan shall provide for the establishment of an air quality surveillance system which shall be completed and in operation as expeditiously as practicable, but not later than 2 years after the date of the Administrator's approval of the plan; and which shall meet, as a minimum, the following requirements:

Classification of region	Pollutant	Measurement method [i]	Minimum frequency of sampling	Region population	Minimum number of air quality monitoring sites [b]
I	Suspended particulates	High volume sampler	One 24 hour sample every 6 days [a]	Less than 100 000	4
				100 000-1 000 000	4+0.6 per 100 000 population [c]
				1 000,001-5 000 000	7.5+0.25 per 100 000 population [c]
				Above 5 000 000	12+0.16 per 100 000 population [c]
		Tape sampler	One sample every 2 hours		One per 250 000 population [c] up to eight sites
	Sulfur dioxide	Pararosaniline or equivalent [d]	One 24 hour sample every 6 days (gas bubbler) [a]	Less than 100 000	3
				100 000-1 000 000	2.5+0.5 per 100 000 population [c]
				1 000,001-5 000 000	6+0.15 per 100 000 population [c]
				Above 5,000 000	11+0.05 per 100,000 population [c]
			Continuous	Less than 100 000	1
				100 000-5 000 000	1+0.15 per 100,000 population [c]
				Above 5 000 000	6+0.05 per 100 000 population [c]
	Carbon monoxide	Nondispersive infrared or equivalent [e]	Continuous	Less than 100 000	1
				100,000-5 000 000	1+1.15 per 100 000 population [c]
				Above 5 000 000	6+0.05 per 100,000 population [c]
	Photochemical oxidants	Gas phase chemiluminescence or equivalent [f]	Continuous	Less than 100 000	1
				100 000-5 000 000	1+0.15 per 100 000 population [c]
				Above 5,000 000	6+0.05 per 100,000 population [c]
	Nitrogen dioxide	24 hour sampling method (Jacobs Hochheiser method)	One 24 hour sample every 14 days (gas bubbler) [b]	Less than 100 000	3
				100 000-1 000 000	4+0.6 per 100,000 population [c]
				Above 1,000,000	10
II	Suspended particulates	High volume sampler,	One 24 hour sample every 6 days [a]		3
		Tape sampler	One sample every 2 hours		1
	Sulfur dioxide	Pararosaniline or equivalent [d]	One 24 hour sample every 6 days (gas bubbler) [a]		3
			Continuous		1
III [g]	Suspended particulates	High volume sampler	One 24 hour sample every 6 days [a]		1
	Sulfur dioxide	Pararosaniline or equivalent [d]	One 24 hour sample every 6 days (gas bubbler) [a]		1

[a] Equivalent to 61 random samples per year.
[b] Equivalent to 26 random samples per year.
[c] Total population of a region. When required number of samplers includes a fraction, round off to nearest whole number.
[d] Equivalent methods are: (1) Gas Chromatographic Separation—Flame Photometric Detection (provided Teflon is used throughout the instrument system in parts exposed to the air stream), (2) Flame Photometric Detection (provided interfering sulfur compounds present in significant quantities are removed), (3) Coulometric Detection (provided oxidizing and reducing interferences such as O_3, NO_2, and H_2S are removed), and (4) the automated Pararosaniline Procedure.
[e] Equivalent method is Gas Chromatographic Separation—Catalytic Conversion—Flame Ionization Detection.
[f] Equivalent methods are (1) Potassium Iodide Colorimetric Detection (provided a correction is made for SO_2 and NO_2), (2) UV Photometric Detection of Ozone (provided compensation is made for interfering substances), and (3) Chemiluminescence Methods differing from that of the reference method.
[g] It is assumed that the Federal motor vehicle emission standards will achieve and maintain the national standards for carbon monoxide, nitrogen dioxide, and photochemical oxidants, therefore no monitoring sites are required for these pollutants.
[h] In interstate regions, the number of sites required should be prorated to each State on a population basis.
[i] All measurement methods except the Tape Sampler method are described in the national primary and secondary ambient air quality standards published in the FEDERAL REGISTER on Apr. 30, 1971 (36 F.R. 8186). Other methods together with those specified under footnotes (d), (e), and (f) will be considered equivalent if they meet the following performance specifications:

Specification	Pollutants		
	Sulfur dioxide	Carbon monoxide	Photochemical oxidant (corrected for NO_2 and SO_2)
Range	0-2 620 μg /m³ (0-1 p.p.m.)	0-58 mg /m³ (0-50 p.p.m.)	0-880 μg /m³ (0-0.5 p.p.m.)
Minimum detectable sensitivity	26 μg /m³ (0.01 p.p.m.)	0.6 mg /m³ (0.5 p.p.m.)	20 μg /m³ (0.01 p.p.m.)
Rise time 90 percent	5 minutes	5 minutes	5 minutes
Fall time 90 percent	5 minutes	5 minutes	5 minutes
Zero drift	±1 percent per day and ±2 percent per 3 days	±1 percent per day and ±2 percent per 3 days	±1 percent per day and ±2 percent per 3 days
Span drift	±1 percent per day and ±2 percent per 3 days	±1 percent per day and ±2 percent per 3 days	±1 percent per day and ±2 percent per 3 days
Precision	±2 percent	±4 percent	±4 percent
Operation period	3 days	3 days	3 days
Noise	±0.5 percent (full scale)	±0.5 percent (full scale)	±0.5 percent (full scale)
Interference equivalent	26 μg /m³ (0.01 p.p.m.)	1.1 mg /m³ (1 p.p.m.)	20 μg /m³ (0.01 p.p.m.)
Operating temperature fluctuation	±5° C.	±5° C.	±5° C.
Linearity	2 percent (full scale)	2 percent (full scale)	2 percent (full scale)

The various specifications are defined as follows:
Range. The minimum and maximum measurement limits.
Minimum detectable sensitivity. The smallest amount of input concentration which can be detected as concentration approaches zero.
Rise time 90 percent. The interval between initial response time and time to 90 percent response after a step increase in inlet concentration.
Fall time 90 percent. The interval between initial response time and time to 90 percent response after a step decrease in the inlet concentration.
Zero drift. The change in instrument output over a stated time period of unadjusted continuous operation, when the input concentration is zero.
Span drift. The change in instrument output over a stated period of unadjusted continuous operation, when the input concentration is a stated upscale value.
Precision. The degree of agreement between repeated measurements of the same concentration (which shall be the midpoint of the stated range) expressed as the average deviation of the single results from the mean.
Operation period. The period of time over which the instrument can be expected to operate unattended within specifications.
Noise. Spontaneous deviations from a mean output not caused by input concentration changes.
Interference equivalent. The portion of indicated concentration due to the total of the interferences commonly found in ambient air.
Operating temperature fluctuation. The ambient temperature fluctuation over which stated specifications will be met.
Linearity. The maximum deviation between an actual instrument reading and the reading predicted by a straight line drawn between upper and lower calibration points.

is adequate for attainment and maintenance of the national standard(s) to which such control strategy applies

(2) With respect to control of carbon monoxide and nitrogen oxides, the proportional model which may be used for purposes of this paragraph is described in § 420 13(d)(2) *Provided,* With respect to the national standard for nitrogen dioxide, that the degree of air quality improvement indicated to be necessary by the proportional model will be achieved by a corresponding degree of reduction of total nitrogen oxides emissions from stationary and mobile sources

(3) In any region where the degree of nitrogen oxides emission reduction necessary for attainment and maintenance of the national standard for nitrogen dioxide is greater than that which can be achieved by the application of (i) the Federal motor vehicle emission standards promulgated under section 202 of the Act, (ii) reasonably available control technology to nitrogen oxides sources, and (iii) any transportation control measures which may be necessary for attainment and maintenance of the national standards for carbon monoxide and photochemical oxidants, the plan shall provide for the degree of hydrocarbon emission reduction attainable through the application of reasonably available control technology In any such region, a control strategy which provides for such hydrocarbon emission reduction shall be deemed adequate for attainment of the national standard for nitrogen dioxide

(4) With respect to hydrocarbons and photochemical oxidants, it may be assumed that (i) there is no background concentration of photochemical oxidants and (ii) the degree of total hydrocarbon emission reduction necessary for attainment and maintenance of the national standard for photochemical oxidants will also be adequate for attainment of the national standard for hydrocarbons The proportional model to be used to determine the necessary hydrocarbon emission reduction is set forth in Appendix J to this part

(5) The plan shall show that the control strategy will result in the degree of emission reduction indicated to be necessary by the proportional model The plan shall contain a summary of the computations used to determine the emission reductions that will result from application of the control strategy to each point source and each group of area sources Such summary shall be included in a table similar to that presented in Appendix D to this part The detailed computations shall be retained by the State agency and made available for inspection by the Administrator

(6) If a diffusion/photochemical model is used, the plan shall include a description of such model

(d) *Emission data* Emission data on carbon monoxide, hydrocarbons, and nitrogen oxides shall be submitted in accordance with the requirements of § 420 13(e)

(e) *Air quality data* Data showing existing air quality levels shall be presented in accordance with this section

(1) For Priority I regions, data on carbon monoxide, nitrogen dioxide, and photochemical oxidants shall, as a minimum, include the results of measurements made during a period of approximately 3 months beginning on or about July 1, 1971, in accordance with the following procedures

Pollutants	Measurement method[1]	Number of sites per region	Frequency of sampling
Carbon monoxide	Nondispersive infrared	One	Continuous.
Nitrogen dioxide	24 hour (gas bubbler) methods (Jacobs-Hochheiser)	do	One 24 hour sample, every 3 days
Photochemical oxidants	Gas phase chemiluminescence	do	Continuous

[1] Equivalent methods are specified in § 420 17

(2) For Priority I regions, only available air quality data for hydrocarbons must be submitted.

(3) For Priority III regions, no air quality data for carbon monoxide, hydrocarbons, nitrogen dioxide, and photochemical oxidants need be submitted

(4) Air quality data required by this subparagraph shall be submitted in the form similar to that shown in Appendix H to this part.

§ 420 15 Compliance schedules

(a) (1) Except as otherwise provided in subparagraph (2) of this paragraph, each plan shall contain legally enforceable compliance schedules setting forth the dates by which all stationary and mobile sources or categories of such sources must be in compliance with any applicable portions of the control strategy set forth in such plan

(2) A plan may provide that a legally enforceable compliance schedule will be negotiated with the owner or operator of an individual source following submittal of the plan Such compliance schedule shall be submitted to the Administrator as early as possible but in no case later than the prescribed date for submittal of the first semiannual report required by § 420 7 Unless disapproved by the Administrator, such compliance schedule shall be part of the applicable plan

(b) (1) Any compliance schedule designed to provide for attainment and maintenance of a primary standard shall provide for compliance with applicable portions of the control strategy as expeditiously as practicable and in no case, except as otherwise provided by Subpart C of this part, later than 3 years after the Administrator's approval of the plan, or portion thereof, which sets forth such control strategy

(2) Any compliance schedule designed to provide for attainment and maintenance of a secondary standard shall provide for compliance with applicable portions of the control strategy in a reasonable time and in no case later than the date specified for attainment of such secondary standard pursuant to § 420 10(c)

(c) Any compliance schedule extending over a period of 18 or more months from the date of its adoption shall provide for periodic increments of progress toward compliance by any affected source(s) or categories of sources

(d) Except as otherwise provided by Subpart C of this part, neither the State agency nor a local agency shall grant any variance of, or exception to, any compliance schedule included in an applicable plan if such variance or exception will prevent, or interfere with, attainment or maintenance of a national standard within the time(s) specified pursuant to § 420 10 (b) and (c)

§ 420.16 Prevention of air pollution emergency episodes.

(a) For the purpose of preventing air pollution emergency episodes, each plan for a Priority I region shall include a contingency plan which shall, as a minimum, provide for taking such control actions necessary to prevent ambient pollutant concentrations at any location in such region from reaching levels which would constitute imminent and substantial endangerment to the health of persons, which levels shall be prescribed by the Administrator.

(b) Each contingency plan shall (1) specify two or more stages of episode criteria such as those set forth in Appendix L to this part, or their equivalent (2) provide for public announcement whenever any episode stage has been determined to exist, and (3) specify emission control actions to be taken at each episode stage, including, but not necessarily limited to, actions such as those set forth in Appendix L to this part, or their equivalent

(c) (1) For each stationary source emitting 100 tons (90 7 metric tons) per year or more, the contingency plan shall include, or provide for preparation of, a specific legally enforceable emission control action program and shall show that the owner and/or operator of such stationary source has been notified of the requirements of such emission control action program

(2) Any emission control action programs required by subparagraph (1) of this paragraph which are not included in the contingency plan shall be submitted to the Administrator in the first semiannual report required under § 420 7 Unless disapproved by the Administrator, such emission control action programs shall be part of the applicable plan

(d) To the maximum extent practicable, emission control actions taken pursuant to a contingency plan shall be consistent with the extent of any air pollution episode, e g , if a single source is determined to be responsible for the occurrence of any episode stage, then the emission control action steps applicable to such source shall be taken.

(e) Each contingency plan for a Priority I region shall provide for:

be achieved through the application of reasonably available control technology, "reasonable time" for attainment of such secondary standard, pursuant to § 420 10 (c), shall be not more than 3 years unless the State shows that good cause exists for postponing application of such control technology

(2) In any region where application of reasonably available control technology will not be sufficient for attainment and maintenance of such secondary standard, or where the State shows that good cause exists for postponing the application of such control technology, "reasonable time" shall depend on the degree of emission reduction needed for attainment of such secondary standard and on the social, economic, and technological problems involved in carrying out a control strategy adequate for attainment and maintenance of such secondary standard

(c) For purposes of developing a control strategy, background concentration shall be taken into consideration with respect to particulate matter As used in this subpart, "background concentration" is that portion of the measured ambient levels of particulate matter that cannot be reduced by controlling emissions from manmade sources, "background concentration" shall be determined by reference to measured ambient levels of particulate matter in nonurban areas

(d) Example regions

(1) A control strategy which provides for the attainment and maintenance of a national standard for sulfur oxides or particulate matter in any region in a State (excluding Priority IA regions) will be deemed by the Administrator to be adequate for attainment and maintenance of such standard in any or all other regions of the regions of the same Priority classification in which measured or estimated levels of the pollutant are lower than those in the region for which the control strategy was formulated *Provided*, That such control strategy is sufficiently comprehensive to include adequate control of sulfur oxides or particulate emissions from sources listed in Appendix C to this part Any region (i) for which the State formulates a control strategy which is applied to other regions or (ii) for which a control strategy is developed, without regard to whether such strategy is applied outside of the region, is referred to hereinafter as an "example region"

(2) The State shall obtain, through the appropriate Regional Office, the concurrence of the Administrator in the selection of an example region

(3) Nothing in this section shall be construed in any manner to preclude a State from preparing, adopting, and submitting a separate plan for each region.

(e) Adequacy of control strategy

(1) The plan shall demonstrate that the control strategy for each national standard for sulfur oxides or particulate matter is adequate for attainment and maintenance of such standard in the example region(s) to which it applies The adequacy of a control strategy shall be demonstrated by means of a proportional model or diffusion model or other procedure which is shown to be adequate and appropriate for such purpose

(2) (i) If such demonstration is made by use of a proportional model, such model shall be one in which the following equation is employed to calculate the degree of improvement in air quality needed for attainment of a national standard:

$$\frac{A-C}{A-B}\times 100 = \text{percent reduction needed}$$

Where

A = Existing air quality at the location having the highest measured or estimated concentration in the region

B = Background concentration

C = National standard

(ii) The above equation does not account for topography, spatial distribution of emissions, or stack height, but the significance of these parameters shall be considered in developing the control strategy

(iii) The plan shall show that application of the control strategy will result in the degree of emission reduction indicated to be necessary by the above calculation, as modified by appropriate consideration of factors set forth in subdivision (ii) of this subparagraph The plan shall contain a summary of the computations used to determine the emission reductions that will result from application of the control strategy to each point source and group of area sources, such summary shall be included in a table similar to that presented in Appendix D to this part The detailed computations shall be retained and be made available for inspection by the Administrator

(3) (i) If such demonstration is made by use of a diffusion model, such model shall be identified and described *Provided, however*, That if either of the two diffusion models described in the following publications is used, it need only be identified

Air Quality Implementation Planning Program (IPP), Volume I, Operator's Manual, National Air Pollution Control Administration, Environmental Protection Agency, Washington, D C , November 1970

Air Quality Display Model (AQDM), National Air Pollution Control Administration, Department of Health, Education, and Welfare, Washington, D C , November 1969

(ii) The plan shall contain a summary of emission levels expected to result from application of the control strategy, which summary shall be included in a table similar to that presented in Appendix D to this part

(iii) The plan shall also show the air quality levels expected to result from application of the control strategy, presented either in tabular form or as an isopleth map showing maximum pollutant concentrations and expected concentration gradients Computer printouts of the input and output data associated with use of a diffusion model shall be retained and made available for inspection by the Administrator

(f) Emission data

(1) Each plan shall include the following data on emissions of sulfur oxides and particulate matter

(i) For each example region in the State, a detailed inventory of emissions from point sources and area sources in each county shall be summarized in a form similar to that shown in Appendix D, and the data described in Appendices E and F to this part shall be retained and made available for inspection by the Administrator

(ii) For all regions, point-source and area-source data shall be submitted in summary form, as shown in Appendix G, except that for regions classified as Priority III, only point-source data and any existing area-source data shall be submitted Data described in Appendices E and F to this part shall be retained and made available for inspection by the Administrator

(g) Air quality data Data showing existing air quality with respect to sulfur dioxide and particulate matter shall be submitted for each example region Actual measurements shall be used where available if based on use of the measurement methods specified in § 420 17, sulfur dioxide measurements based on use of the continuous conductimetric method also will be acceptable for this purpose If actual measurements are not available and cannot be made in time to be employed in the development of the control strategy, air quality may be estimated by the procedure described in Appendix A to this part Air quality data, measured or estimated, shall be submitted in a form similar to that shown in Appendix H to this part

§ 420 14 Control strategy Carbon monoxide, hydrocarbons,, photochemical oxidants, and nitrogen dioxide

(a) *Priority I Regions* (1) Each plan for a region classified Priority I with respect to carbon monoxide, photochemical oxidants, or nitrogen dioxide shall set forth a control strategy which shall provide for the degree of emission reduction necessary for attainment and maintenance of the national standard for each such pollutant after consideration of the emission reductions that will result from the application of Federal motor vehicle emission standards promulgated pursuant to section 202 of the Act

(2) Unless specific data are available for a region, a State shall assume that such Federal motor vehicle emission standards will result in the emission reductions shown in Appendix I to this part If specific data are used, such data must be submitted in the plan for such region

(b) *Control strategy development* In a region in which attainment and maintenance of a national standard will require emission reductions in addition to those which will result from application of the Federal motor vehicle emission standards, the control strategy shall provide for application of such other measures as may be necesary for attainment and maintenance of such national standard

(c) *Adequacy of control strategy* (1) The plan shall demonstrate, by means of a proportional model or diffusion/photochemical model or other procedure which is adequate and appropriate, that the control strategy included in each plan for a region classified as Priority

cordance with § 420 5 within 60 days following its adoption

(e) Revisions other than those covered by paragraph (b) of this section shall be identified and described in the semiannual report required by § 420 7

§ 420.7 Reports

(a) On a quarterly basis commencing with the end of the first full quarter after approval of a plan, or any portion thereof, by the Administrator, the State shall submit to the Administrator (through the appropriate Regional Office) information on air quality. The quarters of the year are January 1–March 31, April 1–June 30, July 1–September 30, and October 1–December 31.

(b) On a semiannual basis commencing with the end of the first full semiannual period after approval of a plan, or any portion thereof, by the Administrator, the State shall submit to the Administrator (through the appropriate Regional Office) reports on progress in carrying out the applicable plan The semiannual periods are January 1–June 30 and July 1–December 31

(c) The reports required by this section shall be submitted within 45 days after the end of each reporting period in a manner which shall be prescribed by the Administrator

§ 420.8 Approval of plans.

The Administrator shall approve any plan, or portion thereof, or any revision of such plan, or portion thereof, if he determines that it meets the requirements of the Act Revisions of a plan, or any portion thereof, shall not be considered part of an applicable plan until such revisions have been approved by the Administrator in accordance with this part

Subpart B—Plan Content and Requirements

§ 420 10 General requirements.

(a) During development of a plan, the State is encouraged to identify alternative control strategies, as well as the costs and benefits of each such alternative, for attainment and maintenance of the national standards

(b) Each plan implementing a primary standard shall provide for the attainment of such standard as expeditiously as practicable, but in no case, except as otherwise provided by Subpart C of this part, later than 3 years after the date of the Administrator's approval of such plan or any revision thereof to take account of a revised primary standard The projected date of attainment of such standard shall be specified in the plan

(c) Each plan implementing a secondary standard shall provide for the attainment of such standard by a specified date, which shall be within a reasonable time after the date of the Administrator's approval of such plan

(d) The plan for each region shall have adequate provisions to insure that pollutant emissions within such region will not interfere with attainment and maintenance of any national standard in any portion of an interstate region or in any other region

(e) Each plan shall provide for public availability of emission data reported by source owners or operators or otherwise obtained by a State or local agency Such emission data shall be correlated with applicable emission limitations or other measures As used in this paragraph, "correlated" means presented in such a manner as to show the relationship between measured or estimated amounts of emissions and the amounts of such emissions allowable under the applicable emission limitations or other measures

§ 420 11 Legal authority.

(a) Each plan shall show that the State has legal authority to carry out the plan, including authority to

(1) Adopt emission standards and limitations and any other measures necessary for attainment and maintenance of national standards

(2) Enforce applicable laws, regulations, and standards, and seek injunctive relief

(3) Abate pollutant emissions on an emergency basis to prevent substantial endangerment to the health of persons, i e, authority comparable to that available to the Administrator under section 303 of the Act

(4) Prevent construction, modification, or operation of any stationary source at any location where emissions from such source will prevent the attainment or maintenance of a national standard

(5) Obtain information necessary to determine whether air pollution sources are in compliance with applicable laws, regulations, and standards, including authority to require recordkeeping and to make inspections and conduct tests of air pollution sources

(6) Require owners or operators of stationary sources to install, maintain, and use emission monitoring devices and to make periodic reports to the State on the nature and amounts of emissions from such stationary sources, also authority for the State to make such data available to the public as reported and as correlated with any applicable emission standards or limitations

(b) Where a plan sets forth a control strategy that provides for application of (1) inspection and testing of motor vehicles and/or other transportation control measures or (2) land use measures other than those referred to in § 420 11(a)(4), such plan shall set forth the State's timetable for obtaining such legal authority as may be necessary to carry out such measures

(c) The provisions of law or regulation which the State determines provide the authorities required under this section shall be specifically identified, and copies of such laws or regulations shall be submitted with the plan

(d) (1) Except as otherwise provided by paragraph (b) of this section, the plan shall show that the legal authorities specified in this section are available to the State at the time of submission of the plan.

(2) Legal authority adequate to fulfill the requirements of paragraph (a) (5) and (6) of this section may be delegated the State pursuant to section 114 of the Act

(e) A State governmental agency other than the State air pollution control agency may be assigned responsibility for carrying out a portion of a plan *Provided*, That such plan demonstrates, to the Administrator's satisfaction, that such State governmental agency has the legal authority necessary to carry out such portion of the plan or, pursuant to paragraph (b) of this section, has a timetable for obtaining such authority

(f) The State may authorize a local agency to carry out a plan, or portion thereof, within such local agency's jurisdiction *Provided*, That such plan demonstrates, to the Administrator's satisfaction, that such local agency has the legal authority necessary to implement such plan, or portion thereof, and further *Provided*, That such authorization shall not relieve the State of responsibility under the Act for carrying out such plan, or portion thereof

§ 420 12 Control strategy General

(a) In any region where existing (measured or estimated) ambient levels of a pollutant exceed the levels specified by an applicable national standard, the plan shall set forth a control strategy which shall provide for the degree of emission reduction necessary for attainment and maintenance of such national standard, including the degree of emission reduction necessary to offset emission increases that can reasonably be expected to result from projected growth of population, industrial activity motor vehicle traffic, or other factors that may cause or contribute to increased emissions

(b) In any region where measured or estimated ambient levels of a pollutant are below the levels specified by an applicable secondary standard, the plan shall set forth a control strategy which shall be adequate to prevent such ambient pollution levels from exceeding such secondary standard

(c) Portions of a control strategy applicable to area sources may differ from portions applicable to point sources

(d) For purposes of developing a control strategy, data derived from measurements of existing ambient levels of a pollutant may be adjusted to reflect the extent to which occasional natural or accidental phenomena, e g, dust storms, forest fires, industrial accidents, demonstrably affected such ambient levels during the measurement period

§ 420 13 Control strategy Sulfur oxides and particulate matter

(a) In any region where emission reductions are necessary for attainment and maintenance of a primary standard for sulfur oxides or particulate matter, the plan shall set forth a control strategy which shall be adjusted for the attainment of such primary standard within the time prescribed by the Act

(b) (1) In any region where the degree of emission reduction necessary for attainment and maintenance of a secondary standard for sulfur oxides can

§ 120 3 Classification of regions

This section establishes a classification system to categorize regions for purposes of plan development and evaluation The requirements of this part vary according to the classification of each region, in order that the time and resources to be expended in developing the plan for that region, as well as the substantive content of the plan, will be commensurate with the complexity of the air pollution problem The classification will be based upon measured ambient air quality, where known, or, where not known, estimated air quality in the area of maximum pollutant concentration All regions will be classified by the Administrator after consultation with State agencies Each region will be classified separately with respect to each of the following pollutants Sulfur oxides, particulate matter, carbon monoxide, nitrogen dioxide, and photochemical oxidants

(a) For sulfur oxides and particulate matter, each region will be classified into one of three categories, defined as Priority I, Priority II, or Priority III

(1) (i) Ambient concentration limits, expressed as micrograms per cubic meter and parts per million by volume (p p m in parentheses) which define the classification system for sulfur oxides and particulate matter are

Pollutant	Priority		
	I	II	III
Sulfur oxides	*Greater than*	*From—To*	*Less than*
Annual arithmetic mean	100 (0 04)	60–100 (0 02–0 04)	60 (0 02)
24 hour maximum	455 (0 17)	260–455 (0 10–0 17)	260 (0 10)
3 hour maximum		[1]–1,300 (0 50)	1,300 (0 50)
Particulate matter			
Annual geometric mean	95	60–95	60
24 hour maximum	325	150–325	150

[1] Any concentration above 1,300 $\mu g/m^3$ (0 50 p p m)

(ii) The more restrictive classification will be chosen where there is a difference between the maximum value(s) and the annual averages e g, if a region is Priority I with respect to an annual average and Priority II with respect to a 24-hour maximum value, the classification will be Priority I

(2) Procedures which may be used, where appropriate, to estimate air quality in regions where no measured data or inadequate data exist are described in Appendix A to this part

(b) For carbon monoxide, nitrogen dioxide, and photochemical oxidants, each region will be classified into one of two categories defined as Priority I or Priority III

(1) Ambient concentration limits which define the classification system are

(i) Carbon monoxide Priority I Equal to or above 55 milligrams per cubic meter (48 p p m), 1-hour maximum, or 14 milligrams per cubic meter (12 p p m), 8-hour maximum, Priority III Below such values

(ii) Nitrogen dioxide Priority I Equal to or above 110 micrograms per cubic meter (0 06 p p m), Priority III Below such value

(iii) Photochemical oxidants Priority I Equal to or above 195 micrograms per cubic meter (0 10 p p m), 1-hour maximum, Priority III Below such value

(2) In the absence of measured data to the contrary, classification with respect to carbon monoxide, photochemical oxidants and nitrogen dioxide will be based on the following estimate of the relationship between these pollutants and population Any region containing an area whose 1970 "urban place" population, as defined in the U S Bureau of Census, exceeds 200,000 will be classified Priority I All other regions will be classified Priority III

(3) Where a region is classified Priority I on the basis of population, the air quality data requirements of § 420 14 (e) (1) shall apply If these data indicate the pollutant concentrations are below the values stipulated in subparagraph (1) of this paragraph, the region will be reclassified Priority III

(4) Classifications with respect to hydrocarbons will be the same as the classifications with respect to photochemical oxidants

(c) Where a region is classified Priority I on the basis of measured or estimated air quality levels reflecting emissions predominantly from a single point source, it shall be further classified Priority IA The requirements applicable to Priority IA regions shall be the same as those for other Priority I regions, except that the requirements applicable to Priority II regions under §§ 420 16 and 420 17 shall apply A procedure for estimating air quality levels reflecting emissions from a single point source is described in Appendix A to this part

§ 420 4 Public hearings

(a) The State shall, prior to adoption of a plan and after reasonable notice thereof, conduct one or more public hearings on each plan Separate hearings may be held for plans to implement primary and secondary standards

(b) For purposes of this part, "reasonable notice" shall be considered to include, at least 30 days prior to the date of such hearing(s)

(1) Notice given to the public by prominent advertisement announcing the date(s), time(s), and place(s) of such hearing(s) and the availability of the principal portions of the proposed plan, including, as a minimum, all rules and regulations which are proposed to be included in such plan, for public inspection in at least one location in each region to which the plan will apply

(2) Notification to the Administrator (through the appropirate Regional Office)

(3) Notification to any local air pollution control agencies in each region to which the plan will apply

(4) In the case of an interstate region, notification to any other States included, in whole or in part, in the region

(c) The State shall prepare and retain, for submission to the Administrator upon his request, a record of the hearing(s) The record shall contain, as a minimum, a list of witnesses together with the text of each presentation

(d) The State shall submit with its plan (1) a copy of any advertisement published, broadcast, or otherwise issued pursuant to this section, and (2) a certification that the hearing was held in accordance with the notice required by this section

§ 420 5 Submission of plans, preliminary review of plans.

(a) Submission to the Administrator shall be accomplished by delivering five copies of the plan to the appropriate Regional Office and a letter to the Administrator notifying him of such action Plans shall be adopted by the State and submitted to the Administrator by the Governor as follows

(1) For any primary standard, within 9 months after promulgation of such standard

(2) For any secondary standard, within 9 months after promulgation of such secondary standard or by such later date prescribed by the Administrator pursuant to Subpart C of this part

(b) Plans for different regions within a State may be submitted as a single document or as separate documents

(c) Upon request of a State, the Administrator will provide preliminary review of a plan or portion thereof submitted in advance of the date such plan is due Such requests shall be made in writing to the appropriate Regional Office and shall be accompanied by five copies of the materials to be reviewed. Requests for preliminary review shall not operate to relieve a State of the responsibility of adopting and submitting plans in accordance with prescribed due dates

§ 420 6 Revisions.

(a) The plan shall be revised from time to time, as may be necessary, to take account of

(1) Revisions of national standards,

(2) The availability of improved or more expeditious methods of attaining such standards, such as improved technology or emission charges or taxes, or

(3) A finding by the Administrator that the plan is substantially inadequate to attain or maintain the national standard which it implements

(b) The plan shall be revised within 60 days following notification by the Administrator under paragraph (a) of this section, or by such later date prescribed by the Administrator after consultation with the State

(c) Revisions of rules and regulations included in an applicable plan shall be adopted after reasonable notice and public hearings, as prescribed in § 420 4

(d) Any revision of rules and regulations and of compliance schedules shall be submitted to the Administrator in ac-

Sec
420 19 Source surveillance
420 20 Resources
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AUTHORITY The provisions of this Part 420 issued under section 301(a) of the Clean Air Act (42 U S C 1857(a), as amended by section 15(c)(2) of Public Law 91-604, 84 Stat 1713

Subpart A—General Provisions

§ 420 1 Definitions

As used in this part, all terms not defined herein shall have the meaning given them in the Act

(a) "Act" means the Clean Air Act (42 U S C 1857–18571 as amended by Public Law 91–604, 84 Stat 1676)

(b) "Administrator" means the Administrator of the Environmental Protection Agency (EPA) or his authorized representative

(c) "Primary standard' means a national primary ambient air quality standard promulgated pursuant to section 109 of the Act

(d) "Secondary standard' means a national secondary ambient air quality standard promulgated pursuant to section 109 of the Act

(e) "National standard" means either a primary or a secondary standard.

(f) "Plan" means an implementation plan, under section 110 of the Act, to attain and maintain a national standard

(g) "Applicable plan" means a plan or portion thereof, or the most recent revision of such plan or portion thereof, which has been approved or promulgated by the Administrator pursuant to section 110 of the Act

(h) "Regional Office" means one of the ten (10) EPA Regional Offices

(i) "State agency" means the air pollution control agency primarily responsible for development and implementation of a plan under the Act

(j) "Local agency" means any air pollution control agency other than a State agency, which is charged with responsibility for carrying out a portion of a plan.

(k) "Point source" means

(1) Any stationary source causing emissions in excess of 100 tons (90 7 metric tons) per year of any pollutant for which there is a national standard in a region containing an area whose 1970 "urban place" population, as defined by the Bureau of Census, was equal to or greater than 1 million or

(2) Any stationary source causing emissions in excess of 25 tons (22 7 metric tons) per year of any pollutant for which there is a national standard in a region containing an area whose 1970 "urban place" population, as defined by the U S Bureau of the Census, was less than 1 million and

(3) Without regard to amount of emissions, stationary sources such as those listed in Appendix C to this part

(l) "Area source" means any small residential, governmental, institutional, commercial, or industrial fuel combustion operations onsite waste disposal facility, motor vehicles, aircraft, vessels, or other transportation facilities, or other miscellaneous sources such as those listed in Appendix D to this part, as identified through inventory techniques similar to those described in "A Rapid Survey Technique for Estimating Community Air Pollution Emissions," Public Health Service Publication No 999-AP-29, October 1966

(m) "Region" means (1) an air quality control region designated by the Secretary of Health, Education, and Welfare or the Administrator, (2) any area designated by a State agency as an air quality control region and approved by the Administrator, or (3) any area of a State not designated as an air quality control region under subparagraph (1) or (2) of this paragraph

(n) "Control strategy" means a combination of measures designated to achieve the aggregate reduction of emissions necessary for attainment and maintenance of a national standard, including, but not limited to, measures such as

(1) Emission limitations

(2) Federal or State emission charges or taxes or other economic incentives or disincentives

(3) Closing or relocation of residential, commercial, or industrial facilities

(4) Changes in schedules or methods of operation of commercial or industrial facilities or transportation systems, including, but not limited to, short-term changes made in accordance with standby plans

(5) Periodic inspection and testing of motor vehicle emission control systems, at such time as the Administrator determines that such programs are feasible and practicable

(6) Emission control measures applicable to in-use motor vehicles, including, but not limited to, measures such as mandatory maintenance, installation of emission control devices, and conversion to gaseous fuels

(7) Measures to reduce motor vehicle traffic, including, but not limited to, measures such as commuter taxes, gasoline rationing, parking restrictions, or staggered working hours

(8) Expansion or promotion of the use of mass transportation facilities through measures such as increases in the frequency, convenience, and passenger-carrying capacity of mass transportation systems or providing for special bus lanes on major streets and highways

(9) Any land use or transportation control measures not specifically delineated herein

(10) Any variation of, or alternative to, any measure delineated herein

(o) "Reasonably available control technology" means devices, systems, process modifications, or other apparatus or techniques, the application of which will permit attainment of the emission limitations set forth in Appendix B to this part, provided that Appendix B to this part is not intended, and shall not be construed, to require or encourage State agencies to adopt such emission limitations without due consideration of (1) the necessity of imposing such emission limitations in order to attain and maintain a national standard, (2) the social and economic impact of such emission limitations, and (3) alternative means of providing for attainment and maintenance of such national standard

§ 420 2 Stipulations

Nothing in this part shall be construed in any manner

(a) To encourage a State to prepare, adopt, or submit a plan which does not provide for the protection and enhancement of air quality so as to promote the public health and welfare and productive capacity

(b) To encourage a State to adopt any particular control strategy without taking into consideration the cost-effectiveness of such control strategy in relation to that of alternative control strategies

(c) To preclude a State from employing techniques other than those specified in this part for purposes of estimating air quality or demonstrating the adequacy of a control strategy, provided that such other techniques are shown to be adequate and appropriate for such purposes

(d) To encourage a State to prepare, adopt, or submit a plan without taking into consideration the social and economic impact of the control strategy set forth in such plan, including, but not limited to, impact on availability of fuels, energy, transportation, and employment

(e) To preclude a State from preparing, adopting, or submitting a plan which provides for attainment and maintenance of a national standard through the application of a control strategy not specifically identified or described in this part,

(f) To preclude a State or political subdivision thereof from adopting or enforcing any emission limitations or other measures or combinations thereof to attain and maintain air quality better than that required by a national standard

(g) To encourage a State to adopt a control strategy uniformly applicable throughout a region unless there is no satisfactory alternative way of providing for attainment and maintenance of a national standard throughout such region.

Title 42—PUBLIC HEALTH

Chapter IV—Environmental Protection Agency

PART 420—REQUIREMENTS FOR PREPARATION, ADOPTION, AND SUBMITTAL OF IMPLEMENTATION PLANS

On April 30, 1971 (36 F R. 8186), pursuant to section 109 of the Clean Air Act, as amended, the Administrator promulgated national ambient air quality standards for sulfur oxides, particulate matter, carbon monoxide, photochemical oxidants, hydrocarbons, and nitrogen dioxide Within 9 months thereafter, i e, no later than January 30, 1972, each State is required by section 110 of the Act to adopt and submit to the Administrator a plan which provides for the implementation, maintenance, and enforcement of such national ambient air quality standards within each air quality control region (or portion thereof) within the State An additional period of no longer than 18 months may be allowed for adoption and submittal of that portion of a plan relating to implementation of secondary ambient air quality standards State plans must provide for attainment of national primary ambient air quality standards within 3 years after the date of the Administrator's approval of such plans, except that a 2-year extension of this deadline may be granted by the Administrator upon application by a Governor if the application satisfies the requirements set forth in section 110(e) of the Act State plans must provide for attainment of national secondary ambient air quality standards within a reasonable time Within 4 months from the date on which State plans are required to be submitted, the Administrator must approve or disapprove such plans or portions thereof

A notice of proposed rule making published in the FEDERAL REGISTER on April 7, 1971 (36 F R 6680), set forth regulations applicable to preparation, adoption, and submittal by the States of such implementation plans Interested parties have been afforded an opportunity to participate in the rule making by submitting comments A total of more than 400 interested parties, including Federal, State, and local agencies, citizens groups, and commercial and industrial organizations submitted comments Following review of the proposed regulations, and consideration of the comments, the regulations, including the appendices, have been revised and are being promulgated today The principal revisions are described below

1 Provisions have been added to encourage States to consider the socio economic impact and the relative costs and benefits of the various emission control strategies which can be employed to attain and maintain the national standards Emission charges or taxes or other economic incentive schemes have been included among the measures which States may employ as part of a control strategy

2 The requirement that States establish and operate a permit system has been eliminated, States still will be required to have authority to prevent construction, modification, or operation of sources

3 The system for classification of regions has been modified to provide for a subclassification of Priority I regions in certain cases The provisions for use of an example region in the formulation and application of control strategies have been modified

4 Where a State plan provides for inspection and testing of motor vehicles and/or other transportation control measures or land use control measures, the plan will have to indicate when the State will have legal authority to impose such measures All other legal authority will have to be available at the time the plan is submitted Legal authority adequate to fulfill some of the requirements of § 420 11 may be delegated to a State under section 114 of the Act Section 420 11 has also been revised to emphasize that State agencies other than State air pollution control agencies, as well as local agencies, may participate in carrying out an implementation plan

5 The provisions dealing with public hearings have been revised to require at least 30 days' notice of public hearings on proposed State implementation plans and to define "reasonable notice" to include prominent advertisement of the dates, times, and places of such hearings and of the availability of the proposed plans for public inspection

6 The fixed deadline for requests for preliminary review of State plans has been eliminated Nevertheless, State agencies desiring such preliminary review by the Environmental Protection Agency should make their requests well ahead of the statutory deadline for submittal of plans, i e, January 30, 1972, preferably, at least 90 days in advance Preliminary review results will be made available, on requests, to all interested parties

7 Section 420 10 has been revised to require that State plans provide for public availability of emission data reported by source owners or operators or otherwise obtained by a State or local agency, such emission data must be correlated with applicable emission limitations

8 The definition of "reasonable time" for attainment of national secondary ambient air quality standards for sulfur oxides and particulate matter has been modified As revised it provides for consideration of the degree of emission reduction needed for attainment of such secondary standards and the social, economic, and technological factors in those cases where it is shown that more than 3 years will be necessary

9 Requirements for legally enforceable compliance schedules have been more clearly spelled out

10 The provisions dealing with emergency episode planning have been modified In the near future, the Administrator will identify the ambient pollutant concentrations which, in his judgment, would cause substantial endangerment

11 Air quality surveillance systems will be required to be in operation not later than 2 years after the Administrator's approval of a State plan There also have been revisions with respect to measurement methods in order to insure that the results obtained with methods other than those prescribed (36 F R 8186) as reference methods have a consistent relationship to the results obtained with the reference methods

12 Appendix B has been recast as a series of statements reflecting emission limitations attainable through the application of reasonably available control technology This change was made as a way of avoiding misinterpretation of appendix B A revised introduction to the appendix explains its purpose more clearly

13 A great many other revisions have also been made States and other interested parties are therefore urged to make a careful reading of these regulations

In the comments submitted to the Environmental Protection Agency following publication of the notice of proposed rule-making, many questions were raised about land use and transportation control measures The Environmental Protection Agency is engaged in the preparation of information to assist States in employing such measures in their programs for attainment and maintenance of the national ambient air quality standards There will be included, among other things, information on the extent to which motor vehicle inspection programs and emission control devices applicable to in-use motor vehicles can be expected to contribute to improvements in ambient air quality

The Regulations for Preparation, Adoption, and Submittal of Implementation Plans, Part 420, are hereby promulgated effective upon publication (8-14-71)

Dated August 3, 1971

ROBERT W FRI,
Acting Administrator

A new Part 420 is added to Chapter IV, Title 42, Code of Federal Regulations, as follows

Subpart A—General Provisions

Sec	
420 1	Definitions
420 2	Stipulations
420 3	Classification of regions
420 4	Public hearings
420 5	Submittal of plans, preliminary review of plans
420 6	Revisions
420 7	Reports
420 8	Approval of plans

Subpart B—Plan Content and Requirements

420 10	General requirements
420 11	Legal authority
420 12	Control strategy General
420 13	Control strategy Sulfur oxides and particulate matter
420 14	Control strategy Carbon monoxide, hydrocarbons, photochemical oxidants, and nitrogen dioxide
420 15	Compliance schedules
420 16	Prevention of air pollution emergency episodes
420 17	Air quality surveillance
420 18	Review of new sources and modifications

Federal Register

PART II

ENVIRONMENTAL PROTECTION AGENCY

Requirements for Preparation, Adoption, and Submittal of Implementation Plans

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RELACION DE ASISTENTES AL CURSO SOBRE CONTROL DE LA CONTAMINACION ATMOSFERICA

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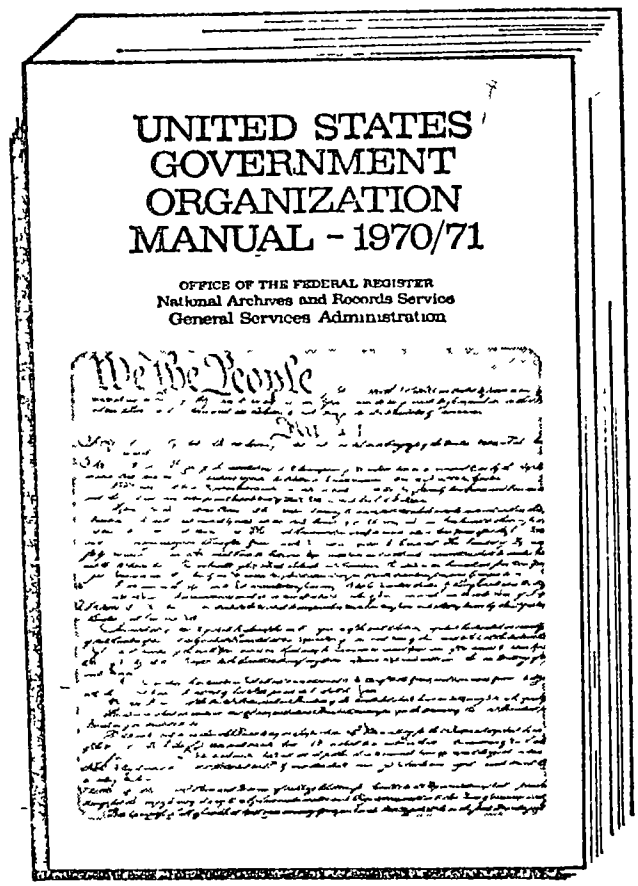

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ENVIRONMENTAL PROTECTION AGENCY

AIR POLLUTION PREVENTION AND CONTROL

List of Air Pollutants, Issuance of Air Quality Criteria

Section 108(a)(1) of the Clean Air Act, as amended December 31, 1970 (Public Law 91-604), directs the Administrator of the Environmental Protection Agency to publish, no later than January 30, 1971, and from time to time thereafter revise, a list that includes each air pollutant which in his judgment has an adverse effect on public health or welfare, which is present in the ambient air as a result of emissions from numerous or diverse mobile or stationary sources, and for which no air quality criteria were issued prior to the enactment of the amendments Within twelve (12) months from the inclusion of a pollutant on the list, the Administrator is required to issue air quality criteria for such pollutant

The Administrator, after evaluating available information, has concluded that nitrogen oxides clearly meet the above requirements Evaluation of other air pollutants, including fluorides, polycyclic organic matter, and odorous substances, is being conducted, and the list will be revised as the Administrator deems appropriate Accordingly, there is hereby established a list of air pollutants under section 108(a)(1) of the Act, as follows

LIST OF AIR POLLUTANTS

1 NITROGEN OXIDES

Pursuant to sections 108 (a) and (d) of the Clean Air Act, as amended December 31, 1970 (Public Law 91-604) notice is hereby given that the Administrator of the Environmental Protection Agency after consultation with appropriate advisory committees experts, and Federal departments and agencies in accordance with section 117(f) of the Act has today issued the document "Air Quality Criteria for Nitrogen Oxides" (EPA Publication No AP-84) As required by the Act, issuance of this document follows the inclusion of nitrogen oxides in the list of air pollutants published above

The air quality criteria reflect the latest scientific knowledge useful in indicating the kind and extent of all identifiable effects on public health or welfare which may be expected from the presence of nitrogen oxides in varying quantities in the ambient air

Notice is further given that the information on control techniques for nitrogen oxides required to be issued pursuant to section 108(b) of the Act was issued on March 19, 1970 (35 FR 4768) in the following documents

Control Techniques for Carbon Monoxide, Nitrogen Oxide and Hydrocarbon Emissions from Mobile Sources (NAPCA Publication No AP-66)

Control Techniques for Nitrogen Oxide Emissions from Stationary Sources (NAPCA Publication No AP-67)

The control techniques documents were transmitted to the Governor of each State, and to the agency in each State that is designated by the Governor as the official State air pollution control agency for purposes of the Act

Pursuant to section 109(a)(2) of the Clean Air Act, as amended, there are published in this issue of the FEDERAL REGISTER proposed national primary and secondary ambient air quality standards for nitrogen oxides, which the Administrator is required to publish simultaneously with the issuance of air quality criteria and information on control techniques

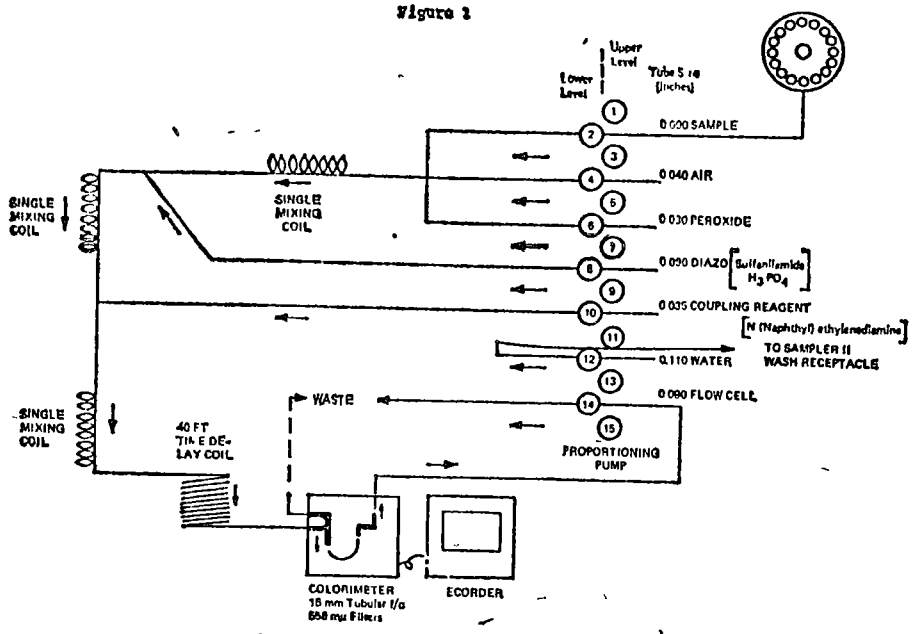
Copies of the documents whose issuance is announced herein are available to the general public from the Superintendent of Documents, Government Printing Office, Washington, D C. 20402

WILLIAM D RUCKELSHAUS,
Administrator.

JANUARY 25, 1971

[FR Doc 71-1264 Filed 1-29-71,8 45 am]

Figure 2



[FR Doc 71-1263 Filed 1-29-71,8 45 am]

to 10 minutes Disconnect the zero gas and connect the span gas to the column so that span gas passes through the column before the analyzer Allow the instrument to run 5 to 10 minutes Remove the old column and insert a freshly purged carbon column Observe the analysis tag attached to zero-gas cylinder and note the indicated p p m Disconnect the span gas and reconnect the zero gas wait until reading has stopped changing then adjust the ZERO control to bring the recorder pen to the same reading (in p p m) as indicated on analysis tag Reconnect the span gas and adjust the recorder with SPAN control to indicated value in p p m Repeat zero and span adjustment until no further adjustments are required Connect the column back to sample air Check to see that the sample pressure gauge reading is still the same as originally set Turn off the zero and span cylinder valves

9 *Calculation* 9 1 Meter is read directly in p p m as CH_4

10 *Bibliography* 1 Ortman, G C, Monitoring Methane in Atmosphere with a Flame Ionization Detector, Anal Chem 38, 644 (1966).

2 Beckman Instruction Manual 1306, Beckman Instruments, Inc (1964)

APPENDIX F

METHOD FOR DETERMINATION OF NITROGEN DIOXIDE IN THE ATMOSPHERE

(24-HOUR SAMPLING METHOD)

1 *Principle and applicability* 1 1 Nitrogen dioxide is collected by bubbling air through a sodium hydroxide solution A dilute solution of sodium nitrite is produced which need not be analyzed immediately

1 2 The nitrite ion produced during sampling is determined colorimetrically by reacting the exposed absorbing reagent with phosphoric acid, sulfanilamide, and N-(1-naphthyl)-ethylenediamine dihydrochloride

1 3 The methods of sampling and analysis are applicable to field collection of 24-hour samples and return to a central laboratory for analysis

2 *Range and sensitivity* 2 1 The range of the analysis is 0 04 to 1 5 μg NO_2^-/ml For the efficiency stated in section 8 3, 50 ml absorbing reagent and a sampling rate of 200 ml /min for 24 hours, the range of the method is 20–740 μg /m^3 (0 01–0 4 p p m) nitrogen dioxide

2 2 A nitrite concentration of 0 04 μg NO_2^-/ml will produce an absorbance of 0 02 with 1-cm cells

3 *Interferences* 3 1 The interference of sulfur dioxide is eliminated by conversion to sulfuric acid with hydrogen peroxide before analysis[1]

4 *Precision, accuracy, and stability* 4 1 The relative standard deviations are 14 4 percent and 21 5 percent at nitrogen dioxide concentrations of 140 μg /m^3 (0 072 p p m) and 200 μg /m^3 (0 108 p p m) These data are based on 10 samples collected from test atmospheres generated with nitrogen dioxide permeation tubes are analyzed by automating the procedure with a Technicon Autoanalyzer

4 2 No accuracy data are available

4 3 Collected samples are stable for at least 6 weeks

5 *Apparatus*—5 1 *Sampling* See Figure 1

5 1 1 Absorber—Polypropylene tubes 164 by 32 mm, equipped with polypropylene two-port tube closures Rubber stoppers cannot be used because high and varying blank values are obtained A gas dispersion tube with a fritted disc of porosity B (70–100 μm maximum pore diameter) is used.

5 1 1 1 *Measurement of maximum pore diameter of frit* Carefully clean the frit with dichromate-concentrated sulfuric acid cleaning solution and rinse well with distilled water Insert the frit in one hole of a two-hole rubber stopper and install the frit in a tube containing sufficient distilled water to cover Attach a vacuum source to the other hole of the rubber stopper and measure the vacuum required to draw the first perceptible stream of air bubbles through the frit Apply the following equation

$$\text{maximum pore diameter, } \mu m = \frac{30s}{P}$$

s = Surface tension of water in dynes/cm at the test temperature (73 at 18° C, 72 at 25° C and 71 at 31° C)

P = Vacuum mm Hg

5 1 2 *Probe* Teflon or glass tube with a polypropylene or glass funnel at the end and a membrane filter to protect the frit Replace filter after use with no more than five samples

5 1 3 *Flow control device* Calibrated 27-gauge hypodermic needles, ⅜-in long The needle should be protected by a membrane filter or fiber glass filter Change filter after use with 10 samples

5 1 4 *Air pump* Capable of maintaining a flow of 0 2 liter/min through the absorber, and a vacuum of 0 7 atmosphere

5 1 5 *Calibration equipment* One ball-float flowmeter for measuring air flows up to approximately 275 ml /min, one stopwatch, and one precision wet test meter, 1 liter/revolution

5 2 *Analysis*

5 2 1 *Volumetric flasks* 50, 100, 200, 250, 500, 1,000 ml

5 2 2 *Graduated cylinder* 1,000 ml

5 2 3 *Pipets* 1, 2, 5, 10 ml

5 2 4 *Test tube*

5 2 5 *Spectrophotometer or colorimeter* Capable of measuring absorbance at 540 nm Band width is not critical

6 *Reagents*—6 1 *Sampling*

6 1 1 *Absorbing reagent* Dissolve 4 0 g sodium hydroxide and dilute to 1,000 ml with distilled water

6 2 *Analysis*

6 2 1 *Sulfanilamide* Dissolve 20 g sulfanilamide in 700 ml distilled water Add, with mixing, 50 ml phosphoric acid (85 percent) and dilute to 1 000 ml This solution is stable for a month if refrigerated

6 2 2 *NEDA solution* Dissolve 0 5 g N-(1-naphthyl)-ethylenediamine dihydrochloride in distilled water This solution is stable for a month if refrigerated and protected from light

6 2 3 *Hydrogen peroxide* Dilute 0 2 ml 30 percent hydrogen peroxide to 250 ml with distilled water This solution is stable for a month if protected from light

6 2 4 *Standard nitrite solution* Dissolve sufficient desiccated sodium nitrite ($NaNO_2$, assay of 97 percent or greater) and dilute with distilled water to 1,000 ml so that a solution containing 100 μg NO_2^-/ml is obtained The amount of $NaNO_2$ to use is calculated as follows

$$G = \frac{1\,500}{A} \times 1000$$

G = Amount of $NaNO_2$ g

1 500 = Gravimetric factor in converting NO_2^- into $NaNO_2$

A = Assay, percent

7 *Procedure*—7 1 *Sampling* Assemble the sampling train as shown in Figure 1 Add 50 ml absorbing reagent to the absorber Disconnect funnel, insert calibrated flowmeter, and measure flow before sampling If flow rate before sampling is less than 85 percent of needle calibration, check for leak or change filters as necessary Sample for 24 hours and measure flow at end of sampling period

7 2 *Analysis* Replace any water lost by evaporation during sampling Pipet 10 ml of the collected sample into a test tube Add 1 0 ml hydrogen peroxide solution, 10 0 ml sulfanilamide solution, and 1 4 ml NEDA solution with thorough mixing after the addition of each reagent Prepare a blank in the same manner using 10 ml absorbing reagent After a 10-min color development interval measure the absorbance at 540 nm against the blank Read μg NO /ml from standard curve (section 8 2)

8 *Calibration and efficiencies*—8 1 *Sampling*

8 1 1 *Calibration of ball float flowmeter* Using a wet test meter and a stopwatch determine the rates of air flow (ml /min) through the flowmeter at several ball positions Plot ball positions versus flow rates

8 1 2 *Calibration of hypodermic needle* Connect the calibrated flowmeter, the needle to be calibrated, and the source of vacuum in such a way that the direction of air flow through the needle is the same as in the sampling train Read the position of the ball and determine flow rate in ml /min from the calibration chart prepared in 8 1 1 Reject all needles not having flow rates of 190 to 210 ml /min before sampling

8 2 *Calibration curve* Dilute 5 0 ml of the 1,000 μg NO_2^-/ml solution to 200 ml with absorbing reagent This solution contains 25 μg NO_2^-/ml Pipette 1, 2, 5, and 15 ml of the 25 μg NO_2^-/ml solution into 50-, 50-, 100-, and 250-ml volumetric flasks and dilute to the mark with absorbing reagent The solutions contain 0 50, 1 00, 1 25, and 1 50 μg NO_2^-/ml, respectively Run standards as instructed in 7 2 Plot absorbance vs μg NO_2^-/ml

8 3 *Efficiencies* An overall average efficiency of 35 percent was obtained from test atmospheres having nitrogen dioxide concentrations of 140 μg /m^3 and 200 μg /m^3 by automated analysis[1]

9 *Calculation*—9 1 *Sampling*

9 1 1 Calculate volume of air sampled

$$V = \frac{F_1 + F_2}{2} \times T \times 10^{-6}$$

V = Volume of air sampled, m^3

F_1 = Measured flow rate before sampling ml /min

F_2 = Measured flow rate after sampling, ml /min

T = Time of sampling min

10^{-6} = Conversion of ml to m^3

9 2 Calculate the concentration of nitrogen dioxide as μg NO_2/m^3

μg NO /m^3 =

$$\frac{(\mu g\ NO_2^-/ml) \times 50}{V \times 0.35} = \frac{(\mu g\ NO_2^-/ml) \times 143}{V}$$

50 = Volume of absorbing reagent used in sampling, ml

V = Volume of air sampled, m^3

0 35 = Efficiency

9 2 1 If desired, concentration of nitrogen dioxide may be calculated as p p m NO at 25° C and 760 mm

p p m = (μg NO/m^3) $\times$ 5 319 $\times$ 10^{-4}

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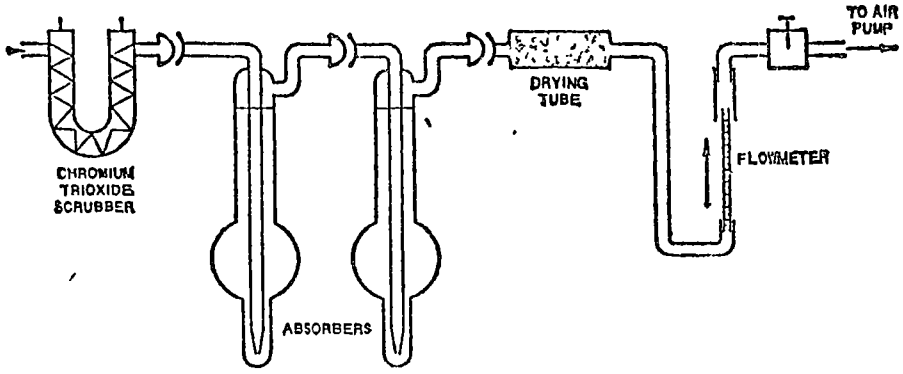

Figure 1 Sampling train.

APPENDIX E

PART 1 METHOD FOR CONTINUOUS MEASUREMENT OF HYDROCARBONS (FLAME IONIZATION METHOD)

1 *Principle and applicability* 1 1 The sampling system is an integral part of the most commercial total hydrocarbon analyzers designed to measure continuously the concentration of hydrocarbons (and other organic compounds) in the atmosphere The sample line is attached to the inlet and the sample is pumped into a flame ionization detector A sensitive electrometer coupled with a potentiometric recorder detects the increase in ion intensity resulting from the introduction into a hydrogen flame of a sample of air containing any organic compound (e g hydrocarbons, aldehydes, alcohols) The response is approximately proportional to the number of carbon-hydrogen bonds in the sample The analyzer is calibrated using methane and the results reported as methane equivalents See addendum for description of method for measurement of methane

1 2 The sample introduction pump may be bypassed for analysis of gases under pressure as is done with calibration gases

2 *Range and sensitivity* 2 1 The range of the analyzer may be varied so that full scale may be 2 6 mg /m³ (4 p p m) to 1960 mg /m³ (3 000 p p m) hydrocarbon as methane by varying the attenuation and the sample flow rate to the detector The 13 mg /m³ (20 p p m) range is normally for atmospheric sampling

2 2 Sensitivity is 1 percent of full scale recorder response

3 *Interferences* 3 1 Carbon atoms bound to oxygen, nitrogen or halogens give reduced or no response There is no response to nitrogen, carbon monoxide, carbon dioxide, or water vapor

4 *Precision accuracy and stability* 4 1 Precision is approximately 0 5 percent full recorder scale on the 13 mg /m³ (20 p p m) scale

4 2 Accuracy is dependent on instrument linearity and absolute concentration of the calibration gases used Generally, accuracy is +1 percent of full scale on the 0–13 mg /m³ range

4 3 Zero drift necessitates frequent calibration The magnitude of the drift depends on the air flow rate sample flow rate, fuel flow rate, ambient temperature changes, detector contamination, and electronic drift Zero drift observations on various instruments indicate 2 percent/24 hours on the 13 mg /m³ scale

5 *Apparatus*—5 1 *Commercially available total hydrocarbon analyzer* Instruments obtained should be installed on location and demonstrated preferably by the manufacturer to meet or exceed manufacturers specifications and those described in this method Generally, hydrocarbon analyzers consist of a regulated fuel and air delivery system for the hydrocarbon burner, a regulated sample injection system, electrometer for measuring the flame ion current, meter readout with connections for a recorder, and a sample pump

5 2 *Recorder* Potentiometeric type, compatible with analyzer with an accuracy of 0/5 percent or better

5 3 *Sample line* Any tubing that is not a source interferences or an absorbant of hydrocarbons Inert materials such as glass, stainless steel, and Teflon are recommended

6 *Reagents*—6 1 *Combustion air* High purity air containing less than 1 3 mg /m³ (2 p p m) hydrocarbon as methane

6 2 *Fuel* Hydrogen or a hydrogen-inert gas mixture, when ordering specify hydrocarbon-free gas A hydrogen generator is strongly advised for safety reasons

6 3 *Zero gas* Less than 0 05 mg /m³ (0 1 p p m) hydrocarbon as methane in air

6 4 *Span gas* Methane in air corresponding to 80 percent of full scale, 10 4 mg /m³ (16 0 p p m) for 13 mg /m³ A certified or guaranteed analysis is required

7 *Procedure* 7 1 For specific operating instructions, see the manufacturer's manual

8 *Calibration and efficiencies* 8 1 Calibrate the instrument at the desired flow rate and attenuator setting Introduce zero gas and set zero control to indicate proper value on the recorder If a live zero recorder is not used, it is recommended that the zero setting be offset at least 5 percent of scale to allow for negative zero drift In this case, the span setting must also be offset by an equal amount Introduce span gas and adjust span control to indicate proper value on recorder scale (e g 0–13 mg /m³ (0–20 p p m) sale set a 10 4 mg /m³ (16 0 p p m) standard to read 80 percent recorder chart) Recheck zero and span until adjustments are no longer necessary Since the scale is linear, the two-point calibration is valid

8 1 1 If attenuation is varied, some discrepancy between the true attenuation and the nominal attenuation may exist The instrument should be calibrated using appropriate standards at each attenuator setting used

9 *Calculations* 9 1 1 The recorder is read directly for hydrocarbon concentration

PART 2 METHOD FOR MEASUREMENT OF METHANE

1 *Principle and applicability* 1 1 The atmospheric sample is continuously passed through a treated charcoal column before introduction into the instrument This column will selectively strip all hydrocarbons other than methane and give a specific analyses for methane[1] The methane level is continuously monitored by flame ionization techniques

1 2 The technique may be applied to a gaseous sample containing low concentrations of methane, since the instrument can sample gases at 5 p s i or more pressure or at ambient pressure

2 *Range and sensitivity* 2 1 The ranges available on commercial continuous hydrocarbon analyzers are commonly 0 to 10 p p m and 0 to 100 p p m A sensitivity of 0 1 p p m can be obtained in the 0 to 10 p p m range

3 *Interferences* 3 1 Ethane is the hydrocarbon most likely to break through the carbon column when ambient urban air is sampled Thus, service life of the column is measured by introducing known concentrations of ethane in amounts equal to the daily average peak for the sampling zone (ref 1) This service life has been found to be as long as 6 days The column must be purged with helium every 3 days

4 *Precision, accuracy, and stability* 4 1 Precision is ±1 percent for successive identical samples under identical conditions

4 2 Accuracy is dependent upon the accuracy of standards used to calibrate the instrument

4 3 At normal temperature, the system is stable

5 *Apparatus*—5 1 *Continuous hydrocarbon analyses* The procedure described is for the Beckman 108A and 109A analyzers

5 2 *Charcoal column* A 5-inch long threaded nipple of ¼-inch pipe packed with 4 5 grams of 6/14 mesh activated charcoal Cloth discs contain the charcoal The freshly packed tube is blown out forcibly with helium for 2 minutes to remove fine dust, which otherwise would interfere with the detector operation

6 *Reagents*—6 1 *Fuel gas* Pure hydrogen or a 40 percent hydrogen/60 percent nitrogen mixture relatively hydrocarbon free A hydrogen generator may be used

6 2 *Air* Water-pumped cylinder air

6 3 *Zero gas* A calibration gas that contains a relatively low amount of hydrocarbons is required for setting the zero point If the hydrocarbon content of the burner air is sufficiently low and accurately known, this gas can be used as the zero gas

6 4 *Span gas* The span gas is a certified calibration gas used to set an upscale standardization point

6 5 *Helium* Cylinder helium (water-pumped) is required to recondition the carbon filter

7 *Procedure* 7 1 Check that all units are properly connected according to the diagram. Turn on fuel gas Allow fuel pressure to reach proper level according to flow desired Slowly open the air cylinder valve Adjust air pressure to about 30 p s i Again adjust to obtain desired flow Check all fittings for leaks. Insert a carbon column in position Introduce sample and adjust to proper value If all pressures inside analyzer are proper, turn on analyzer power switch and ignite burner A small pop indicates that the flame has ignited The analyzer meter should show an upscale deflection Adjust attenuator to x30 position, and adjust the zero and span* controls so that meter reading is between 10 and 60 Proceed to calibration

8 *Calibration, standards, and efficiencies* 8 1 Check flow rates with a calibrated bubble flow meter so that sample flow corresponds to optimum values

8 2 If the instrument has just been started, wait at least 3 hours before calibrating Open the cylinder shut-off valves on the span and zero gas cylinders Observe the sample pressure gauge and adjust to the proper flow rate of the zero gas to the carbon asthma kit and through the column and thermometer to the analyzer Allow the instrument to run on zero gas for 5

*Span control has been added to the Beckman analyzer for convenience

4 3 Analysis should be completed immediately after sampling to obtain consistent results This is necessary because some oxidants release iodine slowly to enhance color, while fading due to slow decomposition of iodine may occur

5 *Apparatus*—5 1 *Absorber* All-glass impingers as shown in Figure 1 are recommended These impingers may be purchased from major glassware suppliers Two absorbers in series are needed to insure complete collection of the sample

5 2 *Air pump* Capable of drawing 2 liters/min through the absorbers The pump should be equipped with a needle valve at the inlet side to regulate flow If a critical orifice (5 7) is used the pump must be capable of maintaining 0 7 atmosphere vacuum

5 3 *U tube* 140 ml for the chromium trioxide scrubber

5 4 *Thermometer* Or other temperature-measuring device with an accuracy of ±2° C

5 5 *Barometer* Atmospheric, accurate to the nearest mm Hg

5 6 *Wet test meter* 1 or 3 liters/revolution

5 7 *Flowmeter* Calibrated metering device for measuring flow of 2 liters/min within ±5 percent A 20-gauge hypodermic needle 1 in long acting as a critical orifice can be used to give a flow of approximately 2 liters/min

5 8 *Drying tube* Containing an indicating drying agent to protect flowmeter

5 9 *Prescrubber* Tube filled with granular MnO_2 and charcoal to remove oxidants

5 10 *Volumetric flasks* 25, 100, 500, 1,000 ml

5 11 *Buret* 50 ml

5 12 *Pipets* 0 5, 1, 2, 3, 4, 10, 25, and 50 ml volumetric

5 13 *Erlenmeyer flasks* 300 ml

5 14 *Oven* Capable of maintaining 105° C

5 15 *Spectrophotometer* Capable of measuring absorbance at 352 nm Matched 1-cm cells should be used

6 *Reagents*—6 1 *Purified water* Used for all reagents To distilled or deionized water in an all-glass distillation apparatus, add a crystal of potassium permanganate and a crystal of barium hydroxide, and redistill

6 2 *Absorbing reagent* Dissolve 13 6 g potassium dihydrogen phosphate (KH_2PO_4), 14 2 g anhydrous disodium hydrogen phosphate (Na_2HPO_4) (or 35 8 g dodecahydrate salt), and 10 0 g potassium iodide (KI) in purified water and dilute to 1,000 ml The pH should be 6 8±0 2 Store the solution in a glass-stoppered amber bottle in a cool dark place It is stable for several weeks

6 3 *Standard arsenious oxide solution (0 05 N)* Use primary standard grade arsenious oxide (As_2O_3) Dry 1 hour at 105° C immediately before using Accurately weigh 2 4 g arsenious oxide from a small glass-stoppered bottle Dissolve in 25 ml 1 N sodium hydroxide in flask or beaker on a steam bath Add 25 ml 1 N sulfuric acid Cool and transfer quantitatively to a 1,000-ml volumetric flask and dilute to volume NOTE Solution must be neutral to litmus, not alkaline

$$\text{Normality } As_2O_3 = \frac{\text{wt } As_2O_3 \text{ (g)}}{49.46}$$

6 4 *Starch indicator solution (0 2 percent)* Triturate 0 4 g soluble starch and approximately 2 mg mercuric iodide (preservative) with a little water, add the paste slowly to 200 ml boiling water Continue boiling until the solution is clear, then allow to cool, and transfer to glass-stoppered bottle

6 5 *Standard iodine solution (0 05 N)*—6 5 1 *Preparation* Dissolve 5 0 g potassium iodide (KI) and 3 2 g resublimed iodine (I) in 10 ml purified water When the iodine dissolves transfer the solution to a 500-ml glass-stoppered volumetric flask Dilute to mark with purified water and mix thoroughly Keep solution in a dark brown glass-stoppered bottle away from light and restandardize as necessary

6 5 2 *Standardization* Pipet accurately 50 ml standard arsenious oxide solution into a 300-ml Erlenmeyer flask Acidify slightly with a 1 10 dilution of sulfuric acid neutralize with solid sodium bicarbonate, and add about 2 g excess Titrate with the standard iodine solution using 5 ml starch solution as indicator Saturate the solution with carbon dioxide at end of titration by adding 1 ml of 1 10 sulfuric acid just before the end point is reached

6 6 *Chromium trioxide scrubber* Dissolve 125 g chromium trioxide (CrO_3) crystals in 35 ml concentrated sulfuric acid and add to 750 ml distilled water Place a 15-by 25-cm sheet of a flash-fired glass-fiber filter in an oven rack equipped with glass rod attachments to prevent the filter from touching metal Saturate the filter with 15 ml chromium trioxide solution Place the filter in an oven set at 65–70° C for 1 hour A freshly prepared filter is brownish pink At the end of this time remove the filter and fold every 1 2 cm along the 15-cm dimension in an accordion fashion While the sheet is folded cut the 15-cm length into 10 equal widths As each strip is cut, place it in the 140-ml U-tube Place five cut strips in each tube, rotating alternate strips 90° so that folds will not match Before the scrubber is used for sampling condition for several hours to ozone at a high concentration from an ozone source such as a UV photolysis lamp As the filters absorb moisture scrubbing efficiency is decreased This condition is evident as a green color Caution When working with chromium trioxide and sulfuric acid wear gloves to prevent irritation of the skin

7 *Procedure*—7 1 *Sampling* Assemble the apparatus as shown in Figure 1 Use ground-glass connections upstream from the impinger Butt-to-butt connections with Tygon tubing may be used Check assembled system for leaks Pipet 10 ml absorbing reagent into first absorber and place MnO_2 prescrubber on the sample probe Draw air through the prescrubber and the sampling train for 15 min at 2 liter/min If an absorbance reading at 352 nm is obtained, repeat until zero or constant absorbance is obtained This system blank absorbance should be subtracted from the absorbance of the first absorber when analyzing for oxidants Remove the prescrubber Pipet 10 ml absorbing reagent into each absorber Draw ambient air through the sampling train at 2 liters/min for 15 min

7 2 *Analysis* Immediately transfer the solutions from each absorber to separate clean 1-cm cells Determine the absorbance of each at 352 nm against unexposed absorbing reagent as the reference Add the absorbance of the two solutions to obtain total absorbance Read total μg O_3 from the calibration curve (see 8 2)

8 *Calibration, standards, and efficiencies*—8 1 *Sampling* The flowmeter must be calibrated with the sampling train assembled and solution in the absorbers Connect the wet test meter to the sample probe and calibrate the flowmeter

8 2 *Analysis* Pipet 1 ml standard iodine solution into a 100-ml volumetric flask Dilute to mark with absorbing reagent Prepare fresh before use Into a series of 25-ml volumetric flasks pipet 0.6, 1.3, 3, and 6 ml of diluted standard iodine solution and dilute each to the mark with absorbing reagent Mix thoroughly and immediately read the absorbance of each at 352 nm against unexposed absorbing reagent as the reference Calculate the concentration of the solutions as total μg O_3 as follows

$$\text{Total } \mu g\ O_3 = (N)(96)(V)$$

N = Normality I (see 6 5 2) meq /ml

V = Volume of diluted standard I added, ml (0 5 1, 2 3, 4)

Plot absorbance versus total μg O

8 3 *Sampling efficiency* Sampling efficiency in the first absorber may be 90–95 percent depending upon the impinger orifice and the ozone concentration When two absorbers are placed in series essentially all ozone is collected

9 *Calculations*—9 1 *Sampling* Correct the volume of air sampled to the volume at standard conditions of 25° C and 760 mm Hg

$$V_s = V \times \frac{P}{760} \times \frac{298}{t + 273}$$

V_s = Volume of air at standard conditions, liters

V = Volume of air at sampling conditions, liters

P = Barometric pressure of mercury, mm Hg

t = Temperature of sample, °C

9 2 Calculate ozone concentration in μg / m^3 at standard conditions

$$\mu g\ O_3/m^3 = \frac{(A)\ (10^3)}{V_s}$$

A = Total μg O_3 read from calibration curve

10^3 = conversion of liters to cubic meters

V_s = volume sampled at standard conditions, liters

9 2 1 If desired, concentration of oxidant may be calculated as p p m 03 at standard conditions of 25 °C and 760 mm Hg

$$\text{p p m } O_3 = (\mu g\ O_3/m^3)\ (5.094 \times 10^{-4})$$

Derivation of above equation

(1) Total μg $O_3 = [N_D$ (meq /ml) × (10 ml) + (24 000 μg / meq)]

(2) N_D = Normality of diluted calibration standard

$$N_D = \left[\frac{1}{100}\text{(list dilution)} \times \frac{V}{25}\text{(2nd dilution)}\right]$$

(3) Therefore Total μg $O = (N)(96)(V)$

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ppm CO = mg CO/m³ × 0.873

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4 Bendix-UNOR Infrared Gas Analyzers, Ronceverte, W Va

11 *Definitions of performance specifications used in this method—Range* The minimum and maximum measurement limits

Output Electrical signal which is proportional to the measurement, intended for connection to readout or data processing devices Usually expressed as millivolts or milliamps full scale at a given impedence

Full scale The maximum measuring limit for a given range

Minimum detectable sensitivity The smallest amount of input concentration that can be detected as the concentration approaches zero

Accuracy The degree of agreement between a measured value and the true value, usually expressed as ± percent of full scale

Lag time The time interval from a step change in input concentration at the instrument inlet to the first corresponding change in the instrument output

Time to 90 percent response The time interval from a step change in the input concentration at the instrument inlet to a reading of 90 percent of the ultimate recorded concentration

Rise time (90 percent) The interval between initial response time and time to 90 percent response after a step increase in inlet concentration

Fall time (90 percent) The interval between initial response time and time to 90 percent response time after a step decrease in the inlet concentration

Zero drift The change in instrument output over a stated time period, usually 24 hours, of unadjusted continuous operation, when the input concentration is zero usually expressed as percent full scale

Span drift The change in instrument output over a stated time period, usually 24 hours of unadjusted continuous operation, when the input concentration is a stated upscale value, usually expressed as percent full scale

Precision The degree of agreement between repeated measurements of the same concentration and is expressed as the average deviation of the single results from the mean

Operational period The period of time over which the instrument can be expected to operate unattended within specifications

Noise Spontaneous deviations from a mean output not caused by input concentration changes

Interference An undesired positive or negative output caused by a substance other than the one being measured

Interference equivalent The portion of indicated input concentration due to the presence of an interferent

Operating temperature range The range of ambient temperatures over which the instrument will meet all performance specifications

Operating humidity range The range of ambient relative humidity over which the instrument will meet all performance specifications

Linearity The maximum deviation between an actual instrument reading and the reading predicted by a straight line drawn between upper and lower calibration points

12 *Suggested minimum performance specifications for NDIR carbon monoxide analyzers*

Range (minimum)	0–58 mg/m³ (0–50 ppm)
Output (minimum)	0–10, 100, 1,000, 5,000 mv full scale
Minimum detectable sensitivity	0.6 mg/m³ (0.5 ppm)
Lag time (maximum)	15 seconds
Time to 90% response (maximum)	30 seconds
Rise time (90% maximum)	15 seconds
Fall time (90% maximum)	15 seconds
Zero drift (maximum)	3%/week not to exceed 1%/24 hours
Span drift (maximum)	3%/week not to exceed 1%/24 hours.
Precision (maximum)	± 0.5%
Operational period (minimum)	3 days
Noise (maximum)	± 0.5%
Interference equivalent (maximum)	1% of full scale
Operating temperature range (minimum)	5–40° C
Operating humidity range (minimum)	10–100%.
Linearity (maximum)	1%.

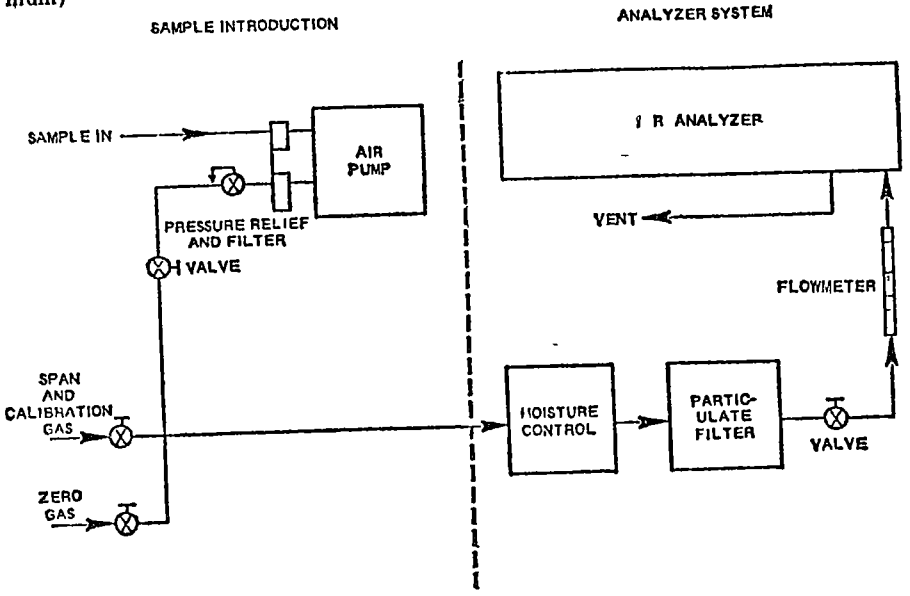

Figure 1 Carbon monoxide analyzer flow diagram

Appendix D

Method for Determination of Oxidants (Neutral Buffered Potassium Iodide Method)

1 *Principle and applicability* 1.1 A sample of ambient air is drawn through a chromium trioxide scrubber to remove sulfur dioxide and then through two absorbers in series containing potassium iodide reagent to collect the oxidants

1.2 Oxidants are defined by this method as those compounds capable of liberating iodine from a 1 percent potassium iodide solution buffered with disodium phosphate and potassium dihydrogen phosphate The iodine produced in the absorbing reagent is measured spectrophotometrically as the triiodide ion

1.3 This method is intended for the measurement of total oxidants as ozone in the atmosphere However, the various oxidizing species, such as ozone, nitrogen dioxide, peroxyacetyl nitrate, and peroxides are present in widely varying concentrations and react with the reagent at different rates Also, reducing compounds in the atmosphere have a negative effect on the oxidant reading Thus the number obtained is a "net" oxidant value, which describes a condition of the atmosphere and is not the total concentration of the oxidizing species present

2 *Range and sensitivity* 2.1 Concentrations of oxidants in the range of about 20 000 $\mu g/m^3$ (0.01 to 10 ppm) can be determined

2.2 At a sampling rate of 2 liters/min for 15 min using 10 ml absorbing reagent, 20 $\mu g/m^3$ (0.01 ppm) should produce an absorbance of approximately 0.025 measured in 1-cm cells At concentrations below 100 $\mu g/m^3$ (0.05 ppm) readings may be quite imprecise because of the instability of oxidants or iodine at very low concentrations

2.3 The above limits are based on a molar absorptivity of 24,200 liters/mole/cm

3 *Interferences* 3.1 Reducing gases such as sulfur dioxide and hydrogen sulfide give very serious negative interferences Sulfur dioxide gives a 100 percent negative interference of an equivalent molar concentration of ozone The interference from sulfur dioxide, even when it is present at ambient concentrations, can be eliminated by a properly conditioned chromium trioxide-scrubber (see 6.3, 7.1)

3.2 The oxidant reading contains a contribution of 10 percent of the molar concentration of NO. When a chromium trioxide scrubber is used, NO is converted to NO_2 thus contributing to the oxidant reading to the same extent as NO_2. If an oxidant value less NO_2 is desired, NO + NO_2 must be measured simultaneously and a correction factor of 10 percent of the NO_2 concentration must be subtracted

3.3 Glassware should be cleaned with chromic acid, since dust or foreign materials may interfere

[illegible] will affect the iodine

[illegible] *bility* 4.1 [illegible] lation [illegible] concentration of 1,000 $\mu g/m^3$ (0.5 ppm) of ozone

4.2 Accuracy cannot be defined, since the sensitivity of the potassium iodine reagent varies widely with the different oxidizing species

9 3 Calculate mass concentration of suspended particulate

$$S.P = \frac{(W_f - W_i) \times 10^6}{V}$$

S P = Mass concentration of suspended particulate $\mu g/m^3$
W_i = Initial weight of filter, g
W_f = Final weight of filter, g
V = Air volume sampled, m^3
10^6 = Conversion of g to μg

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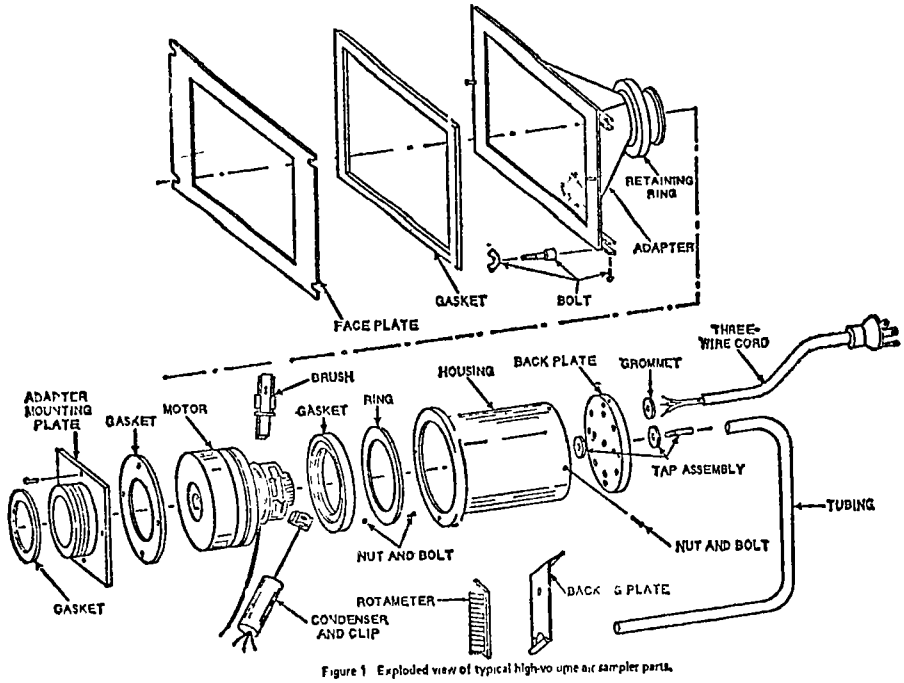

Figure 1 Exploded view of typical high-volume air sampler parts.

Appendix C

Method for Continuous Measurement of Carbon Monoxide (Nondispersive Infrared Spectromftry)

1 *Principle and applicability* 1 1 The measuring principle makes use of absorption of radiation by CO in the infrared region The absorption is measured by a photometer with two parallel beams and a selective detector A source emits energy in the infrared region One beam passes through a reference cell filled with nonabsorbing gas Both beams pass into a detector cell, which contains CO The CO in the detector absorbs the infrared radiation only at its characteristic frequencies and thus the detector is sensitive only to those frequencies With no CO in the sample cell, the detector is balanced for equal absorption from both beams Any CO present in the sample cell will absorb some of the radiation and reduce the amount entering the detector from that beam This reduces the temperature and hence the pressure in one chamber of the detector, causing a diaphragm to be displaced This movement is detected electronically and amplified to provide an output signal

1 2 The sample introduction pump may be bypassed for analysis of gases under pressure, as is sometimes done with the calibration gases.

2 *Range and sensitivity* (See definitions)

2 1 Instruments are available that measure in the range of 0 to 48 mg/m^3 (0–50 p p m), which is the range most commonly used for urban atmospheric sampling, most instruments measure in additional ranges—typically 0 to 29 and 0 to 115 mg/m^3

2 2 Sensitivity is 1 percent of full-scale response per 0 6 mg/m^3 (0 5 p p m)

3 *Interferences* 3 1 The degree of interference varies among individual instruments The effect of carbon dioxide interference at normal concentrations is minimal The primary interference is caused by water vapor With no corrective measures, interference from water may be as high as 12 mg/m^3 Water vapor interference may be minimized by (a) passing the air sample through silica gel or similar drying agents, (b) maintaining constant humidity in the sample and calibration gases by refrigeration, (c) saturating the air sample and calibration gases to maintain constant humidity, (d) using narrow-band optical filters, or (e) combining some or all of these measures

3 2 Hydrocarbons at ambient levels do not cause interferences Effects of specific hydrocarbons are generally rated on the manufacturer's specification sheets for the individual analyzer

4 *Precision, accuracy, and stability* 4 1 Precision with standard calibration gases is ±0 5 percent full scale in the 0–58 mg/m^3 range

4 2 Accuracy is dependent on instrument linearity and absolute concentration of the calibration gases used Generally accuracy is ±1 percent of full scale in the 0–58 mg/m^3 range

4 3 Effects of variations in ambient room temperature are considerable Changes as much as 0 5 mg/m^3 per ° C have been noted The effects can be minimized by operating the analyzer in a controlled-temperature room Further, pressure changes between span checks will cause proportional changes in the reading. If cell temperature and pressure are assumed constant however, zero drift observed with various instruments is less than ±1 percent in 24 hours

5 *Apparatus*—5 1 *Commercially available NDIR carbon monoxide analyzer* Instruments should be installed on location and demonstrated, preferably by the manufacturer, to meet or exceed manufacturers specifications and those described in this method The analyzer consists of an infrared source sample and reference gas cells, a detector capable of sensing differences between levels of infrared energy in the two cells, and a control, power supply, and amplifier unit

5 2 *Sample introduction system* Pump, flow control valve and flowmeter

5 3 *Particulate filter (in-line)* To keep sample cell clean, porosity of the filter should be 2 to 10 microns

5 4 *Moisture control* For systems with which constant humidity control is desired refrigeration units are available with some commercial instruments Drying tubes (with sufficient capacity to operate for 72 hours) containing indicating silica gel or equivalent drying agent may be used for short-term sampling

6 *Reagents*—6 1 *Zero gas* Nitrogen or helium containing less than 0 1 mg/m^3 carbon monoxide

6 2 *Calibration gases* Gases needed for linearity checks are determined by the range of operation of instruments Calibration gases corresponding to 10 20 40 and 80 percent of full scale are needed Gases must be provided with certification or guaranteed analysis of carbon monoxide content

6 3 *Span gas* The calibration gas corresponding to 80 percent of full scale may be used to span the instrument

7 *Procedure* 7 1 Calibrate the instrument as described in 8 1 All gases (sample zero, calibration, and span) must be introduced into the entire analyzer system Figure 1 shows a typical flow schematic For specific operating instructions, refer to the manufacturer s manual

8 *Calibration*—8 1 *Calibration curve* Determine the linearity of the detector response at the operating flow rate and temperature Prepare a calibration curve or check the curve furnished with the instrument Introduce zero gas and set the zero control to indicate a recorder reading of zero Introduce span gas and adjust the span control to indicate the proper value on the recorder scale (e g on 0–58 mg/m^3 scale set 46 mg/m^3 (40 p p m) standard at 80 percent recorder chart) Recheck zero and span until adjustments are no longer necessary Introduce intermediate calibration gases and plot the values obtained If a smooth curve is not obtained, calibration gases should be suspected

9 *Calculation* 9 1 No calculations are involved in this procedure since the concentration is determined directly from the calibration curve

9 2 Carbon monoxide concentration in mg/m^3 can be converted to p p m. as follows

5 1 3 Rotameter—Marked in arbitrary units, frequently 0 to 70, and capable of being calibrated

5 1 4 Orifice Calibration Unit—Consisting of a metal tube 7 6 cm (3 in) ID and 15 9 cm (6¼ in) long with a static pressure tap 5 1 cm (2 in) from one end The tube end nearest the pressure tap is flanged to about 10 8 cm (4¼ in) OD with a male thread of the same size as the inlet end of the high-volume air sampler A single metal plate 9 2 cm (3⅝ in) in diameter and 0 24 cm (⅛ in) thick with a central orifice 2 9 cm (1⅛ in) in diameter is held in place at the air inlet end with a female threaded ring The other end of the tube is flanged to hold a loose female threaded coupling which screws on to the inlet of the sampler An 18-hole metal plate, an integral part of the unit, is positioned between the orifice and sampler to simulate the resistance of a clean glass-fiber filter

5 1 5 Differential Manometer—Capable of measuring to at least 40 cm (16 in) of water

5 1 6 Flow Measuring Device—Positive displacement type, calibrated in cubic meters or cubic feet, to be used as a primary standard

5 1 7 Barometer—Capable of measuring atmospheric pressure to the nearest mm

5 1 8 Folders—Manila cardboard folders, 22 by 28 cm (8½ by 11 in) creased

5 2 Analysis

5 2 1 Balance Room Environment—Maintained at 15 to 35° C and less than 50 percent relative humidity

5 2 2 Analytical Balance—Equipped with a weighing chamber designed to handle unfolded 20- by 25-cm (8- by 10-in) filters and having a sensitivity of 0 1 mg

5 2 3 Light Table—Of the type used to view X-ray films

5 2 4 Numbering Machine—Capable of printing identification numbers of 4 to 8 digits on the filter

6 *Reagents* 6 1 Filter Media—Glass-fiber filters having a collection efficiency of at least 99 percent for particles of 0 3 μm diameter, as measured by the DOP test, are suitable for the quantitative measurement of concentrations of suspended particulate,[5] although some other medium such as paper, may be desirable for some analyses Care must be exercised to prevent use of filters that contain high background concentrations of the pollutant being investigated Careful quality control is required to determine background values of these pollutants

7 *Procedure* 7 1 Sampling

7 1 1 Filter Preparation—Place each filter on a light table and inspect for pinholes, dark particles or other imperfections Filters with visible imperfections should not be used A small brush is useful for removing particles Equilibrate the filters to the conditions of the balance room for 24 hours Weigh the filters to the nearest milligram record tare weight and filter identification number Do not bend or fold the filter before collection of the sample

7 1 2 Sample Collection—Open the shelter, loosen the wing nuts, and remove the face plate from the filter holder Install a numbered preweighted glass-fiber filter in position (rough side up), replace the face plate without disturbing the filter, and fasten securely Undertightening will allow air leakage overtightening will damage the sponge-rubber face-plate gasket A very light application of talcum powder may be used on the sponge-rubber face-plate gasket to prevent the filter from sticking During inclement weather the sampler may be removed to a protected area for filter change Close the roof of the shelter, run the sampler for about 5 min , connect the rotameter to the nipple on the back of the sampler, and read the rotameter ball with rotameter in a vertical position Estimate to the nearest whole number If the ball is fluctuating rapidly, tip the rotameter and slowly straighten it until the ball gives a constant reading Disconnect the rotameter from the nipple, record the initial rotameter reading and the starting time and date on the filter folder The rotameter should never be connected to the sampler except when the flow is being measured Let the sampler run for the desired time (usually 24 hours) and take a final rotameter reading Record the final rotameter reading and ending time and date on the filter folder Remove the face plate as described above and carefully remove the filter from the holder, touching only the outer edges Fold the filter lengthwise so that only surfaces with collected particulate are in contact, and place in a filter folder Record on the folder the filter number, location and any other factors, such as meteorological conditions or razing of nearby buildings, that might affect the results If the sample is defective, void it at this time In order to obtain a valid sample, the high-volume sampler must be operated with the same rotameter and tubing that were used during its calibration

7 1 3 Maintenance

7 1 3 1 Sampler Motor—Replace brushes before they are worn to the point where motor damage can occur

7 1 3 2 Face Plate Gasket—Replace when the margins of samplers are no longer sharp Seal the gasket to the face plate with rubber cement or double-sided adhesive tape

7 1 3 3 Rotameter—clean as required, using alcohol

7 2 Analysis

7 2 1 Equilibrate the exposed filters for 24 hours in the environment of the balance room, then reweigh After they are weighed, the filters may be saved for detailed chemical analysis

8 *Calibration* 8 1 Sampling—Since only a small portion of the total air sampled passes through the rotameter during measurement, the rotameter must be calibrated against actual air flow with the orifice calibration unit Before the orifice calibration unit can be used to calibrate the rotameter, the orifice calibration unit itself must be calibrated against the positive displacement primary standard

8 1 1 Orifice Calibration Unit—Attach the orifice calibration unit to the intake end of the positive displacement primary standard and attach a high-volume motor blower unit to the exhaust end of the primary standard Connect one end of a differential manometer to the differential pressure tap of the orifice calibration unit and leave the other end open to the atmosphere Operate the high-volume motor blower unit so that a series of different, but constant, air flows (usually six) are obtained for definite time periods Record the reading on the differential manometer at each air flow The different constant air flows can be obtained either by placing a series of load plates one at a time between the calibration unit and the primary standard or by varying the speed of the sampler motor with a variable speed transformer with the No 18 plate in position The latter method is considerably more convenient and flexible Placing the orifice before the inlet reduces the pressure at the inlet of the primary standard below atmospheric therefore a correction must be made for the increase in air volume caused by this decreased inlet pressure Attach one end of a second differential manometer to an inlet pressure tap of the primary standard and leave the other end open to the atmosphere During each of the constant air flow measurements made above measure the true inlet pressure of the primary standard with this second differential manometer Measure atmospheric pressure with a barometer Correct the measured air volume to true air volume as directed in 9 1 1 then obtain true air flow rate, Q, as directed in 9 1 2 Plot the differential manometer readings of the orifice unit versues Q

8 1 2 High-Volume Sampler—Assemble a high-volume sampler with a clean filter in place and run for at least 5 min Attach a rotameter read the ball, adjust so that the ball reads 65 and seal the adjusting mechanism so that it cannot be changed easily Shut off motor remove the filter, and attach the orifice calibration unit in its place Operate the high-volume sampler at a series of different but constant, air flows (usually six) Record the reading of the differential manometer on the orifice calibration unit, and record the reading of the rotameter at each flow Convert the differential manometer reading to m^3/min , Q, then plot rotameter reading versus Q

8 1 2 1 If the pressure or temperature during high-volume sampler calibration is substantially different from the pressure or temperature during orifice calibration a correction of the flow rate, Q may be required If the pressures differ by no more than 15 percent and the temperatures differ by no more than 100 percent (°C) the error in the uncorrected flow rate will be no more than 15 percent If necessary obtain the corrected flow rate as directed in Appendix C This correction applies only to orific meters having a constant orifice coefficient The coefficient for the calibrating orifice described in 5 1 4 has been shown experimentally to be constant over the normal operating range of the high-volume sampler (0 6 to 2 2 m^3/min , 20 to 78 ft^3/min)

9 *Calculations* 9 1 Calibration of Orifice

9 1 1 Calculate the true air volume measured by the positive displacement primary standard

$$P_a V_a = P_M V_M$$

$$P_M = P_a - P_m$$

Combining these relationships

$$V_a = \frac{(P_a - P_m)}{P_a} \quad (V_m)$$

V_a = Volume of air at atmospheric pressure, m^3

P_a = Barometric pressure, mm Hg

P_M = Pressure at inlet of the primary standard, mm Hg

P_m = Pressure difference between inlet of primary standard and atmospheric, mm Hg

V_m = Volume measured by primary standard, m^3

9 1 1 1 Conversion Factors

In water × 73 48 × 10 = in Hg

In Hg × 25 4 = mm Hg

Cubic feet × 0 0284 = m^3

9 1 2 Calculate flow rate

$$Q = \frac{V_a}{T}$$

Q = Flow rate m^3/min

T = Time of flow min

9 2 Sample Volume

9 2 1 Convert the initial and final rotameter readings to m^3/min using calibration curve of 8 1 2

9 2 2 Calculate volume of air sampled

$$V = \frac{Q_i + Q_f}{2} \times T$$

V = Air volume sampled, m^3

Q_i = Initial air flow rate, m^3/min.

Q_f = Final air flow rate, m^3/min

T = Sampling time, min

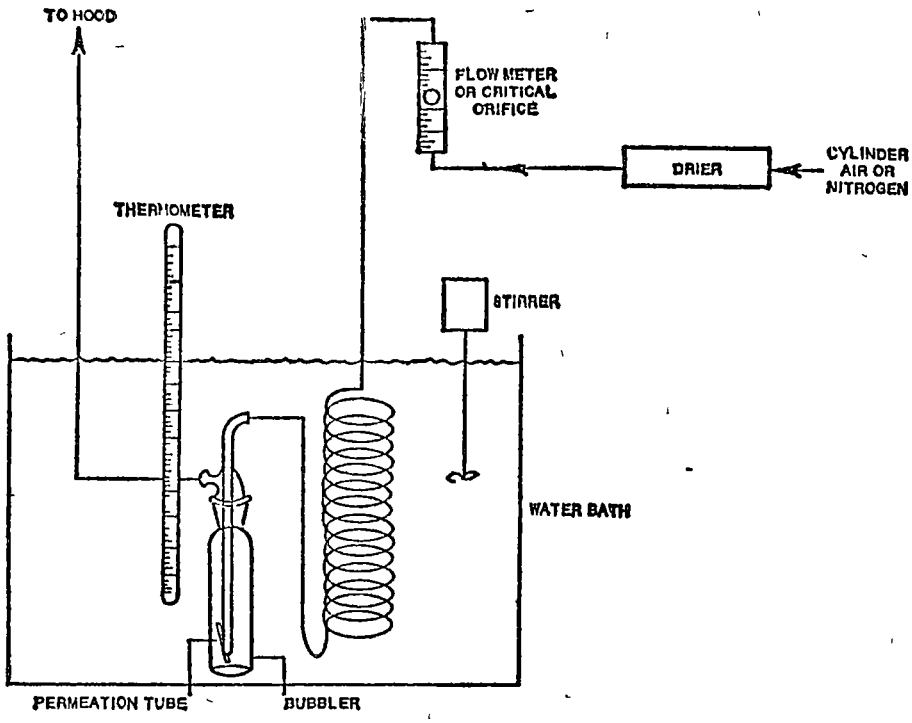

Figure 2. Apparatus for gravimetric calibration and field use.

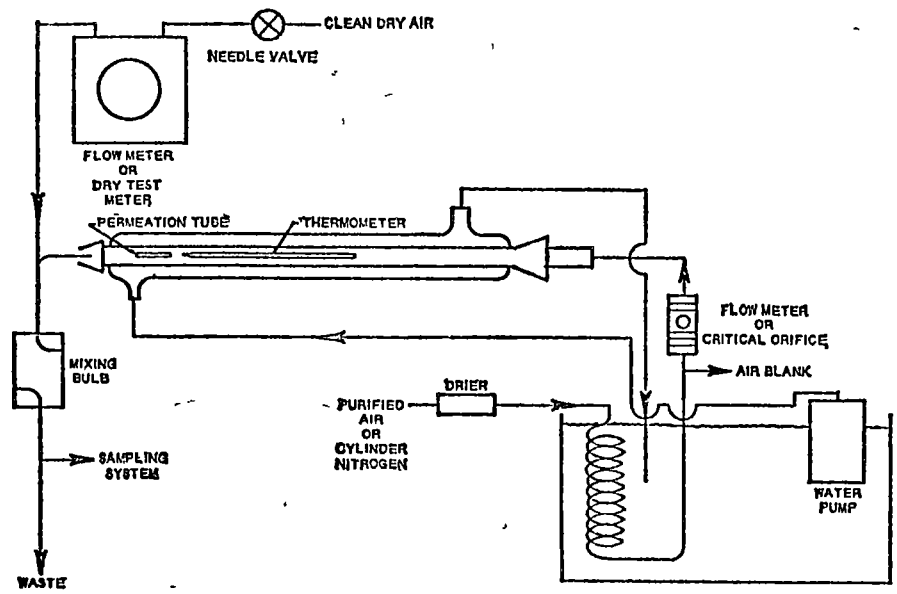

Figure 3 Permeation tube schematic for laboratory use.

Appendix B

Procedure for Determination of Suspended Particulates (High Volume Method)

1. *Principle and applicability* 1 1 Air is drawn into a covered housing and through a filter by means of a high-flow-rate blower at a flow rate (1 13 to 1 70 m³/min, 40 to 60 ft³/min) that allows suspended particles having diameters of less than 100 μm (Stokes equivalent diameter) to pass to the filter surface[1] The particles are ordinarily collected on a glass-fiber filter within the size range of 100 to 0 1 μm diameter

1.2 The mass concentration of suspended particulate in the ambient air (μg/m³) is computed by measuring the mass of collected particulate and the volume of air sampled

1 3 This method is applicable to measurement of the mass concentration of suspended particulate in ambient air This method does not control the flow of air during sampling and for this reason is most applicable to trend measurement The size of the sample collected is usually adequate for other analyses

2 *Range and sensitivity* 2 1 When the sampler is operated at an average flow rate of 1 70 m³/min (60 ft³/min) for 24 hours, an adequate sample will be obtained even in an atmosphere having concentrations of suspended particulate as low as 1 μg/m³ If particulate levels are unusually high a satisfactory sample may be obtained in 6 to 8 hours or less For determination of average concentrations of suspended particulate in ambient air, a standard sampling period of 24 hours is recommended

2 2 Weights are determined to the nearest milligram air flow rates are determined to the nearest 0 03 m³/min (1 0 ft³/min) times are determined to the nearest 2 min and mass concentrations are reported to the nearest microgram per cubic meter

3 *Interferences*[2] 3 1 Particulate that is oily, such as photochemical smog or wood smoke, may block the filter and cause a rapid drop in air flow at a nonuniform rate Dense fog or high humidity can cause the filter to become too wet and severely reduce the air flow through the filter

3 2 Glass-fiber filters are comparatively insensitive to change in relative humidity, but collected particulate can be hygroscopic[2]

4 *Precision, accuracy, and stability* 4 1 At an average mass concentration of 112 μg/m³ of particulate matter in ambient air the standard deviation is 10 μg/m³ (corresponding to a relative standard deviation of 9 percent), at an average of 39 μg/m³ the standard deviation is 6 μg/m³ (corresponding to a relative standard deviation of 15 percent)[3]

4 2 The accuracy with which the sampler measures the true average concentration depends upon the degree of constant air flow rate maintained in the sampler The air flow rate is affected by the concentration and the nature of the dust in the atmosphere, which may clog the filter and significantly reduce the air flow rate Under these conditions the error in the measured average concentration may be as much as ±50 percent or more of the true average concentration depending on the amount of reduction of air flow rate and on the variation of the mass concentration of dust with time during the 24-hour sampling period[4]

5 *Apparatus* 5 1 Sampling

5 1 1 Sampler—The sampler consists of three units (1) the face plate and gasket, (2) the filter adapter assembly, and (3) the motor unit Figure 1 shows an exploded view of these parts, their relationship to each other, and how they are assembled The sampler must be capable of passing environmental air through a 406 5 cm² (63 in²) portion of a clean 20- by 25-cm (8- by 10-in) glass-fiber filter at a rate of at least 1 70 m³/min (60 ft³/min) The motor must be capable of continuous operation for 24-hour periods with input voltages ranging from 110 to 120 volts, 50–60 cycles alternating current and must have third-wire safety ground The housing for the motor unit may be of any convenient construction so long as the unit remains air-tight and leak-free The life of the sampler motor can be extended by lowering the voltage by about 10 percent with a small "buck or boost" transformer between the sampler and power outlet

5 1 2 Sampler Shelter—It is important that the sampler be properly installed in a suitable shelter The shelter is subjected to extremes of environmental conditions such as high and low temperatures, extremes of humidity, and all types of air pollutants For these reasons the materials of the shelter must be chosen carefully Properly painted exterior plywood or heavy gauge aluminum serve well The sample must be mounted vertically in the shelter so that the glass-fiber filter is parallel with the ground The shelter must be provided with a roof so that the filter is protected from precipitation and debris The clearance area between the edge of the roof and the main housing should be 645±65 cm² (100±10 in²) The main housing should be rectangular, with dimensions of 29 by 36 cm (11½ by 14 in).

(1) Commercially available permeation tubes* may be calibrated as follows Obtain an FEP Teflon® permeation tube that emits sulfur dioxide at a rate of 0 2 to 0 4 μg / min (0 08 to 0 15 μl /min at standard conditions of 25° C and 1 atmosphere) A permeation tube with an effective length of 2 to 4 cm and outer diameter of 0 63 cm will yield the desired permeation rate if held at a constant temperature of 20° C Using the system shown in Figure 2 calibrate the tube gravimetrically at the intended operating temperature to a precision within ±2 percent The temperature of the tube must be controlled within 0 1° C Permeation tubes are calibrated under a stream of dry nitrogen to prevent the formation of blisters in the walls and sulfuric acid inside the tube Periodically about every 4 days remove the bubbler from the constant temperature bath and thoroughly dry the bubbler Remove the permeation tube from the bubbler with a Teflon-tipped forcep and weigh the tube to the nearest 0 1 mg Record weight and time to the nearest minute Immediately return tube to bubbler and bubbler to bath Plot gross weight (10 mg to the inch) against time (1,000 minutes to the inch) Compute the slope of the linear portion from the line that best fits the points Linear regression is recommended Alternately, tubes can be rapidly calibrated using a coulometric SO_2 analyzer operating under ideal conditions [1]

(2) A system designed for the preparation of standard concentrations of sulfur dioxide in the laboratory is shown in Figure 3 (Alternately, the apparatus shown in Figure 2 for gravimetric calibration and field use may be used) Assemble the apparatus, consisting of a water-cooled condenser, a constant-temperature water bath maintained at 20° C , a cylinder containing pure dry air or nitrogen and appropriate pressure regulators, needle valves, and flow meters for the nitrogen and dry air diluent gas streams The diluent gases are brought to temperature by passage through a 2-meter copper coil immersed in the water bath Insert a calibrated permeation tube into the central tube of the condenser maintained at 20° C by circulating water from the constant-temperature bath and pass a stream of air or nitrogen over the tube at a fixed rate of approximately 50 ml /min Dilute this gas stream to the desired concentration by varying the air flow rate Normally this flow rate can be varied from 1 1 to 15 liters/min The flow rate of the sampling system determines the lower limit for the flow rate of the diluent gases With a tube permeating sulfur dioxide at a rate of 0 4 μg /min , the range of concentration of sulfur dioxide will be between 27 and 260 μg /m³ (0 01 to 0 14 p p m), a generally satisfactory range for ambient air conditions When higher concentrations are desired, calibrate and use longer permeation tubes

*Available from Metronics, Inc , 3201 Porter Drive, Palo Alto, CA 94304 and Analytical Instrument Developments, Inc , 250 South Franklin Street, West Chester, PA 19380

B *Procedure for preparing calibration curves* One can prepare a multitude of curves by selecting different combinations of sampling rate and sampling time (Calibration should be made under the same conditions used in sampling and analyses) Twenty-four hour samples must be calibrated for 24 hours The above description represents a typical procedure for simulating ambient air sampling of short duration The system is designed to provide an accurate measurement of sulfur dioxide in the range of 0 01 to 0 5 p p m It can be modified easily to meet special needs The concentration of standard SO_2 in air is computed as follows

$$C = \frac{Pr \times 10^3}{R + r}$$

C = Concentration of SO_2 μg /m³
Pr = Permeation rate, μg /min
R = Flow rate of diluent air, liters/min
r = Flow rate of diluent nitrogen, liters/min

Data for a typical calibration curve are listed in Table I A plot of the concentration of sulfur dioxide in μg /m³ (X-axis) against absorbance of the final solution (Y-axis) will yield a straight line, the reciprocal of the slope of which is the factor for conversion of absorbance to μg /m³ This factor includes the correction for collection efficiency Any deviation from linearity at the lower concentration range indicates a change in collection efficiency of the sampling system Actually, the standard concentrations of 25 μg /m³ and below of sulfur dioxide are slightly below the dynamic range of the method If this is the range of interest the diluent air stream must be adjust to deliver these lower concentrations, and the total volume of air collected must be increased to obtain sufficient color within the dynamic range of the procedure The calibration factor must be reestablished, if collection efficiency differs significantly from that obtained above 25 μg./m³. The remainder of the analytical procedure is the same as described in section 7

TABLE I—TYPICAL CALIBRATION DATA

Concentrations of SO_2, μg /m³	Amount of SO_2 in μg for 30 liters	Absorbance of sample
15	0 45	0 013
25	0 75	0 022
100	3 0	0 089
200	6 0	0 179
500	15 0	0 448
800	24 0	0 716
1000	30 0	0 895
1100	33 0	0 985

$$SO_2, \mu g/m^3 = A \times F,$$

Where
$F = 1\ 1 \times 10^3$ = factor, as derived from equation in 9 2
A = Absorbance of solution for 30 liters of sample and a volume of 25 ml for the colored solution

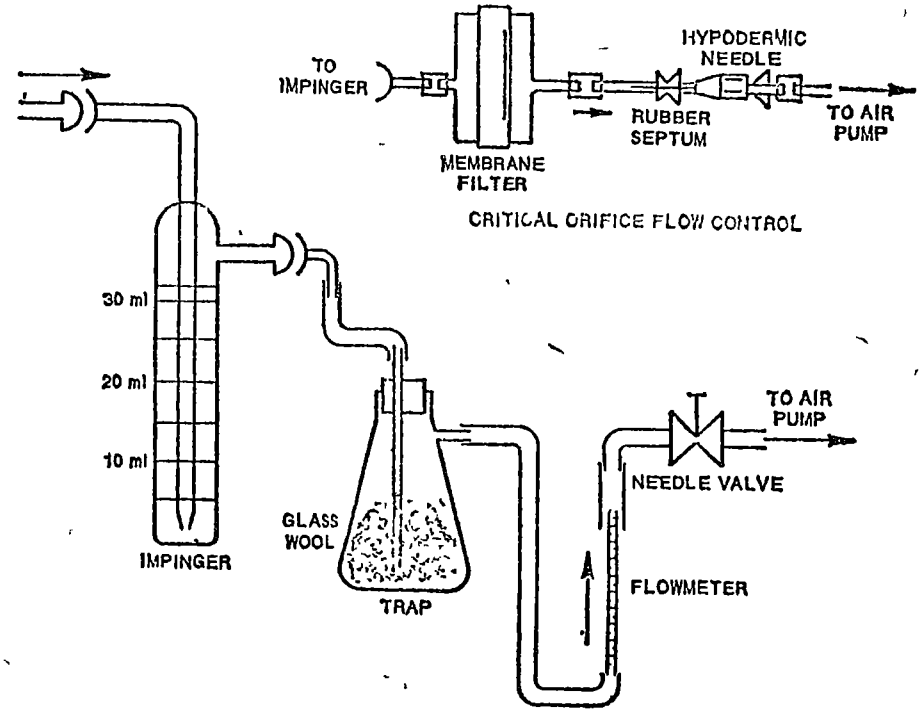

Figure 1. Sampling train.

6 2 11 Pararosaniline Reagent—To a 250-ml volumetric flasks, add 20 ml stock pararosaniline solution Add an additional 0 2 ml stock solution for each percent the stock assays below 100 percent Then add 25 ml 3 M phosphoric acid and dilute to volume with distilled water This reagent is stable for at least 9 months

7 *Procedure* 7 1 Sampling—Procedures are described for short term (30 min) and for long term (24 hours) sampling One can select different combinations of sampling rate and time to meet special needs Fixing sample volume at 30 liters maintains linearity between absorbance and concentration over this dynamic range

7 1 1 30-Minute Sampling—Insert a midget impinger into the sampling system, Figure 1 Add 10 ml TCM solution to the impinger Collect sample at 1 liter/min for 30 min Shield the absorbing reagent from direct sunlight during and after sampling by covering the impinger with aluminum foil, to prevent deterioration Record the actual volume of air by multiplying the flow rate by the time in minutes Remove and stopper the impinger If the sample must be stored for more than a day before analysis, keep it at 5° C in a refrigerator (see 4 2)

7 1 2 24-Hour Sampling—Place 15–20 ml TCM solution in a midget impinger or 50 ml in a larger impinger and collect the sample at 0 2 liter/min for 24 hours Make sure no entrainment of solution results with the impinger During collection and storage protect from direct sunlight Record the total volume of sample by multiplying the flow rate by the time in minutes If storage is necessary, refrigerate at 5° C (see 4 2)

7 2 Analysis

7 2 1 Sample Preparation—After collection, if a precipitate is observed in the sample remove it by centrifugation

7 2 1 1 30-Minute Sample—Transfer the sample quantitatively to a 25-ml volumetric flask, use about 5 ml distilled water for rinsing Delay analyses for 20 min to allow any ozone to decompose

7.2 1 2 24-Hour Sample—Dilute the entire sample to 25 ml for the midget impinger of 50 ml for the larger impinger, with absorbing solution. Pipet one-tenth of the sample into a 25 ml volumetric flask for chemical analyses Delay analyses for 20 min to allow any ozone to decompose

7 2 2 Determination—For each set of determinations prepare a reagent blank by adding 10 ml unexposed TCM solution to a 25 ml volumetric flask Prepare a control solution by adding 2 ml of working sulfite-TCM solution and 8ml TCM solution to a 25-ml volumetric flask To each flask containing either sample, control solution or reagent blank, add 1 ml, 0 6 percent sulfamic acid and allow to react 10 min to destroy the nitrite from oxides of nitrogen Accurately pipet in 2 ml 0 2 percent formaldehyde solution, then 5 ml pararosaniline solution Start a laboratory timer that has been set for 30 minutes Bring all flasks to volume with freshly boiled and cooled distilled water and mix thoroughly After 30 min and before 60 min, determine the absorbances of the sample, reagent blank and the control solution at 548 nm using 1-cm optical path length cells Use distilled water, not the reagent blank, as the reference (NOTE This is important because of the color sensitivity of the reagent blank to temperature changes which can be induced in the cell compartment of a spectrophotometer) Do not allow the colored solution to stand in the absorbance cells, because a film of dye may be deposited Clean cells with alcohol after use If the temperature of the determinations does not differ by more than 2° C from the calibration temperature (8 2), the reagent blank should be within 0 03 absorbance unit of the y-intercept of the calibration curve (8 2) If the reagent blank differs by more than 0 03 absorbance unit, from that found in the calibration curve, prepare a new curve

7 2 3 Absorbance Range—If the absorbance of the sample solution ranges between 1 0 and 2 0, the sample can be diluted 1 1 with a portion of the *reagent blank* and read within a few minutes Solutions with higher absorbance can be diluted up to sixfold with the reagent blank in order to obtain on-scale readings within 10 percent of the true absorbance value

8 *Calibration and efficiencies* 8 1 Flowmeters and Hypodermic Needle—Calibrate flowmeters and hypodermic needle[13] against a calibrated wet test meter

8 2 Calibration Curves

8 2 1 Procedure with Sulfite Solution—Accurately pipet graduated amounts of the working sulfite-TCM solution (such as 0, 0 5, 1, 2, 3, and 4 ml) into a series of 25-ml volumetric flasks Add sufficient TCM solution to each flask to bring the volume to approximately 10 ml Then add the remaining reagents as described in 7 2 2 For maximum precision use a constant-temperature bath The temperature of calibration must be maintained within ±1° C and in the range of 20 to 30° C The temperature of calibration and the temperature of analysis must be within 2 degrees Plot the absorbance against the total concentration in μg SO_2 for the corresponding solution The total μg SO_2 in solution equals the concentration of the standard (Section 6 2 9) in μg SO_2/ml times the ml sulfite solution added (μg $SO_2 = \mu g$ / ml $SO_2 \times$ ml added) A linear relationship should be obtained, and the y-intercept should be within 0 02 absorbance unit of the zero standard absorbance For maximum precision determine the line of best fit using regression analysis by the method of least squares Under these conditions the plot need be determined only once to determine the calibration factor (reciprocal of the slope of the line) (See Section 6 2 10 1 for specifications on the slope of the calibration curve) This calibration factor can be used for calculating results provided there are no radical changes in temperature or pH At least one control sample containing a known concentration of SO_2 for each series of determinations, is recommended to insure the reliability of this factor

8 2 2 Procedure with SO_2 Gas—See Part 2

8 3 Sampling Efficiency—Collection efficiency is above 98 percent, efficiency may fall off, however, at concentrations below 25 $\mu g/m^3$[9]

9 *Calculations* 9 1 Conversion of Volume—Convert the volume of air sampled to the volume at standard conditions of 25° C, 760 mm Hg

$$V_s = V \times \frac{P}{760} \times \frac{298}{(t+273)}$$

V_s = Volume of air at 25° C and 760 mm Hg
V = Volume of air sampled liters
P = Barometric pressure, mm Hg
t = Temperature of air sample, °C

Ordinarily, the correction for pressure is slight and may be neglected

9 2 Sulfur Dioxide Concentration—Compute the concentration of sulfur dioxide in the sample by the following formula

$$SO_2, \mu g/m^3 = \frac{(A - A_o)(10^3)(B)}{V_s}$$

A = Sample absorbance
A_o = Reagent blank absorbance
10^3 = Conversion of liters to cubic meters
V_s = The sample volume corrected to 25° C and 760 mm Hg, liters

$$B = \frac{1}{\text{Slope of calibration}} = \text{calibration factor, } \mu g/\text{absorbance unit curve, absorbance units}/\mu g$$

9 2 1 Conversion of $\mu g/m^3$ to p p m —If desired, the concentration of sulfur dioxide may be calculated as p p m SO_2 at standard conditions as follows

$$\text{p p m } SO_2 = \mu g \text{ } SO_2/m^3 \times 3\,82 \times 10^{-4}$$

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PART 2

A *Gaseous calibration* Certified permeation tubes containing liquified sulfur dioxide are available from the National Bureau of Standards and may be used for gaseous calibration

§ 410 11 National primary and secondary ambient air quality standards for nitrogen dioxide

The national primary and secondary ambient air quality standards for nitrogen dioxide, measured by a method referenced to the 24-hour sampling method, as described in Appendix F to this part are

(a) 100 micrograms per cubic meter—annual arithmetic mean

(b) 260 micrograms per cubic meter—24-hour concentration not to be exceeded more than once per year

APPENDIX A

PART 1—METHOD FOR DETERMINATION OF SULFUR DIOXIDE (PARAROSANILINE METHOD)

1 *Principle and applicability of method* 1 1 Sulfur dioxide is absorbed from air in a solution of potassium tetrachloromercurate (TCM) A dichlorosulfitomercurate complex which resists oxidation by the oxygen in the air, is formed [1,2] Once formed this complex is stable to strong oxidants (e g , ozone, oxides of nitrogen)

1 2 The complex is reacted with pararosaniline and formaldehyde to form intensely colored pararosaniline methyl sulfonic acid The absorbance of the solution is measured spectrophotometrically

2 *Range and sensitivity* 2 1 Concentrations of sulfur dioxide in the range of 25 to 1 000 $\mu g/m^3$ (0 01 to 0 40 p p m) can be measured under the conditions given One can extrapolate to concentrations below 25 g/m^3 by sampling larger volumes of air, but only if the absorption efficiency of the particular system is first determined Higher concentrations can be analyzed by using smaller gas samples, a larger collection volume or a suitable aliquot of the collected sample

2 2 The lower limit of detection of sulfur dioxide in 10 ml TCM is 0 75 μg (based on twice the standard deviation) representing a concentration of 25 $\mu g/m^3$ SO_2 (0 01 p p m) in an air sample of 30 liters

2 3 Beer s Law is followed through the working range from 0 0 to 1 0 absorbance units (0 to 27 μg of sulfite ion in 25 ml final solution computed as SO_2)

3 *Interferences* 3 1 The effects of the principle known interferences have been minimized or eliminated Interferences by oxides of nitrogen are eliminated by sulfamic acid,[1,3] ozone by time-delay [3] and heavy metals by EDTA (ethylenediaminetetraacetic acid disodium salt) and phosphoric acid [1,3] At least 60 μg Fe(III), 10 μg Mn(II), and 10 μg Cr(III) in 10 ml absorbing reagent can be tolerated in the procedure No significant interference was found with 10 μg Cu(II) and 22 μg V(V)

4 *Precision, accuracy, and stability* 4 1 Relative standard deviation at the 95 percent confidence level is 4 6 percent for the analytical procedure using standard samples [4]

4 2 After sample collection the solutions are relatively stable At 25° C losses of sulfur dioxide occur at the rate of 1 5 percent per day When samples are stored at 5° C for 30 days no detectable losses of sulfur dioxide occur The presence of EDTA enhances the stability of SO_2 in solution and the rate of decay is independent of the concentration of SO_2

5 *Apparatus* 5 1 Sampling

5 1 1 Absorber—Absorbers normally used in air pollution sampling are acceptable for concentrations above 25 $\mu g/m^3$ (0 01 p p m) An all-glass midget impinger, as shown in Figure 1, is recommended for 30-minute samples

5 1 2 Pump—Capable of maintaining an air pressure differential greater than 0 7 atmosphere at the desired flow rate.

5 1 3 Air Flowmeter or Volume Meter—Capable of measuring air flow within ±2 percent A wet or dry gas meter, with manometer, or a specially calibrated rotameter, is satisfactory A 22-gauge hypodermic needle 1-in long may be used as a critical orifice to give a flow of about 1 liter/min if it has first been calibrated in the system Use a membrane filter to protect the needle

5 2 Analysis

5 2 1 Spectrophotometer—Suitable for measurement of absorbance at 548 nm with an effective spectral band of less than 15 nm Reagent blank problems may occur with spectrophotometers having greater spectral band width The wavelength calibration of the instrument should be verified If transmittance is measured, this can be converted to absorbance

$$A = \log_{10} (I/T)$$

6 *Reagents* 6 1 Sampling

6 1 1 Distilled water—Must be free from oxidants

6 1 2 Absorbing Reagent (0 04 M Potassium Tetrachloromercurate (TCM))—Dissolve 10 86 g mercuric chloride 0 066 g EDTA (Ethylenediaminetetraacetic acid disodium salt), and 6 0 g potassium chloride in water and bring to mark in a 1 000-ml volumetric flask (Caution highly poisonous If spilled on skin flush off with water immediately) The pH of this reagent should be approximately 4 0 but it has been shown that there is no appreciable difference in collection efficiency over the range of pH 5 to pH 3 The absorbing reagent is normally stable for 6 months If a precipitate forms, discard the reagent

6 2 Analysis

6 2 1 Sulfamic Acid (0 6 percent)—Dissolve 0 6 g sulfamic acid in 100 ml distilled water Prepare fresh daily

6 2 2 Formaldehyde (0 2 percent)—Dilute 5 ml formaldehyde solution (36–38 percent) to 1 000 ml with distilled water Prepare daily

6 2 3 Stock Iodine Solution (0 1 N)—Place 12 7 g iodine in a 250-ml beaker add 40 g potassium iodide and 25 ml water Stir until all is dissolved, then dilute to 1,000 ml with distilled water

6 2 4 Iodine Solution (0 01 N)—Prepare approximately 0 01 N iodine solution by diluting 50 ml of stock solution to 500 ml with distilled water

6 2 5 Starch Indicator Solution—Triturate 0 4 g soluble starch and 0 002 g mercuric iodide (preservative) with a little water and add the paste slowly to 200 ml boiling water Continue boiling until the solution is clear cool, and transfer to a glass-stoppered bottle

6 2 6 Stock Sodium Thiosulfate Solution (0 1 N)—Prepare a stock solution by dissolving 25 g sodium thiosulfate ($Na_2S_2O_3 \cdot 5H_2O$) in 1 000 ml freshly boiled cooled distilled water and add 0 1 g sodium carbonate to the solution Allow the solution to stand 1 day before standardizing To standardize, accurately weigh, to the nearest 0 1 mg 1 5 g primary standard potassium iodate dried at 180° C and dilute to volume in a 500-ml volumetric flask To a 500 ml iodine flask pipet 50 ml of iodate solution Add 2 g potassium iodide and 10 ml of 1 N hydrochloric acid Stopper the flask After 5 minutes, titrate with stock thiosulfate solution to a pale yellow Add 5 ml starch indicator solution and complete the titration Calculate the normality of the stock solution

$$N = \frac{W}{M} \times 2\,80$$

N = Normality of stock thiosulfate solution

M = Volume of thiosulfate required, ml

W = Weight of potassium iodate, grams

$$2\,80 = \frac{10^3 \text{ (conversion of g to mg)} \times 0\,1 \text{ (fraction iodate used)}}{35\,67 \text{ equivalent weight of potassium iodate}}$$

6 2 7 Sodium Thiosulfate Titrant (0 01 N)—Dilute 100 ml of the stock thiosulfate solution to 1 000 ml with freshly boiled distilled water

Normality = Normality of Stock Solution $\times 0\,100$

6 2 8 Standardized Sulfite Solution for Preparation of Working Sulfite-TCM Solution—Dissolve 0 30 g sodium metabisulfite ($Na_2S_2O_5$ or 0 40 g sodium sulfite (Na_2SO_3) in 500 ml of recently boiled cooled distilled water (Sulfite solution is unstable, it is therefore important to use water of the highest purity to minimize this instability) This solution contains the equivalent of 320 to 400 μg /ml of SO_2 The actual concentration of the solution is determined by adding excess iodine and back-titrating with standard sodium thiosulfate solution To back-titrate, pipet 50 ml of the 0 01 N iodine into each of two 500-ml iodine flasks (A and B). To flask A (blank) add 25 ml distilled water, and to flask B (sample) pipet 25 ml sulfite solution Stopper the flasks and allow to react for 5 min Prepare the working sulfite-TCM Solution (6 2 9) at the same time Iodine solution is added to the flasks By means of a buret containing standardized 0 01 N Thiosulfate, titrate each flask in turn to a pale yellow Then add 5 ml starch solution and continue the titration until the blue color disappears

6 2 9 Working Sulfite-TCM Solution—Pipet accurately 2 ml of the standard solution into a 100-ml volumetric flask and bring to mark with 0 04 M TCM Calculate the concentration of sulfur dioxide in the working solution

$$\mu g\ SO_2/ml = \frac{(A-B)\ (N)\ (32\,000) \times 0\,02}{25}$$

32,000 = Milliequivalent wt , μg

A = Volume thiosulfate for blank, ml

B = Volume thiosulfate for sample, ml

N = Normality of thiosulfate titrant

25 = Volume standard sulfite solution, ml

0 02 = Dilution factor

This solution is stable for 30 days if kept at 5° C (refrigerator) If not kept at 5° C prepare daily

6 2 10 1 Dye Specifications—The pararosaniline dye must meet the following performance specifications (1) The dye must have a wavelength of maximum absorbance at 540 nm when assayed in a buffered solution of 0 1 M sodium acetate-acetic acid (2) the absorbance of the reagent blank, which is temperature-sensitive (0 015 absorbance unit/° C), should not exceed 0 170 absorbance unit at 22° C with a 1-cm optical path length, when the blank is prepared according to the prescribed analytical procedure and to the specified concentration of the dye, (3) the calibration curve (Section 8 2 1) should have a slope of 0 030 ± 0 002 absorbance units/μg SO_2 at this path length when the dye is pure and the sulfite solution is properly standardized

6 2 10 2 Preparation of Stock Solution—A specially purified (99–100 percent pure) solution of pararosaniline which meets the above specifications is commercially available in the required 4 80 percent concentration (Harleco*) If this cannot be obtained the stock solution may be prepared by dissolving 0 200 g of the purified dye in 100 ml of 1 N hydrochloric acid in a 100 ml glass stoppered graduated cylinder (See Scaringelli, et al [4] for the purification and assay procedures)

*Hartmen-Leddon, 60th and Woodland Avenue, Philadelphia, PA 19143

orders for any of the above documents should be accompanied by a check or money order payable to the Superintendent of Documents

Copies of the summary-and-conclusions chapter of each air quality criteria document are available free of charge from the Air Pollution Control Office, Environmental Protection Agency, 5600 Fishers Lane, Rockville, MD 20852, Attention Publications Section

Interested persons may submit written comments in triplicate to the Office of the Acting Commissioner Air Pollution Control Office, Environmental Protection Agency, Parklawn Building, Room 17-59, 5600 Fishers Lane, Rockville, MD 20852 All relevant comments received not later than 45 days after the publication of this proposal will be considered The standards, modified as the Administrator deems appropriate after consideration of comments, will be promulgated no later than 90 days from the date of publication of this notice, as required by the Act.

This notice of proposed rulemaking is issued under the authority of section 4, Public Law 91-604, 84 Stat 1679.

Dated January 25, 1971

WILLIAM D RUCKELSHAUS,
Administrator.

A new Part 410 would be added to Chapter IV, Title 42, Code of Federal Regulations, as follows.

PART 410—NATIONAL PRIMARY AND SECONDARY AMBIENT AIR QUALITY STANDARDS

Sec.

410 1 Definitions
410.2 Scope
410.3 Measurement corrections
410 4 National primary ambient air quality standards for sulfur oxides (sulfur dioxide)
410.5 National secondary ambient air quality standards for sulfur oxides (sulfur dioxide)
410 6 National primary ambient air quality standards for particulate matter
410 7 National secondary ambient air quality standards for particulate matter
410 8 National primary and secondary ambient air quality standards for carbon monoxide
410 9 National primary and secondary ambient air quality standards for photochemical oxidants
410 10 National primary and secondary ambient air quality standards for hydrocarbons
410 11 National primary and secondary ambient air quality standards for nitrogen dioxide
Appendix A—Method for Determination of Sulfur Dioxide (Pararosaniline Method)
Appendix B—Procedure for Determination of Suspended Particulates (High Volume Method)
Appendix C—Method for Continuous Measurement of Carbon Monoxide (Nondispersive Infrared Spectrometry)
Appendix D—Method for Determination of Oxidants (Neutral Buffered Potassium Iodide Method)
Appendix E—Part 1 Method for Continuous Measurement of Hydrocarbons (Flame Ionization Method).
Part 2 Method for Measurement of Methane
Appendix F—Method for Determination of Nitrogen Dioxide in the Atmosphere (24-Hour Sampling Method)

§ 410.1 Definitions.

(a) As used in this part, all terms not defined herein shall have the meaning given them by the Act

(b) "Act" means the Clean Air Act, as amended (Public Law 91-604).

(c) "Agency" means the Environmental Protection Agency.

(d) "Administrator" means the Administrator of the Environmental Protection Agency

§ 410 2 Scope.

(a) National primary and secondary ambient air quality standards under section 109 of the Act are set forth in this part

(b) National primary ambient air quality standards define levels of air quality which the Administrator judges are necessary, with an adequate margin of safety, to protect the public health National secondary ambient air quality standards define levels of air quality which the Administrator judges necessary to protect the public welfare from any known or anticipated adverse effects of a pollutant Such standards are subject to revision, and additional primary and secondary standards may be promulgated as the Administrator deems necessary to protect the public health and welfare

(c) The promulgation of national primary and secondary ambient air quality standards shall not be considered in any manner to allow significant deterioration of existing air quality in any portion of any State

(d) The proposal, promulgation, or revision of national primary and secondary ambient air quality standards shall not prohibit any State from establishing ambient air quality standards for that State or any portion thereof which are more stringent than the national standards

§ 410 3 Measurement corrections.

All measurements of air quality are corrected to a reference temperature of 20° C and to a reference pressure of 760 millimeters of mercury

§ 410.4 National primary ambient air quality standards for sulfur oxides (sulfur dioxide).

The national primary ambient air quality standards for sulfur oxides, measured as sulfur dioxide by a method referenced to the pararosaniline method, as described in Appendix A to this part, are

(a) 80 micrograms per cubic meter—annual arithmetic mean

(b) 365 micrograms per cubic meter—maximum 24-hour concentration not to be exceeded more than once per year

§ 410 5 National secondary ambient air quality standards for sulfur oxides (sulfur dioxide).

The national secondary ambient air quality standards for sulfur oxides, measured as sulfur dioxide by a method referenced to the pararosaniline method, as described in Appendix A to this part, are:

(a) 60 micrograms per cubic meter—annual arithmetic mean.

(b) 260 micrograms per cubic meter—maximum 24-hour concentration not to be exceeded more than once per year

§ 410 6 National primary ambient air quality standards for particulate matter.

The national primary ambient air quality standards for particulate matter, measured by the high-volume sampling method, as described in Appendix B to this part, are

(a) 75 micrograms per cubic meter—annual geometric mean

(b) 260 micrograms per cubic meter—maximum 24-hour concentration not to be exceeded more than once per year

§ 410.7 National secondary ambient air quality standards for particulate matter.

The national secondary ambient air quality standards for particulate matter, measured by the high-volume sampling method, as described in Appendix B to this part, are

(a) 60 micrograms per cubic meter—annual geometric mean

(b) 150 micrograms per cubic meter—maximum 24-hour concentration not to be exceeded more than once per year

§ 410 8 National primary and secondary ambient air quality standards for carbon monoxide.

The national primary and secondary ambient air quality standards for carbon monoxide, measured by the nondispersive infrared method, as described in Appendix C to this part, or equivalent method, are

(a) 10 milligrams per cubic meter—maximum 8-hour concentration not to be exceeded more than once per year.

(b) 15 milligrams per cubic meter—maximum 1-hour concentration not to be exceeded more than once per year

§ 410 9 National primary and secondary ambient air quality standards for photochemical oxidants

The national primary and secondary ambient air quality standards for photochemical oxidants, measured by a method referenced to the neutral-buffered 1 percent potassium iodide colorimetric technique and corrected for interferences due to nitrogen oxides and sulfur dioxide, as described in Appendix D to this part, are: 125 micrograms per cubic meter - maximum 1-hour concentration not to be exceeded more than once per year

§ 410 10 National primary and secondary ambient air quality standards for hydrocarbons

The national primary and secondary ambient air quality standards for hydrocarbons, measured by the flame ionization detection method, as described in Appendix E to this part (Part 1), and corrected for methane in the sampled air by the procedures described in Appendix E to this part, or by an equivalent procedure, are: 125 micrograms per cubic meter—maximum 3-hour concentration (6 to 9 a.m.) not to be exceeded more than once per year.

ENVIRONMENTAL PROTECTION AGENCY

[42 CFR Part 410]

NATIONAL PRIMARY AND SECONDARY AMBIENT AIR QUALITY STANDARDS

Notice of Proposed Standards for Sulfur Oxides, Particulate Matter, Carbon Monoxide, Photochemical Oxidants, Hydrocarbons, and Nitrogen Oxides

Section 109 of the Clean Air Act, as amended December 31, 1970 (Public Law 91-640), directs the Administrator of the Environmental Protection Agency to publish, no later than January 30, 1971, proposed national primary and secondary ambient air quality standards for each pollutant for which air quality criteria were issued prior to enactment of the amendments The section also provides that after December 31, 1970, the Administrator shall, simultaneously with his issuance of air quality criteria and information on control techniques for a pollutant, publish proposed national primary and secondary ambient air quality standards for that pollutant Primary ambient air quality standards define levels of air quality which the Administrator judges necessary, based on the air quality criteria and allowing an adequate margin of safety, to protect the public health Secondary ambient air quality standards define levels of air quality which the Administrator judges necessary, based on the air quality criteria to protect the public welfare from any known or anticipated adverse effects of an air pollutant

Prior to December 31, 1970, air quality criteria had been issued for these five pollutants Sulfur oxides and particulate matter (34 F R 1988), carbon monoxide, photochemical oxidants, and hydrocarbons (35 F R 4768) The Administrator has determined that nitrogen oxides, which are present in the ambient air as a result of emissions from numerous and diverse mobile and stationary sources and for which air quality criteria were not issued prior to December 31, 1970, are air pollutants which adversely affect public health and welfare In accordance with section 108 of the Act, the following are published in a notice in this issue of the FEDERAL REGISTER

1 A list of air pollutants, required to be published no later than January 30, 1971, which identifies nitrogen oxides as air pollutants for which air quality criteria will be issued and for which national primary and secondary ambient air quality standards will be promulgated, and

2 An announcement of the issuance of air quality criteria for nitrogen oxides

Pursuant to section 109 of the Clean Air Act, notice is hereby given of proposed national primary and secondary ambient air quality standards as set forth in Part 410 below, which would be added to Chapter IV of Title 42, Code of Federal Regulations With respect to carbon monoxide, hydrocarbons, photochemical oxidants, and nitrogen oxides, adverse welfare effects have not been observed to occur at levels below the levels of the proposed primary standards For each of those pollutants, therefore, the proposed secondary standard has been specified at the level of the proposed primary standard

The characteristics of the six air pollutants named above are, briefly, as follows

Sulfur oxides Sulfur oxides, which arise primarily from the combustion of sulfur-containing fossil fuels, are prevalent in polluted air Their presence in the ambient air has been associated with a variety of respiratory diseases and increased mortality rates They represent a significant economic burden and have a nuisance impact Sulfur dioxide is an indicator of the presence of sulfur oxides in polluted air and is an important index of the effects which have been associated with these contaminants

Detailed information on sulfur oxides is presented in the document "Air Quality Criteria for Sulfur Oxides" (NAPCA Publication No AP-50), which provided a basis for the development of the standards set forth below

Particulate matter. Particulate matter refers to any matter dispersed in the air, whether solid or liquid, in which the individual particles are larger than small molecules but smaller than 500 microns Particles smaller than 1 micron in diameter originate in the atmosphere principally through condensation and combustion, while larger particles arise principally from erosion and abrasion Particulate matter of technological origin is pervasive in its distribution and is associated with a variety of adverse effects on public health and welfare Particulate matter in the respiratory tract may produce injury by itself, or it may act in conjunction with gases, altering their sites or their mode of action Particles cleared from the respiratory tract by transfer to the lymph, blood, or gastrointestinal tract may produce effects elsewhere in the body

Detailed information on particulate matter is presented in the document "Air Quality Criteria for Particulate Matter" (NAPCA Publication No AP-49), which provided a basis for the development of the standards set forth below.

Carbon monoxide Carbon monoxide is the product of incomplete combustion of carbonaceous fuels and is widely prevalent in ambient air It is absorbed through the lungs and reacts primarily with the hemoglobin in red blood cells It decreases the oxygen carrying capacity of the blood and reduces the availability of oxygen transported to vital tissues by the blood

Detailed information on carbon monoxide is presented in the document "Air Quality Criteria for Carbon Monoxide" (NAPCA Publication No AP-62), which provided a basis for the development of the standards set forth below.

Photochemical oxidants Photochemical oxidants are produced in the atmosphere when reactive organic substances, principally reactive hydrocarbons, and nitrogen oxides are exposed to sunlight Photochemical oxidants cause irritation of the mucous membranes, damage to vegetation, and deterioration of materials They affect the clearance mechanism of the lungs and alter resistance to respiratory bacterial infection Photochemical oxidants have been implicated as accelerators in the aging process

Detailed information on photochemical oxidants is presented in the document "Air Quality Criteria for Photochemical Oxidants" (NAPCA Publication No AP-63) which provided a basis for the development of the standards set forth below

Hydrocarbons Hydrocarbons are primarily associated with the processing, marketing, and use of petroleum products and are widely prevalent in the ambient air They constitute the principal portion of these volatile reactive organic substances in the atmosphere which are the precursors of other compounds formed in the atmospheric photochemical system and which result in the manifestations of photochemical smog Methane, which occurs naturally in the atmosphere at relatively high levels, is not considered to be involved in the photochemical reactions The only direct effect attributable to ambient levels of hydrocarbons is the vegetation damage from ethylene

Detailed information on hydrocarbons is presented in the document "Air Quality Criteria for Hydrocarbons (NAPCA Publication No AP-64) which provided a basis for the development of the standards set forth below

Nitrogen oxides Nitrogen oxides result from the fixation of nitrogen and oxygen at high temperatures and are typically associated with combustion processes They are also related to certain chemical processes The principal nitrogen oxide formed in the combustion process is nitric oxide This compound has not been shown to have health or welfare effects at present or anticipated ambient concentrations However, there are several atmospheric reactions which lead to the oxidation of nitric oxide to nitrogen dioxide, and the presence of nitrogen dioxide in ambient air has been associated with a variety of respiratory diseases Nitrogen dioxide is essential to the production of photochemical smog At higher concentrations, its presence has been implicated in the corrosion of electrical components as well as vegetation damage

Detailed information on nitrogen oxides is presented in the document "Air Quality Criteria for Nitrogen Oxides" (EPA Publication No AP-84) which provided a basis for the development of the standards set forth below

The air quality criteria documents referred to above are available from the Superintendent of Documents, Government Printing Office, Washington, D C 20402 Prices are as follows.

Sulfur oxides (AP-50)	$1 25
Particulate matter (AP-49)	1 75
Carbon monoxide (AP-62)	1 50
Hydrocarbons (AP-64)	1 25
Photochemical oxidants (AP-63)	1 75
Nitrogen oxides (AP-84)	1 50

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FEDERAL REGISTER

VOLUME 36 • NUMBER 21

Saturday, January 30, 1971 • Washington, D.C.

PART II

ENVIRONMENTAL PROTECTION AGENCY

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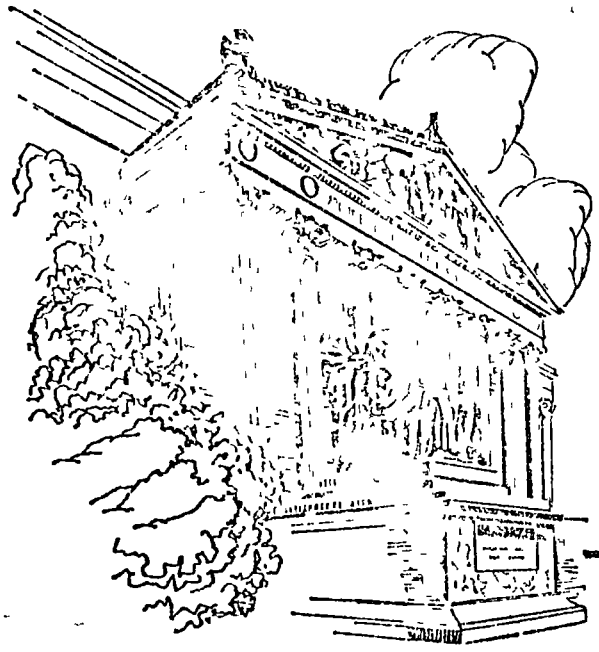
National Primary and Secondary Ambient Air Quality Standards and Air Pollution and Control



Notice of Proposed Standards and List of Air Pollutants

THE NATIONAL ARCHIVES OF THE UNITED STATES * 1934 *

JULY 1971

Comparative DAILY PRECIPITATION Chicago Area

Station	Day of Month																													Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
hland Park, Ill. r Plant	...			18	1 51			1 69		T			T		08	.21		02	09			T	26	T	04	81		T				
vicview, Ill U S Navel Air Station				.39	85			1 17	T	05		T	T		.23	32		T	.03			T	.45		.06			T				
Sanitary District of Chicago Howard & McCormick, Skokie				07	.43			.83		.06									.01	.03			.25		.06			01				
National Weather Service O'Hare International Airport				1 12	48			1 26	T	09		T	T			21		02	.02			01	30		06			T	T			
Sanitary District of Chicago Lawrence & Francisco				90	80			1.05		08						37		02	05				.61		.06			.03				
City of Chicago 4950 Wilson				1 37	69			85		09						13		10					52									
City of Chicago 1747 N. Springfield				1 00	1 51			1 20		12						14		02					70			10						
Sanitary District of Chicago 100 E Erie St				.70	1 40			1 06		05						21			01				59		08	08		05				
City of Chicago 1040 E Ohio St.				.09	41			1 08		03						23		02					52		.16	14		01				
Berwyn, Ill 1644 S Gunderson Paul Kubecka				1.52	1 82			1 03	03	10			T			20		03	T			T	57		17	01		05				
§ 2419 S Christiana Ave Raymond Sterrie					2 70			90	T		12						.34		05				45	28		10		09				
Sanitary District of Chicago 3838 S Racine Ave			OUT OF SERVICE																													
Sanitary District of Chicago 40th & Laramie, Stickney				1 00	1 58			85		08						.11			.04			01	88		10	01		09				
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University of Chicago 5730 S Woodlawn Ave.				50	2 72			.99	.02	10			T			41		07				T	1 48		.01	05		1.				
National Weather Service 6200 S Cicero Ave.				26	1 18			1 28	01	12		T	T			06		07	T	02		T	1 88	T	01	03		08				
Oak Lawn, Ill., 8501 S. Mobile [illegible] Wachowski				1 10	1 90			1 63	T	12		T	T			07		05		T			1 38	T	02	T		T				
City of Chicago 79th & Lake Michigan				.60	1 62			50		09						.20		15					1 08			02		11				
City of Chicago 351 W 104th St.				.64	1 82			1 31		09	.03					11		10					71					.12				
Sanitary District of Chicago 126th & St. Lawrence				95	1 07			1 37		.06						06			06				1 58					09				

AMOUNTS ARE FOR "MIDNIGHT TO MIDNIGHT", EXCEPT AS NOTED § 7 P M TO 7 P M "T" INDICATES AN AMOUNT TOO SMALL TO MEASURE INC MEANS INCOMPLETE M MEANS MISSING.

GPO 826-23

US GPO CHICAGO 8/5/71 7200

JULY 1971 HOURLY TEMPERATURES - MIDWAY AIRPORT

DAY	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	75	74	72	71	69	69	70	71	74	77	79	81	81	82	83	82	82	81	81	79	77	76	73	72
2	71	70	69	68	66	63	67	70	72	75	76	78	79	79	80	79	79	77	76	72	69	67	66	65
3	65	64	63	63	60	60	67	72	75	79	83	84	85	87	86	86	85	86	84	83	80	77	76	73
4	73	72	69	67	65	65	71	75	81	84	87	89	89	89	91	92	90	90	86	80	78	77	75	72
5	71	70	69	70	69	68	69	69	70	75	77	78	80	81	82	85	83	81	80	80	79	77	75	74
6	72	71	70	68	67	67	71	75	79	81	83	84	85	86	86	87	87	86	84	83	81	78	76	74
7	71	69	69	67	67	68	71	75	78	82	84	85	87	87	88	88	88	88	87	85	83	81	79	78
8	78	77	77	77	77	77	71	70	70	70	75	81	83	85	86	83	84	85	83	81	78	77	75	76
9	76	76	75	74	74	73	73	73	75	76	76	74	75	76	76	78	78	77	76	73	72	71	71	70
10	70	70	70	69	69	69	70	71	72	74	75	76	75	77	80	80	78	77	75	74	74	71	69	70
11	69	69	71	70	71	71	70	70	72	73	74	76	77	78	78	78	78	77	75	72	72	69	69	68
12	67	67	67	67	67	67	68	69	73	76	79	82	83	84	85	85	83	83	83	82	79	78	78	77
13	77	76	76	76	76	76	76	77	80	84	85	87	88	88	89	88	88	87	84	80	77	75	73	71
14	70	69	68	67	65	63	65	68	71	75	76	78	80	82	83	79	78	77	77	76	73	72	71	70
15	70	68	67	67	67	66	67	71	73	77	78	80	81	82	83	83	82	83	82	80	77	74	72	71
16	69	69	67	67	66	65	67	71	75	77	80	82	83	85	87	89	90	89	87	84	83	81	77	69
17	69	69	68	67	66	66	67	68	70	71	71	72	73	73	74	75	74	73	72	70	68	66	64	64
18	63	63	61	61	60	59	62	67	70	73	74	76	78	79	80	80	81	82	79	77	76	72	73	69
19	69	69	68	68	68	67	67	67	67	67	67	67	67	67	70	71	73	72	69	67	64	61	59	
20	58	58	57	56	56	56	59	65	69	73	76	78	80	76	77	78	75	79	76	74	73	71	70	68
21	66	66	65	64	63	62	64	69	73	74	79	81	84	84	84	84	85	84	82	80	77	75	74	73
22	72	71	69	69	69	69	70	72	77	80	84	84	87	87	88	88	87	86	83	82	79	78	76	75
23	74	72	72	71	70	70	70	71	73	74	79	76	77	79	74	73	72	72	69	69	69	69	69	68
24	67	67	67	66	65	64	64	67	69	69	72	75	76	77	77	76	76	75	74	70	68	68	67	67
25	67	66	66	66	65	65	65	67	70	75	78	80	81	83	84	85	85	84	83	80	77	76	73	72
26	70	69	69	69	68	68	66	66	68	69	69	70	71	73	73	72	73	72	71	70	67	65	64	61
27	61	60	57	57	57	56	56	62	66	70	71	73	74	75	76	76	75	74	73	71	69	68	66	67
28	67	66	66	66	65	66	66	66	66	65	64	65	66	70	73	75	76	74	74	71	68	65	64	61
29	57	56	55	54	54	54	55	63	67	69	70	71	71	71	71	70	69	69	68	67	66	65	63	61
30	60	58	57	58	58	58	57	59	61	63	65	66	67	67	66	68	68	69	68	66	65	64	63	61
31	60	58	57	56	55	54	54	58	64	67	69	72	73	74	74	75	75	74	73	71	69	67	66	65

US DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE

LOCAL CLIMATOLOGICAL DATA

CHICAGO, ILLINOIS
O'HARE INTERNATIONAL AIRPORT
JULY 1971

Latitude 41 ° 59 ' N Longitude 87 ° 54 ' W Elevation (ground) 658 ft CENTRAL Standard time used

UNIVERSITY OF CHICAGO
5730 WOODLAWN AVE.

Date	Temperature (°F) Maximum	Minimum	Average	Departure from normal	Degree days (base 65°)	Precipitation Total (Water equivalent) (In.)	Snow, Sleet (In.)	Snow, Sleet, or Ice on ground at 6 A.M. (In.)	Wind † Prevailing direction	Average speed (m.p.h.)	Fastest mile * Speed (m.p.h.)	† Direction	Sunshine Total (hours and minutes)	Percent of possible	Sky cover Sunrise to sunset (tenths)	Midnight to midnight (tenths)	Thunderstorm or distant lightning	Weather restricting visibility to ¼ mile or less	TEMPERATURES °F MAX	MIN	AVG	DEGREE DAYS	Date
1	82	65	74	+2	0	0	0	0	30	8 6	17	32			6	5			82	69	76	0	1
2	79	62	71	-1	0	0	0	0	03	9 1	15	03			0	0			76	64	70	0	2
3	87	57	72	0	0	0	0	0	17	6 7	15	20			5	3			86	62	74	0	3
4	90	66	78	+6	0	1 12	0	0	19	7 9	19	22			8	8			91	68	80	0	4
5	84	68	76	+4	0	48	0	0	36	7 8	15	01			9	9	T		80	66	73	0	5
6	88	68	78	+5	0	0	0	0	18	4 3	11	25			3	3			85	69	77	0	6
7	87	66	77	+4	0	0	0	0	18	8 8	18	17			8	6			89	66	78	0	7
8	88	71	80	+7	0	1 26	0	0	19	10 5	34	36			9	8	T		86	67	77	0	8
9	79	68	74	+1	0	T	0	0	02	6 6	13	04			10	10			75	70	73	0	9
10	82	67	75	+2	0	.09	0	0	06	8 4	18	04			8	9			78	66	72	0	10
11	78	61	70	-3	0	0	0	0	03	11.0	21	05			6	5			78	67	73	0	11
12	84	60	72	-1	0	T	0	0	19	11 2	31	20			5	5	DL		85	65	75	0	12
13	86	64	75	+2	0	T	0	0	27	14 6	26	28			2	3	DL		89	70	80	0	13
14	82	58	70	-3	0	0	0	0	29	6 6	17	33			3	2			81	64	73	0	14
15	83	64	74	+1	0	0	0	0	25	9 4	23	24			6	5			82	65	74	0	15
16	87	61	74	+1	0	21	0	0	24	10.4	24	30			2	3	T		87	64	76	0	16
17	76	59	68	-5	0	0	0	0	02	8 0	15	06			3	3			73	62	86	0	17
18	81	55	68	-5	0	02	0	0	19	7 2	22	18			8	6	T		79	59	69	0	18
19	73	55	64	-9	1	.02	0	0	36	10 3	22	01			7	6			70	59	65	0	19
20	82	54	68	-5	0	0	0	0	25	7 3	12	09			6	4			81	57	69	0	20
21	84	64	74	+1	0	0	0	0	22	13 2	23	21			4	3			86	62	74	0	21
22	88	70	79	+6	0	.01	0	0	22	12 1	22	23			8	7			89	69	79	0	22
23	80	67	74	+1	0	30	0	0	19	8 2	15	21			10	9			81	66	74	0	23
24	80	62	71	-2	0	0	0	0	02	5.6	14	01			5	4			78	63	71	0	24
25	85	64	75	+2	0	.06	0	0	25	7 3	21	31			6	6	DL	FKH	86	65	76	0	25
26	75	59	67	-6	0	0	0	0	29	9 0	21	28			7	6			76	64	70	0	26
27	79	54	67	-7	0	0	0	0	27	9 2	19	19			4	4			78	57	68	0	27
28	78	56	67	-7	0	T	0	0	22	8 0	16	24			8	6			78	61	70	0	28
29	74	52	63	-11	2	T	0	0	29	7 9	15	25			5	4			75	56	66	0	29
30	72	53	63	-11	2	0	0	0	25	9 4	18	24			5	3			70	56	63	2	30
31	77	49	63	-11	2	0	0	0											77	54	66	0	31
Sum	2530	1899				3 57	0			275 9					185	162			2507	1972		2	
Avg	81.6	61 3								8 9	Fastest	Dir	Possible	%	6 0	5 2			80 9	63 6	72 3		
										Misc	34	36											

T in columns 7 8 9 and in the Hourly Precipitation table indicates an amount too small to measure

TEMPERATURE (°F)

Average monthly			71 5
Departure from normal			-1.2
Highest	90	on	4
Lowest	49	on	31
Number of days with —			
Max. 32° or below			0
Max 90° or above			1
Min 32° or below			0
Min. 0° or below			0

HEATING DEGREE DAYS (base 65°)

Total this month	7
Departure from normal	+7
Seasonal total (since July 1)	7
Seasonal departure from normal	+7

BAROMETRIC PRESSURE (In.)

Avg station (elev 29 255 feet, m s l)			
Highest sea level	30 24	on	2
Lowest sea level	29 64	on	19

PRECIPITATION (In.)

Total for the month	3 57		
Departure from normal	+0 18		
Greatest in 24 hours	1 60	on	4-5
Snow, Sleet—			
Total for the month	0		
Greatest in 24 hours	0	on	
Greatest depth on ground	0	on	
Dates of — Hail	8		
Sleet NONE	Glaze/Rime NONE		

Symbols used in columns 18 19

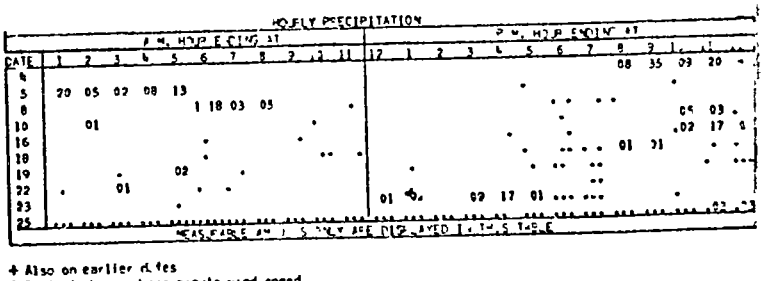
A = Hail
BS = Blowing snow
DL = Distant lightning
D = Dust
E = Sleet
F = Fog
H = Haze
K = Smoke
L = Drizzle
N = Sand
R = Rain
S = Snow
T = Thunderstorm
ZL = Freezing driz
ZR = Freezing rain

Character and Duration of Each Precipitation Period

(Rain or Drizzle unless otherwise indicated. a-A.M; p-P.M.)

DATE:

4. 6 29p to past midnight.
5 Continued to 4 33a
8. 5 20a-8 15a, A 5 25a-5 31a
9. 11 01a-11 21a, 3 15p-4 18p, 6 01p-6 45p.
10. 12 35a-1 38a, 8 35p-11 15p
12. 4 10p-4 15p, 11 20p to past midnight.
13. Continued to 12 40a.
16. 8,21p-10 46p
18 7 09p-9 11p
19. 4,01a-5 17a, 7 45a-9 40a.
22. 2:30a-2 35a
23. 11 37a-4 25p 5 45p-6 18p, 7 44p-8 15p, 9:40p-10 25p
25. 10 01p-10 15p, 10 35p-11 40p.
28. 8:30a-11 15a.
29. 8:50p-9 05p.



+ Also on earlier dates
* Fastest observed one minute wind speed
0 Figures in columns 10 and 13 indicate directions in tens of degrees from true North. For example 09 is East, 18 is South, 27 is West and 36 is North

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U S DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE

LOCAL CLIMATOLOGICAL DATA

SUMMARY

CHICAGO, ILL.
MIDWAY AIRPORT
JULY 1971

Latitude 41 ° 47 ' N Longitude 87 ° 45' W Elevation (ground) 607 feet Central Standard time used

DATE	TEMPERATURE °F MAXIMUM	MINIMUM	AVERAGE	DEPARTURE FROM NORMAL	DEGREE DAYS HEATING	DEGREE DAYS COOLING	PRECIPITATION (Inches) TOTAL (Water equivalent)	SNOWFALL & SLEET	WIND RESULTANT SPEED (m.p.h.)	RESULTANT DIRECTION (tens of degrees)	AVERAGE SPEED (m.p.h.)	FASTEST MILE SPEED (m.p.h.)	FASTEST MILE DIR	SUNSHINE TOTAL (hours and tenths)	SUNSHINE PERCENT OF POSSIBLE	SKY COVER AVERAGE SKY COVER (tenths)	SKY COVER NUMBER OF CLEAR DAYS	SKY COVER NUMBER OF CLOUDY DAYS	WEATHER TYPE OBSERVED BEFORE 0000	VISIBILITY 1/4 MILE OR LESS (Number of Days)	COOLING (Base 65°)	LATEST MAXIMUM WATER EQUIV	PEAK GUST FROM MAX HOUR	PEAK GUST FROM DIR	TEMPERATURES °F MAX	MIN	AVG	DEGREE DAYS
1	84	69	77	+ 3	0	12	0	0	32	9	9	35	NW	12 30	82	6	4			10	64	76	33	79	72	76	0
2	80	63	72	- 3	0	7	0	0	04	9	9	33	NE	15 09	100	0	1			6	65	87	44	75	65	70	0
3	89	59	74	- 1	0	9	0	0	17	8	2	33	S	10 56	77	4	3			11	67	94	31	77	66	72	0
4	94	65	80	+ 5	0	15	26	0	18	10	2	35	SW	9 09	61	7	7	T		13	65	97	33	87	71	79	0
5	86	68	77	+ 2	0	12	1.18	0	35	7	9	35	E	5 57	39	9	9	T		12	66	100	51	78	67	73	0
6	88	66	77	+ 2	0	12	0	0	19	6	0	9	NW	13 25	89	3	3			12	66	90	39	79	74	76	0
7	90	67	79	+ 4	0	14	0	0	18	10	0	27	SE	10 34	70	9	7			15	66	78	46	87	73	80	0
8	86	70	78	+ 3	0	13	1.28	0	18	11	2	27	NW	3 21	22	9	8	T		14	62	90	63	82	69	77	0
9	79	70	75	0	0	10	.01	0	01	7	3	16	NE	1 21	9	10	9			10	62	76	56	76	68	72	0
10	81	69	75	- 1	0	10	.12	0	00	04	7	3	14	NE	18	2 58	20	9	10		9	64	78	54	74	68	71	0
11	79	67	73	- 3	0	8	0	0	0	04	12	0	20	NE	26	12 25	83	4	4		9	68	84	43	73	59	71	0
12	86	67	77	+ 1	0	12	T	0	0	18	13	0	23	SE	32	11 55	80	4	4		13	68	75	51	84	68	76	0
13	90	70	80	+ 4	0	15	T	0	0	27	16	2	28	SW	40	12 13	82	2	3	DL	13	68	79	27	89	72	81	0
14	83	60	73	- 3	0	8	0	0	0	30	8	2	12	E	23	13 51	93	3	2		9	66	70	37	73	69	71	0
15	84	66	75	- 1	0	10	0	0	0	28	10	9	20	SW	29	11 21	76	6	5		10	66	76	34	82	70	76	0
16	90	65	78	+ 2	0	13	06	0	0	23	10	4	23	SW	39	13 37	91	1	3	T	12	64	76	40	88	58	78	0
17	75	63	69	- 7	0	4	0	0	0	06	9	8	16	NE	21	13 24	90	2	3		6	66	82	41	68	65	67	0
18	83	59	71	- 5	0	6	.07	0	0	17	7	7	14	S	17	10 21	70	8	7	T	8	66	80	32	74	52	68	0
19	74	58	66	-10	0	1	T	0	0	36	11	1	20	N	33	5 04	34	7	6		4	65	79	31	70	64	67	0
20	82	56	69	- 7	0	4	02	0	0	14	6	8	12	SE	18	7 19	49	6	4	T	7	66	75	42	78	62	70	0
21	86	62	74	- 2	0	9	0	0	0	19	13	1	21	SW	30	13 37	92	3	2		11	66	81	48	84	65	75	0
22	89	69			2	12	T	0	0	19	13	0	19	SW	26	10 45	73	7	7		13	66	73	41	88	70	79	0
23	80	67			3	10	1.68	0	0	19	9	4	17	SE	22	0 04	0	10	9	T	4	66	94	60	77	64	71	0
24	79	63	71	- 6	0	6	T	0	0	08	5	5	11	NE	16	1 49	12	5	6		9	64	98	66	70	63	67	0
25	85	63	74	- 3	0	9	.01	0	0	23	7	7	14	NW	25	8 00	55	5	6	T	FKL	12	66	100	61	82	63	73	0
26	74	60	67	-10	0	2	03	0	0	30	10	4	17	SW	25	8 32	58	7	6	T		5	67	94	43	73	64	69	0
27	76	54	65	-12	0	0	0	0	0	24	9	4	16	S	23	12 25	85	4	4			5	66	83	38	76	58	67	0
28	76	57	67	- 9	0	2	08	0	0	19	11	7	19	S	32	5 43	39	8	7			5	64	90	52	75	52	69	2
29	72	53	63	-13	2	0	0	0	0	22	6	8	12	SW	18	5 46	40	8	6			3	60	90	49	68	58	63	5
30	69	57	63	-13	2	0	0	0	0	30	7	5	12	W	18	9 47	68	4	4			2	59	90	45	64	56	60	0
31	75	53	64	-12	1	0	0	0	0	24	8	8	14	SW	22	12 09	95	3	2			4	59	86	45	74	56	65	7
	2544	1958				315	5 00	0			297 3					285 30		173	161		283				2406	2041		
	82	63	2							18	9	6	Fastest			possible		5	6			65	85	44	77	69	8717	
													MISC	28	SW													

TEMPERATURE DATA

AVERAGE MONTHLY 72 7
DEPARTURE FROM NORMAL - 2.9
HIGHEST 94 ON 4
LOWEST 53 ON 29,31
NUMBER OF DAYS WITH —
MAX 32° OR BELOW 0
MAX 90° OR ABOVE 4
MIN 32° OR BELOW 0
MIN 0° OR BELOW 0
DEGREE DAYS (BASE 65°) —
TOTAL THIS MONTH 5
DEPARTURE FROM NORMAL + 5
SEASONAL TOTAL 5
DEPARTURE FROM NORMAL + 5

WEATHER

NUMBER OF DAYS —
CLEAR (Scale 0-3) 8
PARTLY CLOUDY (Scale 4-7) 14
CLOUDY (Scale 8-10) 9
WITH 0.01 OR MORE PRECIP 12
WITH 0.10 OR MORE PRECIP 5
WITH 0.50 OR MORE PRECIP 3
WITH 1.00 OR MORE PRECIP 3
DATES OF —
HAIL NONE
SLEET NONE
GLAZE/RIME NONE

PRECIPITATION DATA

TOTAL FOR THE MONTH 5 00 IN.
DEPARTURE FROM NORMAL + 1,63 IN.
GREATEST IN 24 HOURS 1,68 ON 23

SNOWFALL AND SLEET
TOTAL FOR THE MONTH 0 IN.
GREATEST IN 24 HOURS 0 ON —
GREATEST DEPTH ON GROUND 0 ON —

BAROMETRIC PRESSURE
629 Ft Elev
MONTHLY MEAN STATION 29,324 IN.
HIGHEST SEA-LEVEL 30,25 IN. ON 2
LOWEST SEA-LEVEL 29,64 IN. ON 19

SYMBOLS USED

A Hail
BS Blowing Snow
DL Distant Lightning
D Dust
E Sleet
F Fog
H Haze
K Smoke
L Drizzle
N Sand
R Rain
S Snow
T Thunderstorm
ZL Freezing Drizzle
ZR Freezing Rain

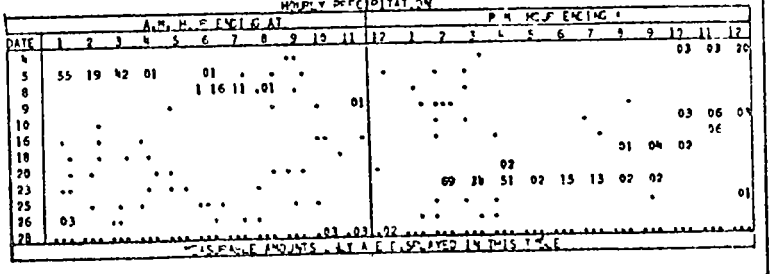
"T" under Precipitation Indicates a Trace, an amount too small to measure

Character and Duration of Each Precipitation Period

(Rain or Drizzle unless otherwise indicated a-A M ; p-P M)

DATE:
4 6 32p to past [illegible]
[illegible] 5 25a-6 12a.
8. 5 29a-6 40a, 6 00a-7 22a
9. 3 42a-4 08a, 10 40a-10 45a, 4 28p-4 40p, 6 33p-7 05p
10. 8 05p-11 23p
12. 5 07p-5 12p
13. 12 05a-12 32a
16 9 40p-11 02p
18 7 25p-9 38p
19. 8 07a-8 19a, 11 09a-11 14a, 11 30a-11 34a.
20 12 46p-1 03p, 2 40p-3 48p, 5 35p-6 15p
22. 4 18a-4 22a
23. 10 39a-11 03a, 12 22p-12 27p, 1 25p-2 22p, 3 00p-9 35p, 11 30p to past midnight
24. Continued to 12 15a
25. 3 45a-5 05a, 11 17p to past midnight
26. Continued to 12 37a, 1 35a-2 17a, 5 05a-5 25a
28. 1 26a-1 35a, 8 35a-12 06p

HOURLY PRECIPITATION



July was wet and cool Heavy rains on the 4th, 5th, 8th, and 23rd caused local flooding The most severe thunderstorms of the month occurred on the morning of the 8th Associated high winds resulted in widespread property damage and power and telephone outages One child was killed and another critically injured when high winds toppled a chimney Injuries to 19 others were reported throughout the Chicago area, mostly due to flying glass Many windows were shattered in the downtown area A seiche was reported along the Chicago shore of Lake Michigan Heavy fog during the morning of the 25th slowed traffic considerably. New daily minimum temperature records were established on the 27th, 29th, 30th and 31st. Only 4 days had readings in the 90's compared with a normal frequency of 3 days

Prevailing wind directions are indicated in tens of degrees from true North For example 09 is East, 18 is South, 27 is West and 36 is North.

I hereby certify that this is an official U S Government publication.

John J Sullivan, Meteorologist
National Weather Service
1819 W Pershing Rd
Chicago Ill 60609

This example "superimposes" the results of Examples 5, 6 and 7.

From Eq. (28), $H = H_o + H_v + H_p = (100 - 18) + 21 + 150$

$H = 253$ meters; say, $H = 250$ meters.

4.0 Concentration Distributions

4.1 The Differential Equation and its Solution. Consider the problem of the flow of a gas or smoke from a chimney of actual height, H_o, and effective height, H, as indicated in Fig. 7. In the following analysis we will suppose that the flow is emitted at a constant rate, not from the chimney, but from a fictitious point source located at an elevation, $z = H$, above the ground and a negligible distance upwind from the chimney. For mathematical reasons, an image source of the same strength is located at $z = -H$. A wind, $u = u(z)$, flows in the positive x-direction; y is the crosswind axis and z is the vertical direction.

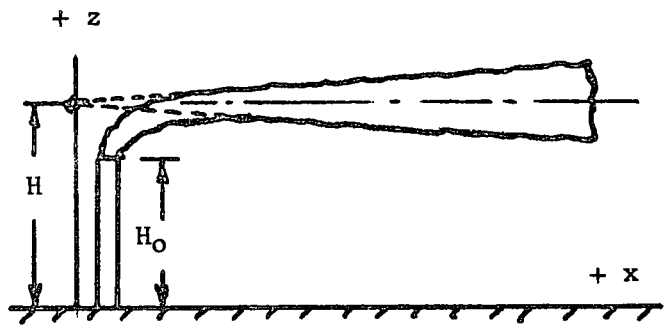


Fig. 7

The volumetric flow rate from the chimney is Q_o (met^3/sec). The stack effluent contains a gas constituent and particulate matter, for example, sulphur dioxide and dust, with concentrations C_o (mg/met^3) at the source. The question is: what is the concentration, C, of these pollutants at any point, (x,y,z), and especially what is their concentration along (x,0,0), i.e., along the ground surface of the downwind axis from the chimney?

It is not difficult to obtain the following differential equation for this physical situation,

$$u \frac{\partial C}{\partial x} = \frac{\partial}{\partial y}\left(K_y \frac{\partial C}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z \frac{\partial C}{\partial z}\right) \qquad (30)$$

In this analysis of the problem, Sutton (8,9) used the power-law expression of Eq. (14) for the vertical velocity distribution, $u = u(z)$. The quantities, K_y and K_z, are eddy diffusion coefficients whose values are closely related to the various parameters of the wind structure. For these, Sutton employed equations of the form

$$\frac{K}{K_1} = \left(\frac{z}{z_1}\right)^n \qquad (31)$$

Furthermore, he was able to establish a relationship between the exponent, m, in the wind profile equation and the exponent, n, in the relationships for the eddy diffusion, viz.,

$$m = \frac{n}{2-n} \tag{32}$$

The quantity, n, is frequently termed the "turbulence index."

With these relationships and the appropriate boundary conditions, Sutton (9) obtained the following solution to Eq. (30),

$$C = \frac{Q_o C_o}{\pi C_y C_z u x^{2-n}} e^{-\frac{y^2}{C_y^2 x^{2-n}}} \left[e^{-\frac{(z-H)^2}{C_z^2 x^{2-n}}} + e^{-\frac{(z+H)^2}{C_z^2 x^{2-n}}} \right] \tag{33}$$

in which C_y and C_z are generalized diffusion coefficients. The magnitudes of C_y, C_z and n depend very much on the temperature gradient, the wind profile, the degree of turbulence and other factors. These quantities have been studied by numerous researchers including Gosline, Falk and Helmer; some of their results are reported in Strauss (7). Typical values of these quantities, presented here only for illustration, are given below. Since C_y and C_z are dimensional quantities, the numbers in the table refer to the MKS system of units. Generally we can take $C_y = C_z$ without introducing appreciable error.

Atmospheric Condition	n	C_y and C_z
Large lapse	0.20	0.37
Zero or small lapse	0.25	0.21
Moderate inversion	0.33	0.12
Large inversion	0.50	0.09

4.2 Concentrations at the Ground Level. Utilizing Eq. (33), it is possible to determine concentrations at ground-level downwind from the stack. To do so, we substitute y = 0 and z = 0 in Eq. (33). The result is

$$C = \frac{2 Q_o C_o}{\pi C_y C_z u x^{2-n}} e^{-\frac{H^2}{C_z^2 x^{2-n}}} \tag{34}$$

Differentiating this last equation with respect to x and setting the result equal to zero to determine a maximum, we find that at,

$$x_o = \left(\frac{H}{C_z} \right)^{2/(2-n)} \tag{35}$$

the concentration of a pollutant has a maximum value and this maximum is,

$$C_{max} = \frac{2 Q_o C_o}{\pi e u H^2} \frac{C_z}{C_y} \tag{36}$$

This answer reflects the interesting feature that the maximum concentration at the ground is inversely proportional to the wind velocity and also inversely proportional to the square of the effective height of emission. The latter result emphasizes the need to make H as large as possible.

Example 9. A gas flow is emitted from a source at an effective height, H = 250 meters. The volumetric flow rate is Q_o = 144 met^3/sec and the concentration of sulphur dioxide is C_o = 115 x 10^3 mg/met^3, based on ambient pressure and temperature. There is a moderate inversion of the temperature, dT/dz = - 0.0060 ^oC/met. The wind velocity is u = 10 met/sec.

(a) Where will the concentration of SO_2 at ground level reach a maximum and
(b) what will be the magnitude of this concentration?

From the above brief table, we select C_y and C_z = 0.12; and, n = 0.33.

(a) From Eq. (35), $x_o = \left(\frac{250}{0.12}\right)^{2/(2-0.33)}$ = 10,700 met = 10.7 km

(b) From Eq. (36), $C_{max} = \frac{2\,(144)(115 \times 10^3)}{\pi\, e\, (10.0)(250)^2} \frac{0.12}{0.12}$ = 6.2 mg/met^3

As our final topic we consider the problem in which a chimney effluent contains particulate matter which has a non-negligible fall velocity. In this instance, the particles are transported and dispersed through the atmosphere by essentially the same mechanics described above. Simultaneously these particles are also falling due to their weight. Again the question is: where will the particles begin to reach the ground and in what concentrations? Strauss (7) presents a summary of the work by Bosanquet et al on this subject. The main result of Bosanquet's analysis is,

$$M = \frac{W b \times 10^6}{H^2} \cdot F\left(\frac{f}{u}, \frac{x}{H}\right) \qquad (37)$$

in which,

M = rate of particle deposition, tons/mile^2 year
W = rate of particle emission, gr/sec
b = fraction of the time the wind is within the 45° sector under consideration
f = fall velocity of particle, units of u
u = wind velocity

The fall velocity, f, can be determined from Stokes law or from direct experiments. The function, F(f/u, x/H) in Eq. (37) is presented in Fig. 8.

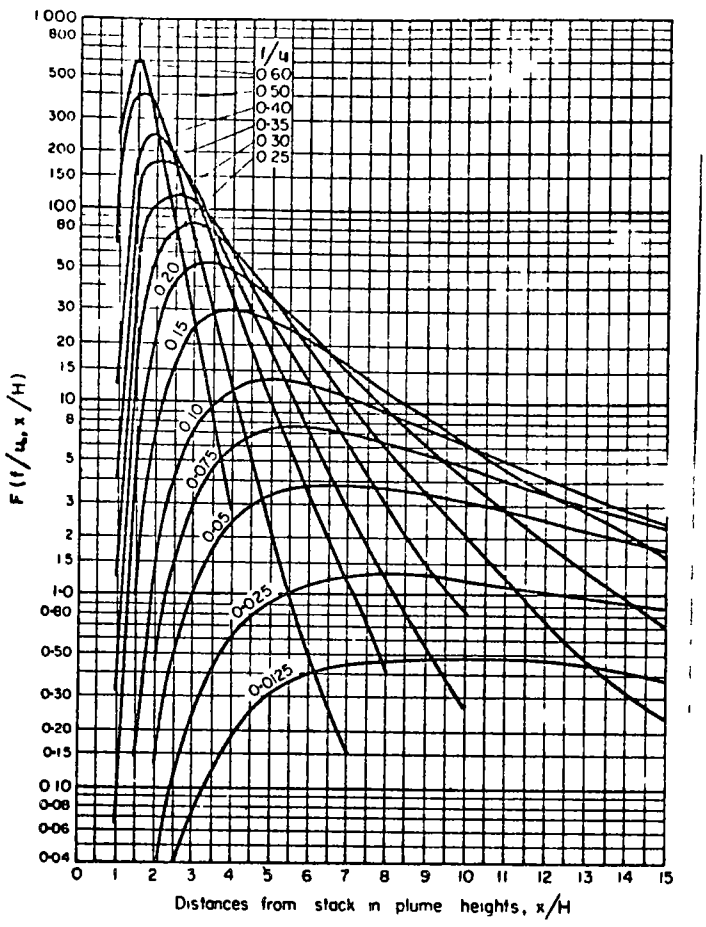


Fig. 8

Example 10. Smoke is emitted from a chimney at a volumetric rate, Q_o = 144 met^3/sec. The concentration of dust particles in the chimney smoke is C_o = 1.65 x 10^3 mg/met^3. The mass density of a particle is ρ_p = 2.0 gr/cm^3 and a representative diameter is D = 50 μ (1 μ = 10^{-4}cm). At 25 °C, the viscosity of air is η = 1.8 x 10^{-4} poise. The effective height of smoke emission is H = 820 feet (250) meters). The wind velocity is u = 10 met/sec and the wind blows in nearly the same direction about 40% of the time (b = 0.4).

(a) Where will the concentration of dust particles at ground level reach a maximum and (b) what will be the magnitude of this concentration?

(a) From Stokes law,

$$f = \frac{g\,(\rho_p - \rho_o)\,D^2}{18\,\eta} \qquad (38)$$

in which ρ_o and η are respectively the density and viscosity of ambient air. Substituting into Eq. (38), using CGS units,

$$f = \frac{980(2.0 - 1.2 \times 10^{-3})(5 \times 10^{-3})^2}{18\ (1.8 \times 10^{-4})} = 15.0 \text{ cm/sec} = 0.15 \text{ met/sec}$$

So, $f/u = 0.15/10 = 0.015$

From Fig. 8, the maximum value of the function F occurs, for $f/u = 0.015$, at about $x/H = 10$. This corresponds to $x = 2{,}500$ met = 2.5 km downwind from the chimney.

(b) From Fig. 8, for $f/u = 0.015$, $F_{max} = 0.60$

Also, $W = Q_o C_o = (144)(1.650) = 237$ gr/sec

Substituting into Eq. (37),

$$M = \frac{(237)\ (0.40) \times 10^6}{(820)^2}\ (0.60) = 86\ \frac{\text{tons}}{\text{mi}^2\ \text{yr}}$$

or, $M = 86\ (3.27) = 280\ \frac{\text{gr}}{100\ \text{met}^2\ \text{month}}$

5.0 References

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ABSORPTION TREATMENT METHODS IN AIR POLLUTION CONTROL

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Presented at a Course on

ATMOSPHERIC POLLUTION CONTROL

National Autonomous University of Mexico

November 20-December 4, 1971

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1.0 Introduction

There are numerous methods to remove pollutants from industrial waste gases before these gases are released to the atmosphere. To name a few such methods: gravity and momentum separation, filtration, centrifugal separation, electrostatic precipitation, and absorption by liquids.

This latter scheme, absorption by liquids, is considered in the following pages. Two main topics are presented:

- Absorption in packed towers and tanks
- Liquid scrubbing

Regarding the second topic, we examine three very important types of equipment: spray towers, centrifugal spray scrubbers, and venturi scrubbers.

Included in the following are five numerical examples to illustrate methods of computation. In addition, eight references are identified for information to those who wish to probe deeper into the subject.

Finally, in the present work numerous references have been made to the comprehensive book by Strauss (7)* on the topic of cleaning of industrial gases.

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*Numerals shown in parentheses identify publications listed in Section 4: References.

2.0 Absorption in Packed Towers and Tanks

2.1 Solute Removal in a Counter-Current Operation. Let us suppose that we have a gas which contains a large amount of a solute, for example, carbon dioxide or hydrogen sulfide, and that we want to remove most of this solute from the gas before the gas is released to the atmosphere. One method to accomplish this is shown in Fig. 1. Here, a flue gas containing a large concentration of, for example, carbon dioxide, is introduced into the bottom of a tank through some kind of material or device to produce very small gas bubbles. A liquid, for example, water, flows through the tank which may consist of a series of cells as shown in the figure. The gas bubbles move in the upward direction and the water moves downward. In this "counter-current" mode of operation, the carbon dioxide is transferred from the "gas phase" to the "liquid phase" where it is dissolved or absorbed by the water.

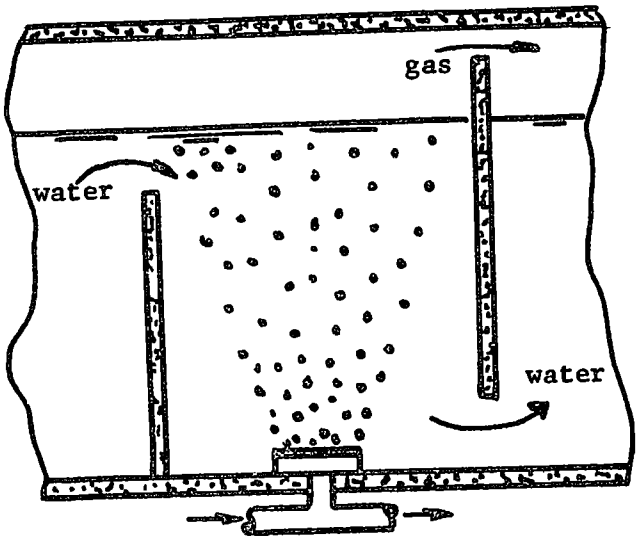


Fig. 1

After having passed through several such cells the water is delivered to an appropriate treatment process, if necessary, for removal of the carbon dioxide by chemical precipitation. The gas bubbles rise to the water surface at the top of the tank and the released gas, now low in carbon dioxide concentration, is discharged directly to the atmosphere or it might be collected for transfer to a chimney. In the scheme of Fig. 1, we would say that the liquid is the continuous phase and the gas the dispersed phase.

Another method to remove the carbon dioxide from a gas is illustrated in Fig. 2. In this instance, gas is introduced at the bottom of a tower and water at the top. The tower is packed with some sort of material which will cause the falling water to break into small drops and to create efficient mixing between the rising gas and the falling water. Once again we have a "counter-current" flow, only this time the gas is the continuous phase and the water the dispersed phase. The water and gas effluents are disposed of as mentioned before.

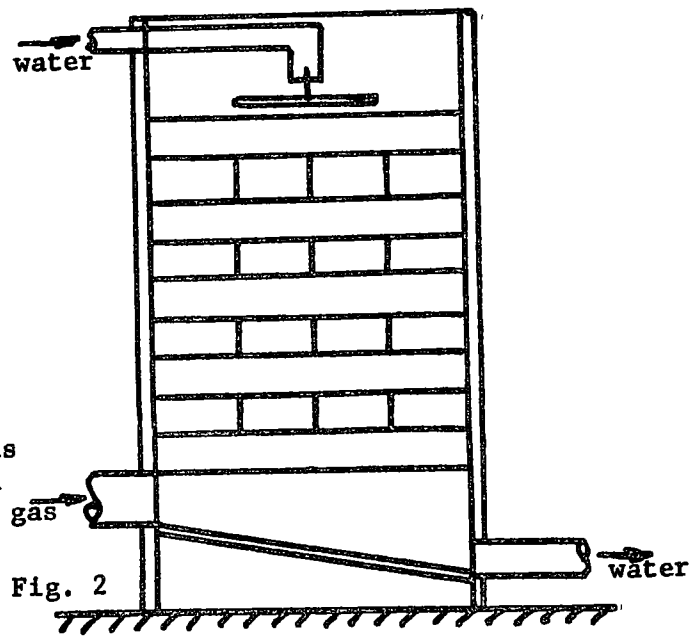


Fig. 2

These two schemes have several features in common:

- There is a transfer of a solute from a gas phase to a liquid phase and subsequently the solute is dissolved by the liquid. This phenomenon is known as absorption. The reverse process, desorption (or "stripping"), occurs when there is transfer of a dissolved gas, i.e., the solute, from a liquid phase to a gas phase.

- Both schemes are "counter-current" flows. "Co-current" operation could be utilized but this method of operation is not used to a great extent usually because of complication in design.

- There is either a very large number of small gas bubbles (Fig. 1) or a very large number of small liquid drops (Fig. 2). As we shall see, the rate of mass transfer is directly proportional to the total surface area of interface between the two phases. Although we do not know, in most cases, the amount of transfer area per unit volume of tank or tower we do know that this area should be as large as possible.

2.2 The Two Film Theory. We now cut into half one of the bubbles of Fig. 1 or one of the drops of Fig. 2. For either, a small portion of the gas-liquid interface is shown, with great magnification, in Fig. 3. From this figure, perhaps the concept of the "two-film theory" is clear. It is suppposed that on both sides of the actual interface there are very thin films, one gas and one liquid. In the main region of the gas some distance from the interface, the partial pressure of the solute is P. Likewise, in the main region of the liquid, the concentration of the solute is C. Because of the pressure gradient in the gas film and the concentration gradient in the liquid film, molecules of the solute will be transported by molecular diffusion through the gas film, the interface, and the liquid film. By this means the solute is transferred from the gas phase to the liquid phase. It is assumed that at the interface P_i and C_i are in equilibrium.

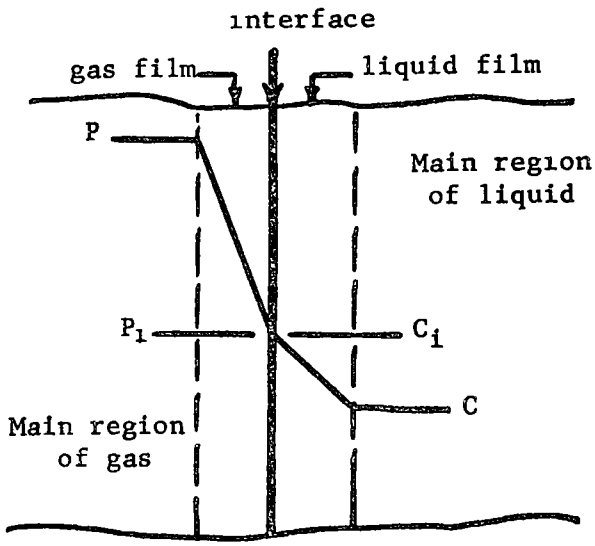


Fig. 3

The rate of transfer of the solute from the gas phase to the liquid phase may now be written,

$$N = k_G (P - P_i) = k_L (C_i - C) \qquad (1)$$

in which, N = mass of solute transferred per second per unit transfer area
k_G = gas film mass transfer coefficient
k_L = liquid film mass transfer coefficient

Only in rare cases are we able to determine the values of P_i and C_i and without this knowledge it is impossible to compute the values of these mass transfer coefficients. So instead of Eq. (1) we write,

$$N = K_G (P - P^*) = K_L (C^* - C) \qquad (2)$$

where, K_G = overall gas film mass transfer coefficient
K_L = overall liquid film mass transfer coefficient
P^* = partial pressure of the solute that would be in equilibrium with the concentration in the main region of the liquid, C

C^* = concentration of the solute that would be in equilibrium with the partial pressure in the main region of the gas, P

A graphical interpretation of the preceeding is shown in Fig. 4 in which P is plotted against C. The solid curve is known as the "equilibrium line." If the equilibrium line is a straight line, then we have the linear relationship that,

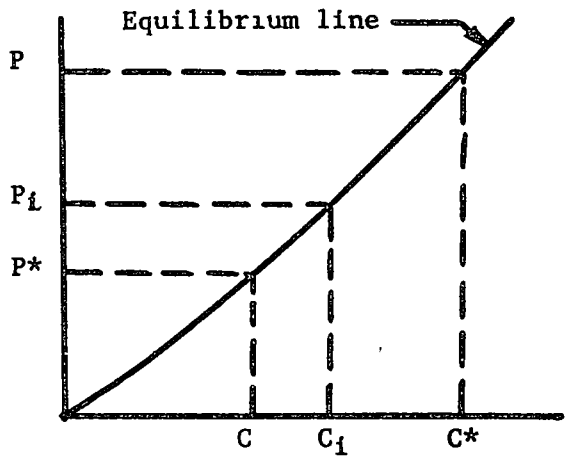


Fig. 4

$$P^* = HC \qquad \text{and} \qquad P = HC^* \qquad (3)$$

in which H is Henry's constant and is the slope of the equilibrium line. From Eqs. (1), (2), and (3) we can obtain,

$$\frac{1}{K_G} = \frac{1}{k_G} + \frac{H}{k_L} \qquad (4)$$

$$\frac{1}{K_L} = \frac{1}{k_L} + \frac{1}{H k_G} \qquad (5)$$

$$\frac{1}{K_G} = \frac{H}{K_L} \qquad (6)$$

If H is relatively small, as in the case of very soluble gases, then Eq. (4) becomes $k_G = K_G$. In this instance, the gas film controls the rate of mass transfer; the liquid film offers negligible resistance. Alternatively, if H is quite large, i.e., the gas is relatively insoluble, then Eq. (5) reduces to $k_L = K_L$. In this case, the gas film exerts very little resistance and it is the liquid film that controls the mass transfer rate.

2.3 Mass Balance and Mass Transfer. A definition sketch for the following analysis is shown in Fig. 5. We have a tower or tank of height, Z, and cross sectional area, A_o. Gas is introduced at the bottom of the tower, liquid at the top. The other quantities in Fig. 5 have the following definitions,

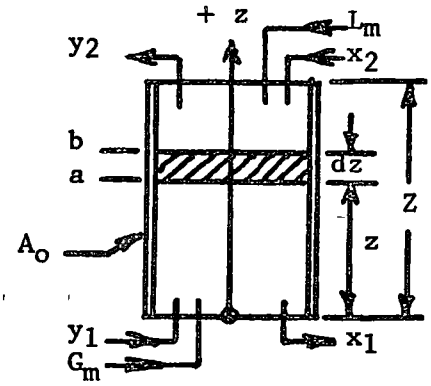


Fig. 5

G_m = gas flow rate, mols of gas/sec met^2
L_m = liquid flow rate, mols of liquid/sec met^2
y = kg-mols of solute in gas/mol of gas
x = kg-mols of solute in liquid/mol of liquid

First we carry out a mass balance of the solute in the elemental volume, $A_o dz$. The amount of solute which enters the volume per second in the gas (i.e., the amount crossing plane-a in the upward direction) is,

$$G_m y A_o \tag{7}$$

and hence the amount leaving per second in the gas is,

$$G_m y A_o + \frac{\partial}{\partial z}\left(G_m y A_o\right) dz \tag{8}$$

Likewise, the amount of solute entering the elemental volume per second in the liquid (i.e., the amount crossing plane-b in the downward direction) is,

$$L_m x A_o \tag{9}$$

and so the amount leaving per second in the liquid is,

$$L_m x A_o + \frac{\partial}{\partial z}\left(L_m x A_o\right)(-dz) \tag{10}$$

Since there is no accumulation of solute in the elemental volume, i.e., the phenomenon is "steady state," the total amount of solute entering per second is equal to the total amount leaving. So, equating the sum of Eqs. (7) and (9) to the sum of Eqs. (8) and (10) we get,

$$G_m \frac{\partial y}{\partial z} = L_m \frac{\partial x}{\partial z} \tag{11}$$

Integrating, with the boundary conditions that $y = y_1$ when $x = x_1$ and $y = y_2$ when $x = x_2$,

$$y = y_1 + \frac{L_m}{G_m}(x - x_1) \tag{12}$$

and

$$y_2 = y_1 + \frac{L_m}{G_m}(x_2 - x_1) \tag{13}$$

A plot of Eqs. (12) and (13) is presented in Fig. 6. This line is termed the "operating line."

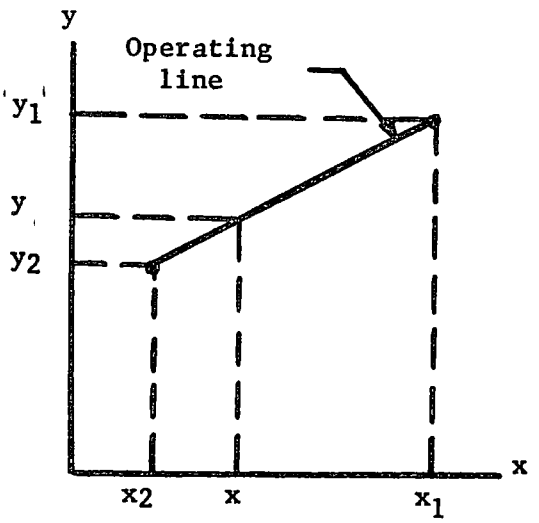


Fig. 6

Next we examine the question of mass transfer of the solute within the elemental volume of Fig. 5. Clearly, the amount of solute entering the volume per second in the gas minus the amount of solute leaving the element per second in the gas must be equal to the amount transferred per second from the gas to the liquid. Accordingly, from Eqs. (7), (8), and (2),

$$[G_m y A_o] - \left[G_m y A_o + \frac{\partial}{\partial z}(G_m y A_o) dz\right] = K_c (P - P^*)(a) A_o dz \tag{14}$$

in which "a" is the transfer area per unit volume of packed tower. From Eq. (14) we obtain,

$$G_m \frac{dy}{dz} = K_c a (P - P^*) \tag{15}$$

Now be definition,

$$P = y P_T \quad \text{and} \quad P^* = y^* P_T \tag{16}$$

in which P_T is the total pressure, in atmospheres. So Eq. (15) becomes,

$$G_m \frac{dy}{dz} = K_c a P_T (y - y^*) \tag{17}$$

In the same way it is easy to show that,

$$L_m \frac{dx}{dz} = K_L a C_T (x^* - x) \tag{18}$$

in which C_T is the total molar concentration.

We are now able to integrate Eq. (17). Recalling that Z is the height of the tower, we get,

$$Z = \frac{G_m}{K_G a P_T} \int_{y_2}^{y_1} \frac{dy}{y - y^*} \tag{19}$$

and this can be re-written,

$$Z = H_{OG} N_{OG} \tag{20}$$

where H_{OG} and N_{OG} have the following definitions,

$$H_{OG} = \frac{G_m}{K_G a P_T} = \text{height of a transfer unit based on the overall gas film mass transfer coefficient} \tag{21}$$

$$N_{OG} = \int_{y_2}^{y_1} \frac{dy}{y - y^*} = \text{number of transfer units based on the overall gas film mass transfer coefficient} \tag{22}$$

In the same manner, we can extend Eq. (18) to obtain,

$$Z = \frac{L_m}{K_L a C_T} \int_{x_2}^{x_1} \frac{dx}{x^* - x} \tag{23}$$

with obvious definitions of H_{OL} and N_{OL} based on the overall liquid film mass transfer coefficient.

In order to integrate Eq. (19) we proceed as follows. If the equilibrium line is linear, i.e., if Henry's law applies, then from Eqs. (3) and (16) we have,

$$y^* = \frac{P^*}{P_T} = \frac{H}{P_T} x = mx \; ; \quad y = mx^* \tag{24}$$

with the understanding that the units of C and x are the same, viz., mols of solute/mol of liquid. Clearly, $m = H/P_T$.

From the equation of the operating line, Eq. (12), we have,

$$x = x_1 + \frac{G_m}{L_m} (y - y_1) \tag{25}$$

Substituting Eq. (25) into Eq. (24) and the result into the definition of N_{OG}, Eq. (22), the following integral is obtained,

$$N_{OG} = \int_{y_2}^{y_1} \frac{dy}{\left[y - m \left\{ x_1 + \frac{G_m}{L_m} (y - y_1) \right\} \right]} \tag{26}$$

This equation is not difficult to integrate. The result is,

$$N_{OG} = \frac{1}{1 - \frac{mG_m}{L_m}} \log_e \left[\left(1 - \frac{mG_m}{L_m}\right)\left(\frac{y_1 - mx_2}{y_2 - mx_2}\right) + \frac{mG_m}{L_m} \right] \quad (27)$$

An identical analysis for N_{OL} produces,

$$N_{OL} = \frac{1}{1 - \frac{L_m}{mG_m}} \log_e \left[\left(1 - \frac{L_m}{mG_m}\right)\left(\frac{x_2 - \frac{y_1}{m}}{x_1 - \frac{y_1}{m}}\right) + \frac{L_m}{mG_m} \right] \quad (28)$$

The function expressed by Eq. (27) is shown in Fig. 7, reproduced from Sherwood and Pigford (6). Finally, Fig. 8 is a graphical display of the topics covered so far.

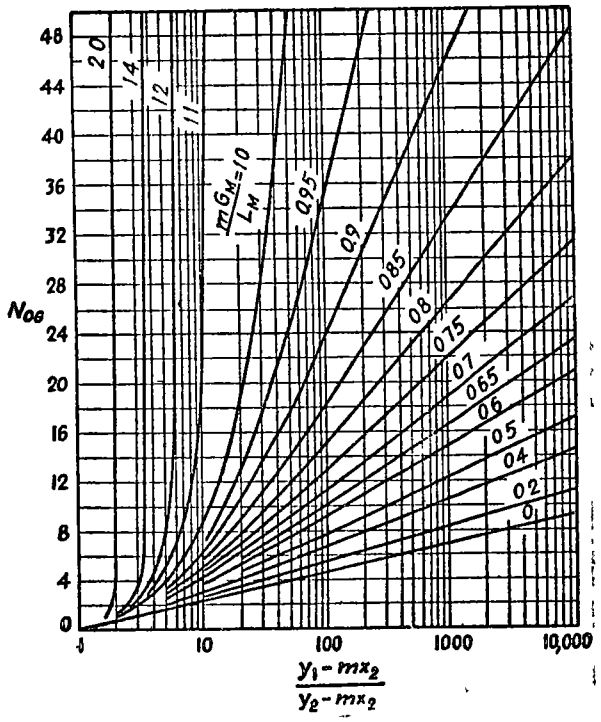


Fig. 7

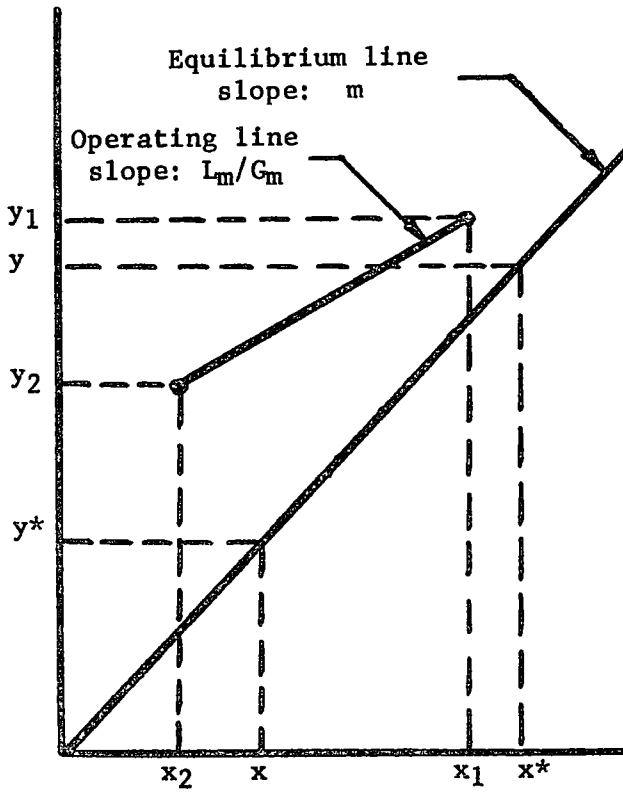


Fig. 8

2.4 Henry's Constant. The following Table 1 presents a list of Henry's constants for several gases that are slightly soluble in water. Values for numerous other gases are given in Perry (4).

Table 1. Values of Henry's Constants for Gases Slightly Soluble in Water. Reference: Rich (5).

$H \times 10^{-4}$, atm/mole fraction

T, °C	Air	CO_2	CO	C_2H_6	H_2	H_2S	CH_4	NO	N_2	O_2
0	4 32	0 0728	3 52	1 26	5 79	0 0268	2 24	1 69	5 29	2 55
10	5 49	0 104	4 42	1 89	6 36	0 0367	2 97	2 18	6 68	3 27
20	6 64	0 142	5 36	2 63	6 83	0 0483	3 76	2 64	8,04	4 01
30	7 71	0 186	6 20	3 42	7 29	0 0609	4 49	3 10	9 24	4 75
40	8 70	0 233	6 96	4 23	7 51	0 0745	5 20	3 52	10 4	5 35
50	9 46	0 283	7 61	5 00	7 65	0 0884	5 77	3 90	11 3	5 88
60	10 1	0 341	8 21	5 65	7 65	0 103	6 26	4 18	12 0	6 29
70	10 5		8 45	6 23	7 61	0 119	6 66	4 38	12 5	6 63
80	10 7		8 45	6 61	7 55	0 135	6 82	4 48	12 6	6 87
90	10 8		8.46	6 87	7 51	0 144	6 92	4 52	12 6	6 99
100	10 7		8 46	6 92	7 45	0 148	7 01	4 54	12 6	7 01

Example 1. The partial pressure of hydrogen sulfide in a flue gas is $P = 0.02$ atm when the total pressure of the gas is $P_T = 1.0$ atm. At 20°C, what would be the saturation concentration, x*, of H_2S in water?

From Table 1, $H \times 10^{-4} = 0.0483$, so $H = 483$

From Eq. (24), $$x^* = \frac{y}{m} = \frac{y}{H/P_T}$$

$$x^* = \frac{0.02}{483/1.0} = 41.5 \times 10^{-6} \ \frac{\text{mol of } H_2S}{\text{mol of water}}$$

$$x^* = 41.5 \times 10^{-6} \ \frac{34}{18} \ \frac{\text{gr } H_2S}{\text{gr water}} = 76 \ \frac{\text{mg } H_2S}{\text{liter water}}$$

2.5 Performance of Absorption Towers. When the equilibrium line is straight, i.e., when m is a constant, N_{OG} may be computed from Eq. (27) or determined from Fig. 7. When m is not constant, N_{OG} can be evaluated by a graphical integration of Eq. (19). In any event, the number of transfer units, N_{OG} or N_{OL}, is a quantity that is analytically determined by one means or another.

In contrast, the height of a transfer unit, H_{OG} or H_{OL}, is a quantity that must be evaluated from laboratory experiments or field measurements. The determination of the heights of transfer units has been the subject of lengthy study during the past. Sherwood and Pigford (6) present considerable information on this topic.

As Eq. (21) indicates, there is a direct relationship between the height of a transfer unit and the overall mass transfer coefficients. In fact, Eqs. (4), (5), and (6) may be put into the following form,

$$H_{OG} = H_G + \frac{m G_m}{L_m} H_L \tag{29}$$

$$H_{OL} = H_L + \frac{L_m}{m G_m} H_G \tag{30}$$

and

$$H_{OG} = \frac{m G_m}{L_m} H_{OL} \tag{31}$$

Some typical experimental results are shown in Figs. 9, 10, and 11. It is noted that values of H_{OG} and H_{OL} depend in general on the liquid loading, the gas loading, and the type of material used for the tower fill. The temperature is also important especially as it affects the viscosity of the liquid or gas.

Example 2. The exhaust gas from a combustion process contains carbon dioxide whose partial pressure, P = 0.09 atm. The volumetric flow rate, measured at P_T = 1.0 atm and 25°C, is Q_G = 0.5 met^3/sec. We desire to reduce the CO_2 concentration in the gas to 0.01 atm before releasing the gas to the atmosphere. We shall use a packed tower with 2-inch Rashig rings as the fill and carbon dioxide-free water as the counter-current absorbing liquid.

a.) Gas flow rate, M_G

$$M_G = \rho_G Q_G = (1.25 \text{ kg/met}^3)(0.5 \text{ met}^3/\text{sec}) = 0.63 \text{ kg/sec}$$

$$M_G = 0.63 \frac{(2.2)(3,600) \text{lb}}{\text{hr}} = 5,000 \text{ lb gas/hr}$$

b.) Liquid loading, L_m

From Fig. 10., select $L_m = 10,000 \frac{\text{lb water}}{\text{hr ft}^2}$

Note: For larger values of L_m, the value of H_L begins to rise sharply.

Then $L_m = \frac{10,000}{18\ (3,600)} = 0.155 \frac{\text{mols water}}{\text{sec ft}^2}$

c.) Height of a transfer unit, H_{OL}

From Fig. 10 , H_{OL} = 1.5 ft at 77°F (25°C)

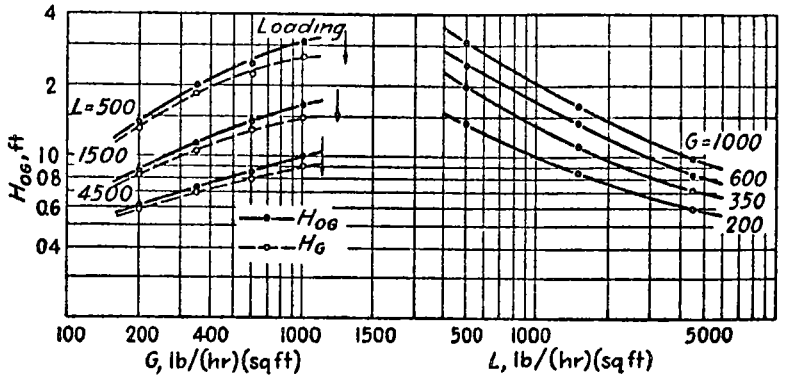


Fig. 9 Values of H T U for absorption of ammonia in water—1½-in ceramic Berl saddles (*Data of Fellinger*)

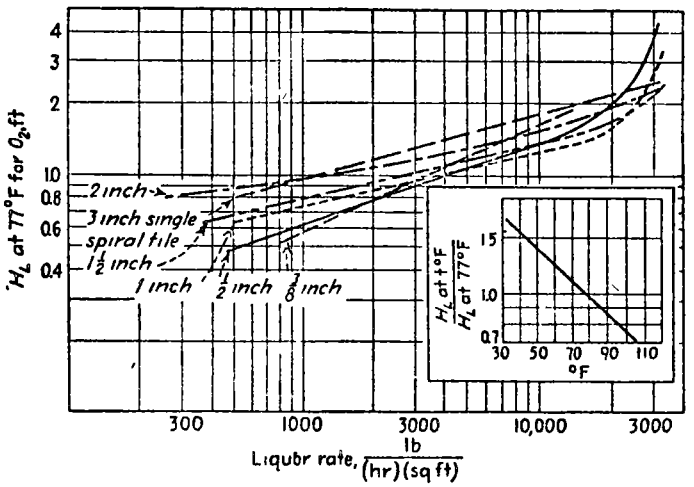


Fig. 10 Liquid-film resistance to mass transfer in towers packed with ceramic Raschig rings and tile (*Data of Sherwood and Holloway*) Desorption of oxygen from water at 77°F

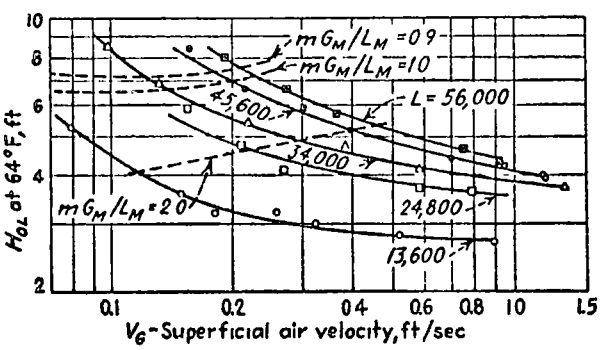


Fig. 11 Liquid-film resistance to mass transfer in packed columns at high liquid rates (*Data of Cooper, Christl, and Peery*) Absorption of CO_2 in H_2O using 2-in steel rings

d.) Gas loading, G_m

Select $G_m = 10.0 \frac{\text{lb gas}}{\text{hr ft}^2}$

Note: As we shall see, this selection will give us a reasonable value of quantity, $m G_m/L_m$

Then $G_m = \frac{10}{(30)(3,600)} = 0.0000925 \frac{\text{mol gas}}{\text{sec ft}^2}$

e.) Slope of equilibrium line, m

From Table 1, at 25°C for carbon dioxide-water system

$H \times 10^{-4} = 0.164; \quad H = 1640$

and $m = H/P_T = 1640/1.0 = 1640$

f.) Tower cross sectional area and flow rates

Now $M_G = 5,000$ lb gas/hr

With $G_m = 10.0$ lb gas/hr ft^2

then $A = \frac{M_G}{G_m} = \frac{5,000}{10} = 500$ ft^2

Using square cross section, $B = \sqrt{A} = \sqrt{500} = 22.3$ ft

So $M_L = AL_m = (500)(10,000) = 5,000,000 \frac{\text{lb liquid}}{\text{hr}}$

or $Q_L = \frac{5,000,000}{(3,600)(62.4)} = 22.2 \frac{\text{ft}^3}{\text{sec}}$

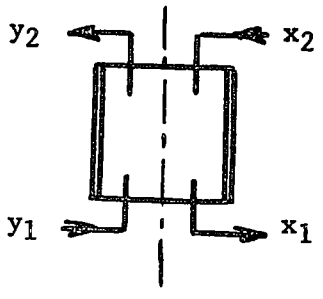
g.) Influent and effluent concentrations

Gas: inlet, $y_1 = 0.09 \frac{\text{mol } CO_2}{\text{mol gas}}$

outlet, $y_2 = 0.01$

Liquid: inlet, $x_2 = 0.000 \frac{\text{mol } CO_2}{\text{mol liquid}}$

outlet, from Eq. (25)



$$x_1 = x_2 + \frac{G_m}{L_m}(y_1 - y_2) = 0 + \frac{0.0000925}{0.155}(0.09 - 0.01)$$

$$x_1 = 48.0 \times 10^{-6} \frac{\text{mol } CO_2}{\text{mol water}} = 119 \frac{\text{mg } CO_2}{\text{lit water}}$$

h.) Number of transfer units, N_{OG}

Now, $$\frac{y_1 - mx_2}{y_2 - mx_2} = \frac{0.09 - 0}{0.01 - 0} = 9.0$$

and $$\frac{mG_m}{L_m} = \frac{(1640)(0.0000925)}{(0.155)} = 0.98$$

From Fig. 7, $N_{OG} = 7.0$

i.) Height of tower, Z

From Eq. (31), and part (c.) above

$$H_{OG} = \frac{mG_m}{L_m} H_{OL} = (0.98)(1.5) = 1.5 \text{ ft}$$

$$Z = H_{OG} N_{OG} = 1.5 (7.0) = 10.5 \text{ ft}$$

Note: The tower dimensions and water flow rates are seen to be excessive in this example. This is because water is used as the absorbing liquid. Other process methods would be preferred in practice; Strauss (7) discusses some of these. The above example is presented as an illustration of the method of computation.

2.6 Absorption Tanks. Another device for the absorption of a gas by a liquid is the absorption tank. In this instance gas is introduced at the bottom of a tank containing an absorbing liquid. The gas passes through some kind of a medium at the bottom of the tank to produce small gas bubbles.

However, better performance will be achieved if the gas is fed into the impeller of a mixing turbine as shown in Fig. 12 . The shearing stresses created by the turbine blades produce very small gas bubbles and this increases the area for mass transfer.

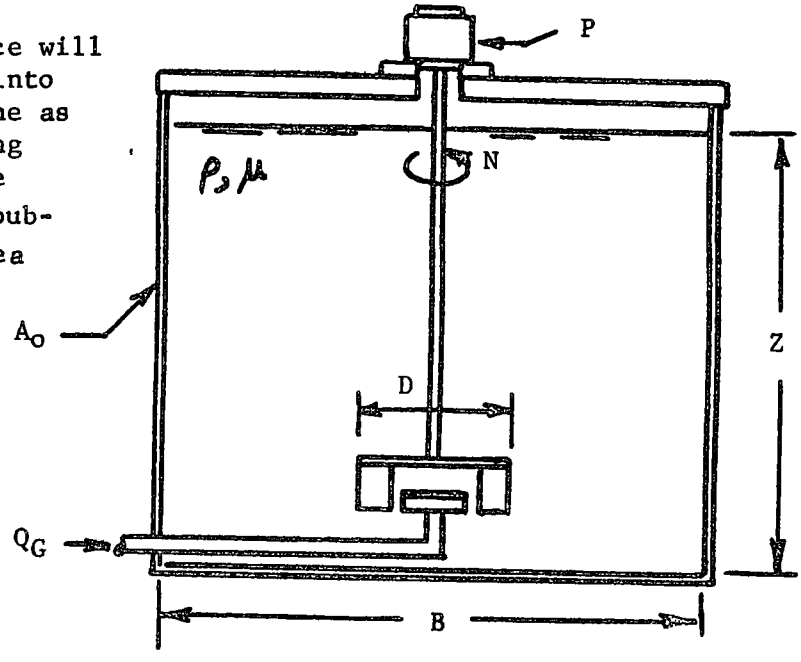


Fig. 12

Coulson and Richardson (1) report the results of the experiments by Cooper et al on the absorption of oxygen from air in an aqueous solution of sodium sulfite. These experiments found a good correlation, shown in Fig. 13, between the quantity $K_G\,a/V_S^{0.67}$ and the power supplied to the turbine per unit volume of liquid in the tank. The quantity V_S is the superficial gas velocity defined as $V_S = Q_G/A_o$.

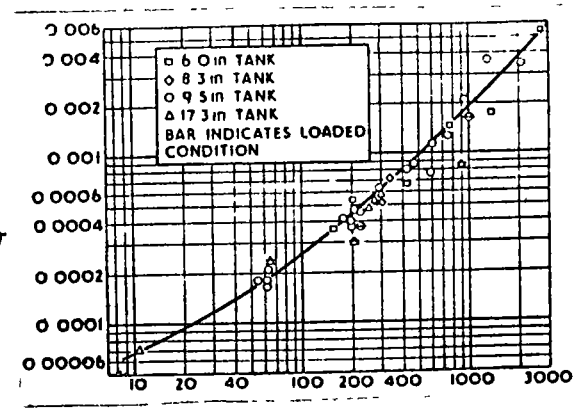


Fig. 13

Example 3. The power needed to rotate a turbine of diameter D at a speed N in a liquid of density ρ can be written

$$P = K_T \rho N^3 D^5 \qquad (32)$$

in which K_T is a function of the Reynolds number, $Re = \rho ND^2/\mu$. For large Re, K_T = constant.

Suppose, $N = 120$ rev/min $= 2.0$ rev/sec; $D = 3.0$ ft
$\rho = 1.94$ slugs/ft^3, $K_T = 5.0$

Then, $P = (5.0)(1.94)(2.0)^3(3.0)^5$

$P = 18{,}800$ ft-lb/sec

$P = \frac{18{,}800}{550} = 34.3$ HP

Taking $B = 4D$ and $Z = B$

Then $B = 4(3) = 12$ ft; $Z = 12$ ft

Tank volume (square cross section), $V = (12 \times 12)\,12$

$V = 1{,}728$ ft^3

Power $= 18{,}800 \frac{\text{ft-lb}}{\text{sec}} = 1{,}130{,}000 \frac{\text{ft-lb}}{\text{min}}$

Power per unit volume $= \frac{1{,}130{,}000}{1{,}728} = 650 \frac{\text{ft-lb}}{\text{min ft}^3}$

From Fig. 13, $K_Ga/V_S^{0.67} = 0.0012$

But V_S (ft/hr) $= Q_G/A_o = Q_G/B^2$

with $Q_G = 0.5$ met^3/sec $= 17.6$ ft^3/sec

$Q_G = 63{,}000$ ft^3/hr

$V_s = 63{,}000/144 = 440$; $V_s^{0.67} = 58.0$

And so $K_G a = 0.0012(58.0) = 0.070$ lb mols/hr ft^3 atm

3.0 Liquid Scrubbing

3.1 Spray Towers. We have long known that rainfall is very effective in removing particulate matter from the atmosphere. So it is not surprising that numerous devices have been developed that utilize this same phenomenon for the scrubbing of pollutants from industrial gas wastes.

One of the simplest types of scrubbers is the spray tower. In this device, a gas stream is fed into the lower region of a tower and moves upward. Liquid drops, produced by spray nozzles at the top of the tower, fall through the rising gas and collect impurities as they descend. The liquid waste is then given appropriate treatment. Operating conditions in the spray tower must be such that the liquid droplets are not entrained by the rising gas; ordinarily the gas velocity is approximately 0.5 to 1.5 meters/second.

There are wide variations in the precise design of spray towers. Some designs feature rings of spray nozzles located at various heights around the periphery of the tower. Other types will have the spray nozzles at various heights along the tower axis. An example of a typical performance of a spray tower is shown in Fig. 14, taken from Strauss (7).

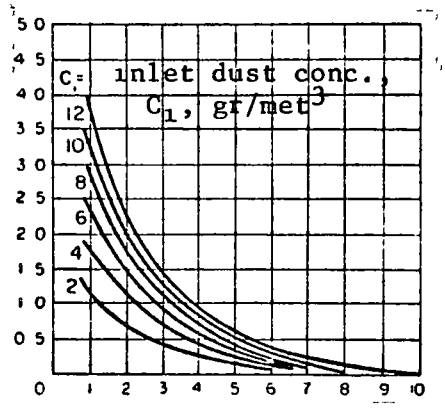


Fig. 14

Example 4. A waste gas whose volumetric flow rate, $Q_G = 3.0$ met^3/sec, has a dust concentration, $C_1 = 10.0$ gr/met^3. The gas is delivered to a spray tower of diameter 2.0 met.

a.) What is the velocity of the gas in the tower?

$$V_G = \frac{Q_G}{A_o} = \frac{3.0}{\frac{\pi}{4}(2.0)^2} = 0.95 \text{ met/sec}$$

b.) We desire a maximum dust concentration in the exit gas, $C_e = 0.25$ gr/met^3. What amount of spray water will be needed to accomplish this?

From Fig. 14, with $C_i = 10$ and $C_e = 0.25$, $Q_L = 6.5$ lit/met^3

So $Q_L = 6.5\ Q_G = 6.5\ (3.0) = 19.5$ lit/sec

3.2 Centrifugal Spray Scrubbers. Spray towers are quite efficient in removing dust particles whose diameters are relatively large, e.g., in the range 10 to 100 microns. However, for small diameters spray tower efficiencies are relatively low. Another device, the centrifugal spray scrubber, comes into good use when dust particles are in the range 1 to 10 microns.

There are two basic designs of centrifugal spray scrubbers. In one design, the influent gas is introducted tangentially at the bottom of the tower to create a swirling gas and the associated centrifugal force field. Inlet velocities are in the range 15 to 60 meters/second. Liquid is distributed from a series of nozzles located along the tower axis. In the other basic design the gas is given a spinning motion by a set of fixed vanes near the bottom of the tower. Usually a single spray nozzle near the top introduces the liquid.

Briefly, the rotational velocity of the spinning gas creates a gravitational field many times larger than that which exists in a spray tower. The result is that very small dust particles are captured by impact with the small water droplets.

3.3 Venturi Scrubbers. A very important device for gas absorption and particle removal is the venturi scrubber. A typical design (Pease-Anthony Venturi Scrubber) is shown in Fig. 15 .

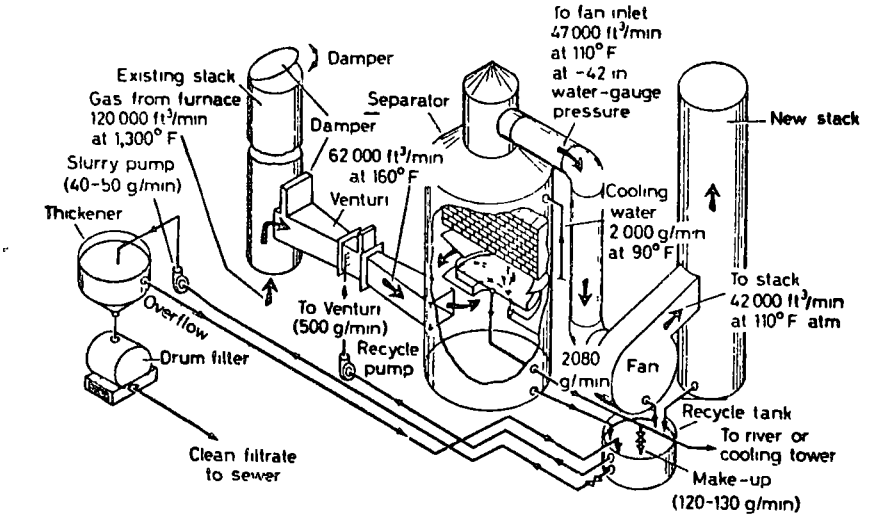


Fig. 15

This kind of scrubber is needed when particle diameters are sub-micron in size, e.g., in the range 0.1 to 1 microns. For such small particle sizes it is necessary to have a very large number of extremely small liquid droplets in order that inertial impact can occur between the two phases. Also very small diameters of liquid particles yield large values of transfer areas for gas absorption.

Liquid, usually water, is introduced into the device either through a distributor located at the throat of the venturi or through a co-axial pipe situated just upstream of the throat. The gas velocity at the throat is very large, usually around 100 to 125 meters/second. From the Bernoulli relationship, this high velocity causes a substantial reduction in pressure in the venturi throat. In turn, this region of low pressure disintegrates the entering liquid into extremely small sizes. The diffuser section of the venturi, where the gas is decelerating and the liquid drops are accelerating, is the region of particle collision and gas absorption. There is variation among the several commercial designs in the way in which the gas and liquid are subsequently separated.

Typically, the inlet gas to a venturi scrubber will have a fume concentration in the range 1 to 10 gr/ft^3 and exit concentrations are generally around 0.05 to 0.10 gr/ft^3. Accordingly, removal efficiencies are about 95% to 99%. A typical performance curve for this kind of device, taken from Strauss (7), is presented in Fig. 16.

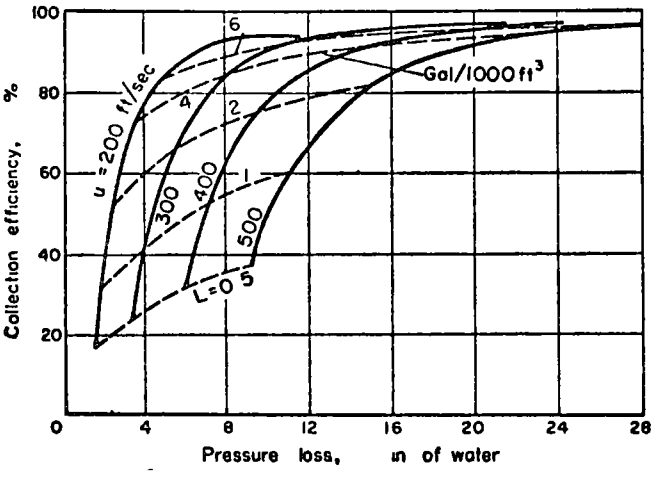


Fig. 16

Example 5. An effluent gas from an industrial plant contains a fume concentration, C_1 = 2.0 gr/ft^3. We intend to use a venturi scrubber to reduce the maximum concentration in the effluent gas to C_e = 0.10 gr/ft^3, i.e., collection efficiency, η = 95%. The volumetric flow rate of the gas is Q_G = 25 met^3/sec = 880 ft^3/sec (STP) = 53,000 ft^3/min (STP).

Using a throat velocity of V_G = 400 ft/sec, the cross sectional area of the throat is,

$$A = \frac{Q_G}{u} = \frac{880}{400} = 2.20 \text{ ft}^2$$

From Fig. 16, with u = 400 ft/sec and with η = 95% the pressure loss through the scrubber is about 20 inches of water and approximately 6.0 gallons of water will be needed per 1000 ft^3 of gas. So the volumetric flow rate of water will be

$$Q_L = 6.0\ (0.880) = 5.3 \text{ gal/sec} = 320 \text{ gal/min}$$

3.4 Other Scrubbing Devices. Three very important types of liquid scrubbing devices have been described above: spray towers, centrifugal scrubbers, and venturi scrubbers. However, there are numerous other types of devices for the purification of gases by liquid scrubbing. For example,

- Scrubbers with self-induced sprays
- Impingement plate scrubbers
- Disintegrator scrubbers
- Foam scrubbers
- Malti-wash scrubber
- Liquid vortex contactor

Descriptions and lists of references relating to these and other liquid scrubbing methods are given in Gilpin (2), Macgill, Holden and Ackley (3), and Strauss (7).

4.0 References

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CURSO SOBRE TRATAMIENTO DE AGUAS

RESIDUALES INDUSTRIALES Y MUNICIPALES

TEMA:

ANALISIS ESTADISTICO

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INGENIERIA UNAM

1971

ANALISIS ESTADISTICO

CONTENIDO:

1- INTRODUCCION. SERIES DE FRECUENCIAS.

2- CURVAS DE DENSIDAD.

3- MOMENTOS DE PRIMERO Y SEGUNDO ORDEN.

4- FUNCION NORMAL DE DENSIDAD.

5- AJUSTE A UNA DISTRIBUICION NORMAL.

6- AREAS BAJO LA CURVA NORMAL.

7- PRECISION Y EXACTITUD.

8- BIBLIOGRAFIA.

Agosto de 1971.

ANALISIS ESTADISTICO

1- INTRODUCCION. SERIES DE FRECUENCIAS.

La estadística puede considerarse como un método usado para recopilar, presentar y analizar datos numéricos.

La recopilación de datos puede obtenerse de las más diversas fuentes, por ejem. publicaciones, dependencias oficiales, oficinas de investigación, mediante mediciones directas, etc.

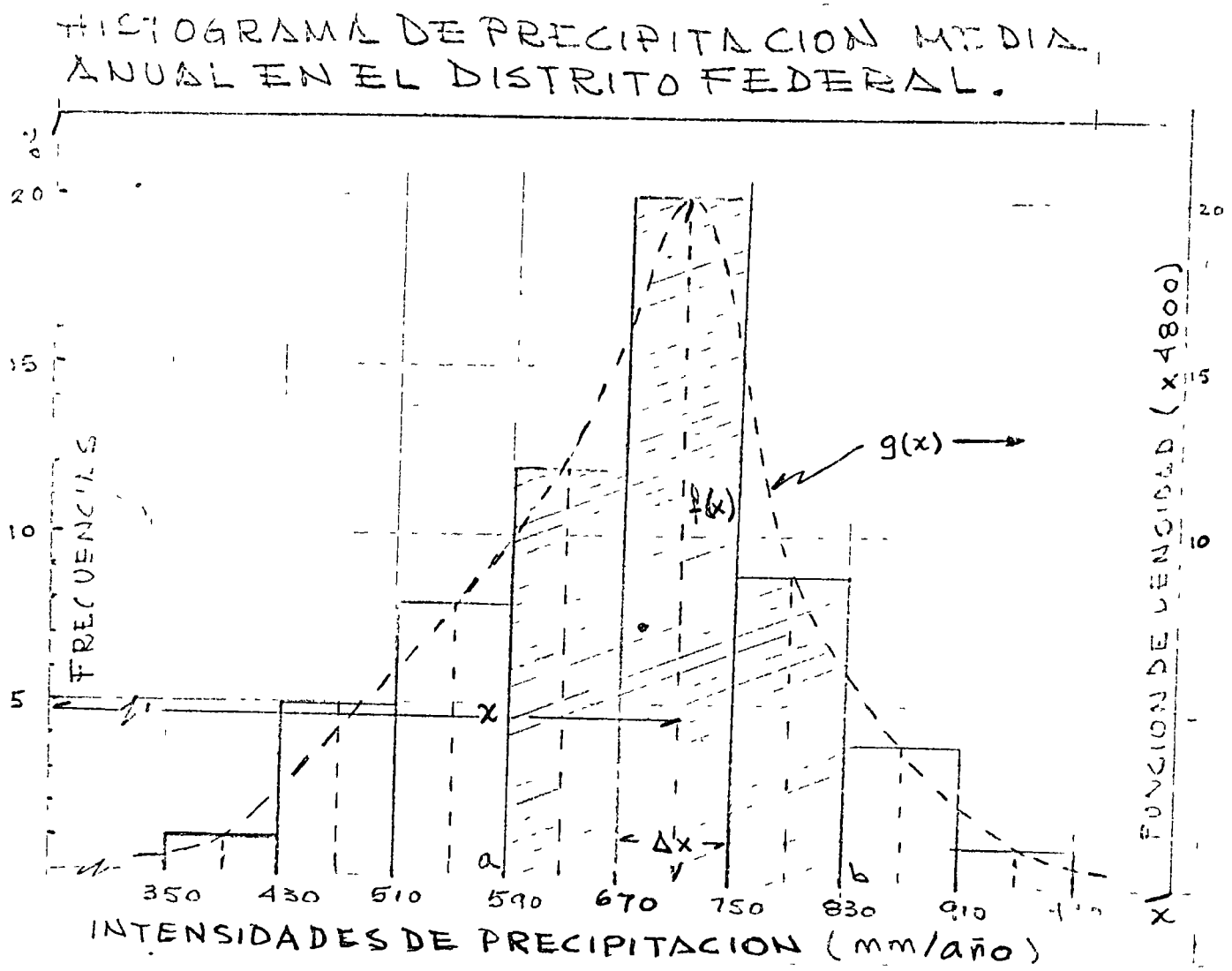
El análisis ~~auxiliar~~ de los datos se comienza a realizar, de hecho, al mismo tiempo que la recopilación, y termina con la presentación, ya que para clasificar los datos o exponerlos es necesario tener idea sobre su condición o categoría con el objeto de analizar los datos, se recurre frecuentemente a arreglos denominados series o distribuciones de frecuencias, en los cuales los datos aparecen clasificados en grupos, indicándose el número de datos correspondientes a cada grupo. Como ejemplo, en el cuadro siguiente se presentan los datos de precipitación pluvial media anual ocurridos en el Distrito Federal en los años de 1890 a 1949.

PRECIPITACION PLUVIAL MEDIA ANUAL EN EL DISTRITO FEDERAL
(AÑOS DE 1980 a 1949).

GRUPO O CLASE	FRECUENCIA OBSERVADA	PUNTO MEDIO DE CLASE
PRECIPITACION MEDIANA ANUAL (mm/año)	F (x)	X
350 - 430	1	390
430 - 510	5	470
510 - 590	8	550
590 - 670	12	630
670 - 750	20	710
750 - 830	9	790
830 - 910	4	870
910 - 990	1	950
SUMAS	60	

FUENTE: OBSERVATORIO METEOROLOGICO DE TACUBAYA.

En la representación gráfica de una serie de frecuencias las abcisas se usan para señalar los grupos, y las ordenadas para señalar las frecuencias. Si sobre del intervalo de cada grupo se construyen rectángulos de altura igual a las frecuencias correspondientes, resultará una gráfica denominada histograma, como el que se presenta enseguida para los datos del ejemplo anterior.



Observese que si por las ordenadas levantadas en los puntos medios de los intervalos de clase se traza una línea continua, esta resulta ser suave y con la forma de campana, para este caso particular

2.- CURVAS DE DENSIDAD

Supongamos que se desea wstimar la probabilidad de que en un año cualquiera lloviera en el Distrito Federal entre 590 y 830 mm, es obvio que tal estimación se obtendría dividiendo el área asciurada entre el área total del histograma, y en general, llamando X a un valor cualquiera de precipitación, y considerando que el intervalo de clase X es constante, la probabilidad de que la precipitación de un año cualquiera tenga un valor comprendido entre x-a y x-b estaría dada por:

$$P\left(a < x \leq b\right) = \frac{\sum_{x=a}^{b} f(x)\,\Delta x}{\sum f(x)\,\Delta x}$$

COMO:

$$\sum_{\forall x} f(x)\,\Delta x = \Delta x \sum_{\forall x} f(x) = \Delta x(n) = \text{constante}$$

donde n es el total de datos observados, resulta:

$$P(a \le x \le b) = \sum_{x=a}^{b} \left(\frac{f(x)}{n\Delta x}\right) \Delta x$$

Expresión en al que $f(x)/n\Delta x$ se denomina densidad de probabilidad, se representa como g (x), y es proporcional a f (x). Por otro lado de la fórmula anterior resulta evidente que la probabilidad total de todos los valores de x es igual a 1.

Supóngase ahora, que el intervalo de clase de una serie de frecuencias es muy pequeño y el número de términos es muy grande, entonces:

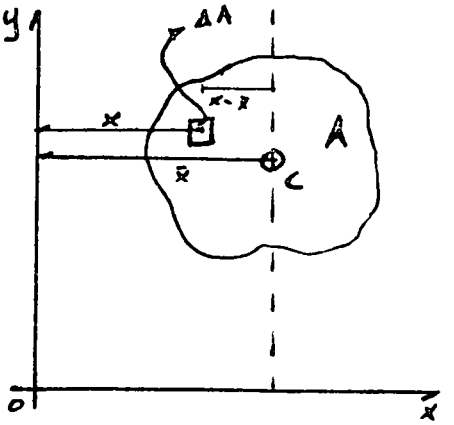
$$P(a \le x \le b) = \lim_{\Delta x \to 0} \sum_{x=a}^{b} g(x)\,\Delta x = \int_a^b g(x)\,dx$$

Y evidentemente la probabilidad total o área total bajo una curva de densidad es igual a 1.

El valor práctico del conocimiento de la función o curva de densidad g (x), radica en el hecho de que resulta mucho más fácil y rápido realizar una integración bajo una curva continua que efectuar una suma de un número muy grande de términos, el cálculo de cada uno de los cuales puede resultar extremadamente complicado. Por otro lado, el conocimiento de g (x) permite realizar extrapolaciones fuera de los valores observados de x; en el caso de nuestro ejem. podría ser de interés conocer la probabilidad de que en un año cualquiera lloviera 1200 mm ó menos, lo que sería imposible determinar directamente a partir de la serie de frecuencias.

3.- MOMENTOS DE PRIMERO Y SEGUNDO ORDEN

Supóngase una área A cualquiera, como la representada en la figura. Si se desea determinar la distancia $\bar{x}$ de un punto C al eje y tal que.



$$A\bar{x} = \sum_{A} x\,\Delta x$$

donde $\sum x\,\Delta A$ se denomina primer momento de A respecto al origen, es obvio que

$$\bar{x} = \frac{\sum_{A} x\,\Delta A}{A}$$

donde $\bar{x}$ es la distancia promedio de los elementos ΔA con respecto al eje y. Como, en general, en una serie de datos estos tienden a-gruparse en torno al promedio, se dice que este es una medida de tendencia central.

Si la fórmula anterior se aplica al área de una
a) Serie de frecuencias.

$$\Delta A = f(x)\,\Delta x \quad ; \quad \Delta x = \text{CONSTANTE}$$

$$\therefore A = \sum_{\forall x} f(x)\,\Delta x$$

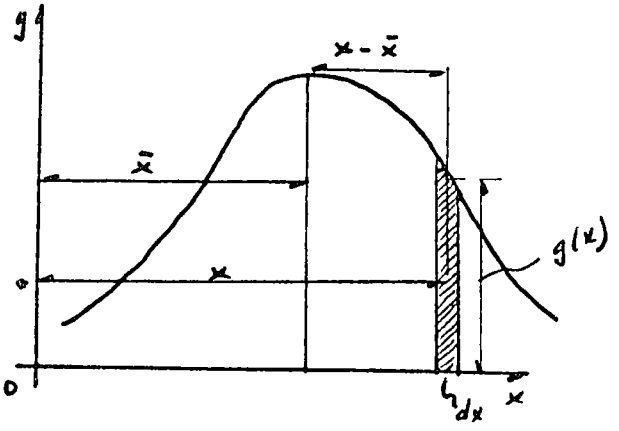
$$\therefore \bar{x} = \frac{\sum_{\forall x} x f(x)\,\Delta x}{\sum_{\forall x} f(x)\,\Delta x} = \frac{\Delta x \sum_{\forall x} x f(x)}{\Delta x \sum_{\forall x} f(x)}$$

$$\bar{x} = \frac{\sum_{\forall x} x f(x)}{n}$$

b) Función de densidad.

$$\Delta A = g(x)\,dx \quad ; \quad A = 1$$

$$\bar{x} = \int_A x\, g(x)\,dx$$



Supóngase ahora que cada elemento de area se multiplica por el cuadrado de su distancia al eje que pasa por el promedio, y se desea calcular una valor S^2 tal que.

$$A S^2 = \sum_A (x-\bar{x})^2\,\Delta A$$

Donde $\sum (x-\bar{x})^2 \Delta A$ se denomina segundo momento con respecto al promedio, es obvio que.

$$S^2 = \frac{\sum_A (x-\bar{x})^2 \Delta A}{A}$$

donde S^2, denominada variancia, es un indicador del alejamiento o dispersión de los elementos de area con respecto al promedio, ya que si los elementos de area están muy retirados del promedio, los factores $(x-\bar{x})^2$ serán grandes y el valor de S^2 también lo será, y viceversa.

Si la fórmula anterior se aplica a una
a) Serie de frecuencias.

$$S^2 = \frac{\sum_{\forall x} (x-\bar{x})^2 f(x)}{n}$$

b) Función de densidad

$$S^2 = \int_A (x-\bar{x})^2 g(x)\,dx$$

Si la raíz cuadrada de la varıancıa, se denomına desvıacıón estandar, y tıene las mısmas unıdades que x.

4.- FUNCION NORMAL DE DENSIDAD

Esta función de densidad, llamada comunmente dıstribuıcıón normal o curva normal tıene como expresıón

$$g(x) = \frac{1}{\sqrt{2\pi}\,\alpha}\, e^{-\frac{1}{2}\left(\frac{x-\beta}{\alpha}\right)^2} \quad ; -\infty \leq x \leq \infty$$

en la que facılmente se observa que

a) la curva es sımétrıca respecto a x=B, ya que para valores de x equıdıstantes de B se obtıenen los mısmos valores de g(x).

b) El valor máxımo de g(x) corresponde a x=B, y es ıgual a ya que el exponente de C es negatıvo.

c) La curva es asıntótica al eje x, para x=t es, ya que para estos valores g(x)=o

d) Como la curva tıene un máxımo en x=B, la derivada de g(x) en este punto es cero.

Y por lo tanto la curva tıene forma de campana. Desde luego, esta afırmacıón puede comprobarse facılmente dando valores a x, calculando los valores correspondıentes de g(x), y dıbujando la gráfıca resultante para valores cualquıera de y

Para obtener el valor del promedıo arıtmético, correspondıente a esta función de densıdad, se debe realizar la sıguıente ıntegracıón.

$$\bar{x} = \int_{-\infty}^{\infty} x \left[\frac{1}{\sqrt{2\pi}\,\alpha}\, e^{-\frac{1}{2}\left(\frac{x-\beta}{\alpha}\right)^2}\right] dx$$

de donde resulta que la resolucıón de estos ıntegrales aparece en el lıbro "Introductıon to mathematıcal Statıstıcs", (Pag 99), por Paul G. Hoel.

$$\bar{x} = \beta$$

por tanto, la varıancıa se obtıene de

$$s^2 = \int_{-\infty}^{\infty} (x-\bar{x})^2 \left[\frac{1}{\sqrt{2\pi}\,\alpha}\, e^{-\frac{1}{2}\left(\frac{x-\bar{x}}{\alpha}\right)^2}\right] dx$$

donde resulta que

$$s = \alpha$$

Por lo anterior, la ecuación de la curva normal se escribe.

$$g(x) = \frac{1}{\sqrt{2\pi}\, s}\, e^{-\frac{1}{2}\left(\frac{x-\bar{x}}{s}\right)^2}$$

Tomando la segunda derivada de esta expresión, e igualdando a cero, se demuestra que la curva normal tiene dos puntos de inflexión que corresponden a los puntos $x=\bar{x}+s$ y $x=\bar{x}-s$, respectivamente.

AJUSTE A UNA DISTRIBUICION NORMAL

Si, como sucede en muchos casos, una serie de datos se distribuyen de tal manera que su histograma se asemeja a una curva normal, ésta podrá usarse, con fines de inter o extrapolación en lugar de la distribución original, en forma semejante a como la ecuación de una hipérbola puede usarse para hacer estimaciones de población futura, cuando la distribución de los datos de población se asemeja a la hipérbola.

Se puede usar ~~una~~ la curva normal en lugar de la serie de frecuencias, simplemente sustituyendo los valores de $\bar{x}$ y S de la serie, en la ecuación de la curva normal. Debe recordarse, sin embargo, que los valores de g(x) no son iguales, sino proporcionales a los de f(x).

$$g(x) = \frac{f(x)}{n\,\Delta x}$$

Si por ejem., se desearan ajustar los datos de precipitación en el Distrito Federal a una curva normal, primero se calcularían el promedio y la variancia, usando las ecuaciones.

$$\bar{x} = \frac{\sum_{\forall x} x f(x)}{n} \quad ; \quad s^2 = \frac{\sum_{\forall x} (x-\bar{x})^2 f(x)}{n}$$

Con la ayuda del siguiente cuadro:

PRECIP (mm/año)	FRECS F(X)	PUNTOS MEDIOS	XF(X)	$(X-\bar{X})$	$(X-\bar{X})^2$	$(X-\bar{X})^2 F(X)$
350 - 430	1	390	390	-293	85849	85849
430 - 510	5	470	2350	-213	45369	226845
510 - 590	8	550	4400	-133	17689	141512
590 - 670	12	630	7540	- 53	2809	33708
670 - 750	20	710	14200	+ 27	729	14580
750 - 830	9	790	7110	+107	11449	103041
830 - 910	4	870	3480	+187	34969	139876
910 - 990	1	950	950	+267	71289	71289
	60		41000			816700

$$\bar{x} = \frac{41000}{60} = 683 \text{ mm/año}$$

$$s^2 = \frac{816700}{60} = 11667 \; ; \; s = 108 \text{ mm/año}$$

Y por lo tanto.

$$g(x) = \frac{1}{\sqrt{2\pi}\,(108)}\, e^{-\frac{1}{2}\left(\frac{x-683}{108}\right)^2}$$

AREAS BAJO LA CURVA NORMAL

Supóngase que se desea conocer la probabilidad de que para un año cualquiera la precipitación pluvial media anual en la ciudad de México tenga un valor comprendido entre 500 y 800 mm/año; recordando que

$$P(a \leq x \leq b) = \int_a^b g(x)\,dx$$

Se tendrá:

$$P(1000 \leq x \leq 1200) = \int_{500}^{800} \frac{1}{\sqrt{2\pi}\,(108)}\, e^{-\frac{1}{2}\left(\frac{x-683}{108}\right)^2} dx$$

Esta integración podría resolverse expandiendo el término en e, e integrando término a término; ~~absolutamente~~, el procedimiento resultaría extremadamente laborioso. Para evitar este problema, considérese la expresión

$$P(a \leq x \leq b) = \int_a^b \frac{1}{\sqrt{2\pi}\,s}\, e^{-\frac{1}{2}\left(\frac{x-\bar{x}}{s}\right)^2} dx$$

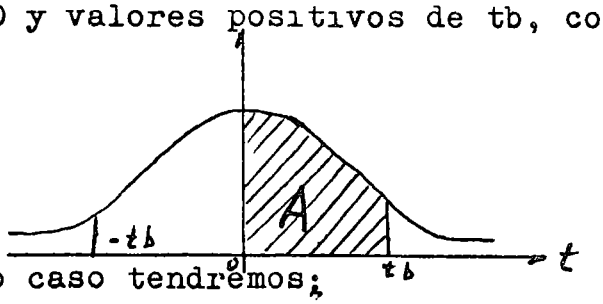
Haciendo:

$$t = \frac{x-\bar{x}}{s} \; ; \; dx = s\,dt$$

Resulta:

$$P(a \leq x \leq b) = \int_{t_a}^{t_b} \frac{1}{\sqrt{2\pi}}\, e^{-\frac{1}{2}t^2} dt$$

Expresión cuyos valores se encuentran tabulados en la tabla anexa, para ta'=0 y valores positivos de tb, como se ilustra en la figura:



En nuestro caso tendremos;

$$t_a = \frac{500 - 683}{108} = -1.69$$

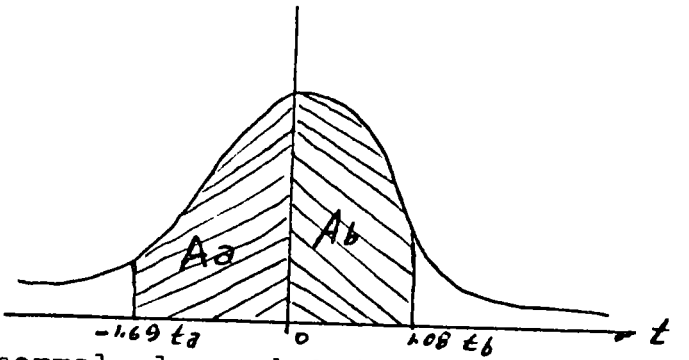
$$t_b = \frac{800 - 683}{108} = +1.08$$

Como la curva es simétrica, el área correspondiente a ta=-1.69, es igual al area correspondiente a ta=1.69, por tanto, de la tabla.

$$A_a = A_{-1.69} = 0.4545$$

$$A_b = A_{1.08} = 0.3599$$

$$P(50 \leq x \leq 800) = 0.8144$$



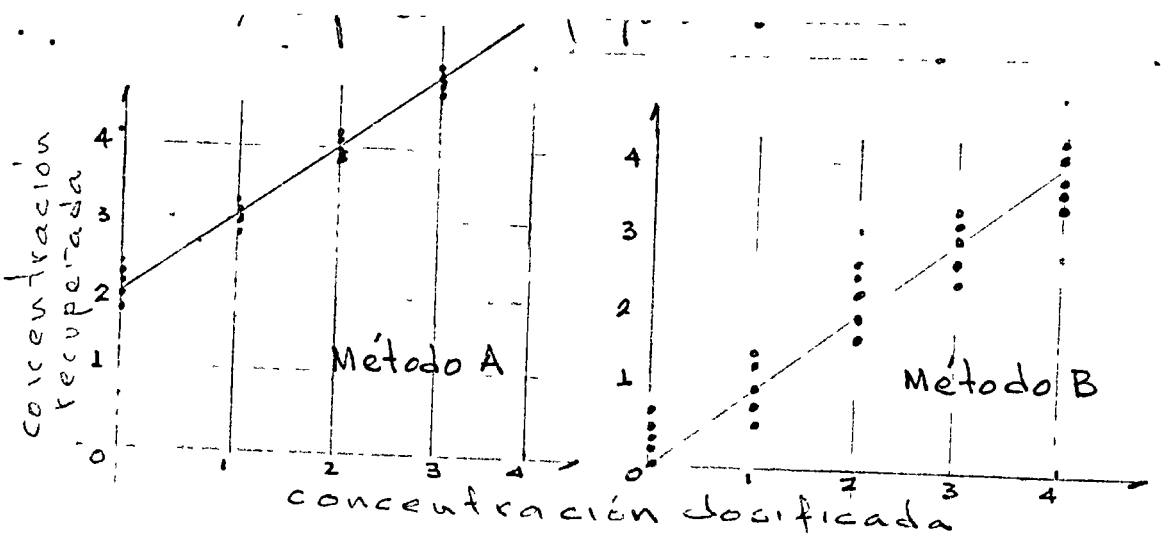
Obsérvese que para cualquier curva normal, la probabilidad de que un valor de x caiga entre $(\bar{x}+s)$ y $(\bar{x}-s)$ es 0.6826, ya que

$$t_a = \frac{(\bar{x}-s)-\bar{x}}{s} = -1 \quad y \quad t_b = \frac{(\bar{x}+s)-\bar{x}}{s} = +1$$

y la tabla Aa=0.3413 y Ab=0.3413. De la misma manera, la probabilidad de que x caiga entre $\bar{x} \pm 1.965$, es 0.95

PRECISION Y EXACTITUD

Supóngase que para comprar dos métodos A y B, de laboratorio, se preparan muestras con concentraciones conocidas de un cierto sustrato, y que a varias muestras de cada concentración se aplican ambos métodos, en tal caso, es posible esperar resultados como los indicados en las siguientes figuras



En tal caso, es evidente que el método A produce resultados que son más reproducibles que los del método B, es más preciso que el método B.

Por otro lado, los resultados obtenidos mediante el método A difieren más de las concentraciones reales, que los obtenidos mediante el método B; el método B es más exacto que el A.

Un método de laboratorio puede ser muy preciso (reproducible), y sin embargo solo recuperar una parte del elemento que se determina, o bien, un método puede ser muy exacto pero carente de precisión, debido a la baja sensibilidad de los instrumentos, la velocidad variable de la actividad biológica u otros factores fuera del control del analista.

Cuando puede disponerse de substancias normales para preparar muestras de distintas concentraciones, es posible determinar tanto la presición como la exactitud de un método, pero cuando esto no es posible, como en el caso de la D.B.O., sólidos o tales y numerosas características físicas, sólo es posible determinar la presición (reproductividad) del método.

Por experiencia se ha demostrado que si una determinación de laboratorio se repite un número grande de veces n, bajo las mismas condiciones, y resultados observados, x, se distribuyen según una curva normal con promedio $\bar{x}$ y desviación estandar S. De la misma manera, si el experimento se repitiera un número grande de veces l para obtener distintos promedios $\bar{x}$ estos promedios se distribuirían según una curva normal con promedio m igual al promedio de los N=n x l resultados observados y desviación estandar $S/\sqrt{N}$; por tanto, puede decirse que en 95% de los casos, el promedio de una muestra caerá entre $\bar{x} = m \pm 1.96 S/\sqrt{n}$, ámbito que se conoce como intervalo del 95% de confianza, y permite una estimación de la confianza que puede tenerse en el promedio, usandose para predecir el número de observaciones que se necesitan para lograr una precisión adecuada.

Si el número de observaciones con que se cuenta es pequño el intervalo del 95% de confianza se modifica:

$$\epsilon = \bar{x} \pm k s/\sqrt{n}$$

expresión en la que k tiene los siguientes valores.

n	2	3	4	5	10	∞
k	12.71	4.30	3.18	2.78	2.26	1.96

Para ilustrar lo anterior supóngase que se desea determinar cuantas determinaciones se deben realizar para determinar la dureza del agua de un pozo, para que el promedio obtenido no difiera del verdadero en más de 5 ppm; si se sabe que después de realizar 5 determinaciones se obtuvieron los resultados mostrados en el siguiente cuadro:

DETERMINACION No.	X DUREZA (PPM)	(X-$\bar{X}$)	(X-$\bar{X}$)^2
1	198	-12	144
2	225	+15	225
3	220	+10	100
4	185	-25	625
5	222	+12	144
SUMAS	1050		1238

$\bar{X} = \frac{1050}{5} = 210$ ppm; $S^2 = \frac{1238}{5-1} = 309.5$

$S = 17.6$ ppm.

El intervalo del 95% de confianza para el verdadero promedio de dureza sería:

$\mu = 210 \pm 2.78\,(17.6)/\sqrt{5} = 210 \pm 21.84$

48.928 ; 2.24 ; 21.84

o en otras palabras, el verdadero promedio, para esta confianza caería entre 188. 16 y 231.84.

El número de determinaciones necesarias para que el verdadero promedio, con 95% de confianza, no difiera del verdadero en más de 10 ppm se obtiene de

$$10 = \left| \pm\ 1.96\,(17.6)/\sqrt{n} \right|$$

$$n = \left(\frac{1.96\,(17.6)}{5} \right)^2 = 47.6 \longrightarrow 48$$

TABLA 24.1
AREAS BAJO LA CURVA NORMAL

$t=\frac{x-m}{F}$	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.0000	.0040	.0080	.0120	.0159	.0199	.0239	.0279	.0319	.0359
0.1	.0393	.0438	.0478	.0517	.0557	.0596	.0636	.0675	.0714	.0753
0.2	.0793	.0832	.0871	.0910	.0948	.0987	.1026	.1064	.1103	.1141
0.3	.1179	.1217	.1255	.1293	.1331	.1368	.1406	.1443	.1480	.1517
0.4	.1554	.1591	.1628	.1664	.1700	.1736	.1772	.1808	.1844	.1879
0.5	.1915	.1950	.1985	.2019	.2054	.2088	.2123	.2157	.2190	.2224
0.6	.2257	.2291	.2324	.2357	.2389	.2422	.2454	.2486	.2518	.2549
0.7	.2580	.2612	.2642	.2673	.2704	.2734	.2764	.2794	.2823	.2852
0.8	.2881	.2910	.2939	.2967	.2995	.3023	.3051	.2078	.3106	.3133
0.9	.3159	.3186	.3212	.3238	.3264	.3289	.3315	.3340	.3365	.3389
1.0	.3413	.3438	.3461	.3485	.3508	.3531	.3554	.3577	.3599	.3621
1.1	.3643	.3665	.3686	.3718	.3729	.3749	.3770	.3790	.3810	.3830
1.2	.3849	.3869	.3888	.3907	.3925	.3944	.3962	.3980	.3997	.4015
1.3	.4032	.4049	.4066	.4083	.4099	.4115	.4131	.4147	.4162	.4177
1.4	.4192	.4207	.4222	.4236	.4251	.4265	.4279	.4292	.4306	.43
1.5	.4332	.4345	.4357	.4370	.4382	.4394	.4406	.4418	.4430	.4441
1.6	.4452	.4463	.4474	.4485	.4495	.4505	.4515	.4525	.4535	.4545
1.7	.4554	.4564	.4573	.4582	.4591	.4599	.4608	.4616	.4625	.4623
1.8	.4641	.4649	.4656	.4664	.4671	.4678	.4686	.4693	.4699	.4706
1.9	.4713	.4719	.4726	.4732	.4738	.4744	.4750	.4758	.4762	.4767
2.0	.4773	.4778	.4783	.4788	.4793	.4798	.4803	.4808	.4812	.4817
2.1	.4821	.4826	.4830	.4834	.4838	.4842	.4846	.4850	.4854	.4857
2.2	.4861	.4865	.4868	.4871	.4875	.4878	.4881	.4884	.4887	.4890
2.3	.4893	.4896	.4898	.4901	.4904	.4906	.4909	.4911	.4913	.4916
2.4	.4918	.4920	.4922	.4925	.4927	.4929	.4931	.4932	.4934	.4936
2.5	.4938	.4940	.4941	.4943	.4945	.4946	.4948	.4949	.4951	.4952
2.6	.4953	.4955	.4956	.4957	.4959	.4960	.4961	.4962	.4963	.4964
2.7	.4965	.4966	.4967	.4968	.4969	.4970	.4971	.4972	.4973	.4974
2.8	.4974	.4975	.4976	.4977	.4977	.4978	.4979	.4980	.4980	.4981
2.9	.4981	.4982	.4983	.4984	.4984	.4984	.4985	.4985	.4986	.4986
3.0	.49865		.4987	.4988	.4988	.4988	.4989	.4989	.4989	.4990
3.1	.49903		.4991	.4991	.4992	.4992	.4992	.4992	.4993	.4993

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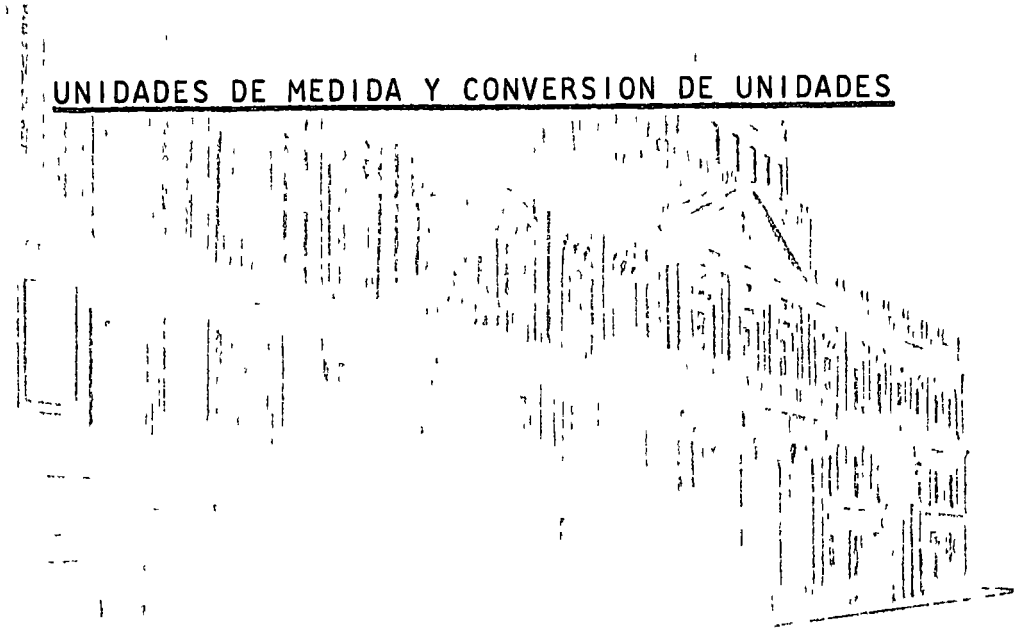
CONTROL DE LA CONTAMINACION ATMOSFERICA

UNIDADES DE MEDIDA Y CONVERSION DE UNIDADES



PROF. UBALDO BONILLA DOMINGUEZ

México, D.F., noviembre-diciembre de 1971

Expresión de resultados

1- Ley general del estado gaseoso

$$\frac{Pv}{T} = R \quad ; \quad V = n\,v \quad ; \quad n = \frac{w}{M}$$

P - presión
v - volúmen
T - temp. absoluta, °k

w - peso del gas
M - peso de una mole
V - vol. del gas
n - numero de moles

$$\frac{P(vn)}{T} = nR \quad ; \quad \boxed{\frac{PV}{T} = \frac{w}{M} R}$$

2- Determinación de R (constante universal de los gases)
Para condiciones normales $P = 760$ mm, $T = 273°K$
$v = 0{,}0224 \frac{m^3}{mole}$.

$$R = \frac{(760)(0.0224)}{273} = 0{,}0628 \ \frac{mm.}{°k} \left| \frac{m^3}{mole} \right.$$

$$\boxed{R = 0{,}0628 \ \frac{mm - m^3}{°k - mole}}$$

3- Expresión de resultados en ppm.
Para $1\,m^3$ de aire (mezcla) y una cantidad de un contaminante de w mg y el volumen que ocuparía el contaminante puro, bajo las condiciones de presión y temperatura de la mezcla será

$$V_c = \frac{w}{M}\frac{RT}{P}\quad \frac{\mu g}{\mu g}\left|\frac{10^{-6}\,g}{g}\right|\frac{mole}{mole}\left|\frac{mm\text{-}m^3}{{}^oK\text{-}mole}\right|\frac{{}^oK}{mm}$$

Por lo tanto, la concentración de contaminante en el aire será:

$$K = \frac{V_c}{V_a}$$

$$\boxed{K = 6.28\times10^{-8}\,\frac{w}{M}\,\frac{T}{P}}$$

o sea:

$$\boxed{K = 6.28\times10^{-2}\,\frac{w}{M}\,\frac{T}{P}\ ppm}$$

V - $\frac{m^3 \text{ de contaminante}}{m^3 \text{ de aire}}$

w - $\frac{\mu g}{m^3}$

M - $\frac{g}{mole}$

R - $\frac{mm.\text{-}m^3}{{}^ok\text{-}mole}$ 0.0628

T - ^oK

La proporción de contaminante puede encontrarse también de la siguiente manera:

- el número de moles en 1 m^3 de aire a T°c y P, mm es:

$$n_a = \frac{PV}{TR};\quad n_a = \frac{P(1)}{T(0.0628)}\left|\frac{mm}{mm}\right|\frac{m^3}{{}^oK}\left|\frac{{}^oK\text{-}mole}{mm\text{-}m^3}\right|$$

- el número de moles de contaminante bajo las mismas condiciones es

$$n_c = \frac{w}{M}\left|\frac{\mu g}{g}\right|\frac{mole}{}\left|\frac{g}{10^{6}\mu g}\right| = \frac{w}{M}\,10^{-6}\ mole$$

por tanto

$$K = \frac{n_c}{n_a} = \frac{w(10^{-6})}{M}\cdot\frac{T(0.0628)}{P}\,\frac{mole}{m^3}\left|\frac{m^3}{mole}\right.$$

$$\boxed{K = 6.28\times10^{-2}\,\frac{w}{M}\,\frac{T}{P}\ p.p.m.}$$

4- Ejemplo

Una muestra de aire tomada en la ciudad de México, a 586 mm de presión y 15°C de temperatura, dió un contenido de SO_2 de 300 µg/m³; expresar este resultado en ppm.

Solución:

- El peso molecular del SO_2 es

$$S - 32$$
$$2O - \frac{32}{64}$$

- Aplicando la fórmula anterior

$$K = 6.28 \times 10^{-2} \frac{300\ (\overbrace{273+15}^{288})}{64\ (586)}$$

$$K = 0.1456 \text{ ppm.}$$

	UNIDADES RECOMEND.	RANGOS OBSERV.½
PARTICULAS DEPOSIT.		
Cantidad	No. por cm^2 por unid. tiempo	
Peso	mg/cm^2 unid. tiempo.	0.5 a 135 mg/cm^2 mes
PARTICULAS SUSPEND.		
Cantidad	No. por m^3	+ 10×10^6 ó más part/m^3
Peso	g/m^3	10 a 5000 g/m^3
GASES Y VAPORES	g/m^3	gran variación.
TRANSMISIBILIDAD DE LUZ	% transmitido	0 a 100 %
VISIBILIDAD	kilómetros	
VOLUMEN DE EMISION	m^3/min	1.5 a 300 + m^3/min
VOLUMENES MUESTREADOS	m^3, dm^3, ó cm^3/min	10 cm^3/min a 3 m^3/min
TEMPERATURA	Escala Celsius	
TIEMPO	0000 a 24000 horas por dia	
PRESION	m.m. de mercurio	
VELOCIDAD	m/seg.	0 - 100 m/seg.
VOLUMEN DE GAS	Reportado a 760 mm Hg y 10° C	

FACTORES DE CONVERSION PARA MEDIDAS GENERALES DE LA CONTAMINACION DEL AIRE. (760 mm H_g y 10° C)

PARA CONVERTIR DE	A	MULTIPLICADO POR
	CAIDA DE POLVO	
Ton/milla^2	Libra/acre	3.125
	Libra/1000 pies^2	0.07174
	Gramos/m^2	0.3503
	Kilogramos/kilómetros^2	350.3
	Miligramos/m^2	350.3
	Miligramos/m^3	0.03503
	Gramos/pies^2	0.03254
Libras/acre	Tons/milla^2	0.32
	Libras/100 pies^2	0.023
	Gramos/m^2	0.1121
	Kilogramos/Kilómetros^2	112.1
	Miligramos/m^2	112.1
	Miligramos/cm^2	0.01121
	Gramos/pies^2	0.0104
Libras/1000 pies^2	Ton/milla^2	13.94
	Libras/acre	43.56
	Gramos/m^2	4.882
	Kilogramos/kilómetro^2	4882.4
	Miligramos/m^2	4882.4
	Miligramos/cm^2	0.4882
	Gramos/pies^2	0.4536

FACTORES DE CONVERSION PARA MEDIDAS GENERALES DE LA CONTAMINACION DEL AIRE. (760 mm H_y y 10 °C) (continuación)

PARA CONVERTIR DE	A	MULTIPLICADO POR
Gramos/m^2	Ton/milla^2	2.855
	Libra/acre	8.921
	Libra/1000 pies^2	0.2048
	Kilogramos/kilómetro^2	1000.
	Miligramos/m^2	1000.
	Miligramos/cm^2	0.1
	Gramos/pies^2	0.0929
Kilogramos/kilómetro^2	Ton/milla^2	2.855×10^{-3}
	Libras/acre	8.921×10^{-3}
	Libras/1000 pies^2	204.8×10^{-6}
	Gramos/m^2	0.001
	Miligramos/m^2	1.0
	Miligramos/cm^2	0.0001
	Gramos/pies^2	92.9×10^{-6}
Miligramos/m^2	Tons/milla^2	2.855×10^{-3}
	Libras/acre	9.921×10^{-3}
	Libras/1000 pies^2	204.8×10^{-6}
	Gramos/m^2	0.001
	Kilogramos/kilómetro^2	1.0
	Miligramos/cm^2	0.0001
	Gramos/pies^2	92.9×10^{-6}

FACTORES DE CONVERSION PARA MEDIDAS GENERALES DE LA CONTAMINACION DEL AIRE. (760 mm H_y y 10 ° C) Continúa.

PARA CONVERTIR DE	A	MULTIPLICADO POR
Miligramos/cm^2	Tons/$milla^2$	28.55
	Libras/acre	89.21
	Libras/1000 $pies^2$	2.048
	Gramos/m^2	10.0
	Kilogramos/$kilómetro^2$	10.0×10^3
	Miligramos/m^2	10.0×10^3
	Gramos/$pies^2$	0.929
Gramos/$pies^2$	Ton/$milla^2$	30.73
	Libras/acre	96.154
	Libras/1000 $pies^2$	2.204
	Gramos/m^2	10.764
	Kilogramos/$kilómetro^2$	10.764×10^3
	Miligramos/m^2	10.764×10^3
	Miligramos/cm^2	1.0764
PARTICULAS MATERIALES EN SUSPENSION		
Miligramos/m^3	Gramos/$pies^3$	283.2×10^{-6}
	Gramos/m^3	0.001
	Microgramos/m^3	1000.0
	Microgramos/$pies^3$	28.32
	Libras/1000 $pies^3$	62.43×10^{-6}
Gramos/$pies^3$	Miligramos ^{3}	$35.3145 \times 10^{+3}$
	Gramos/m^3	35.314
	Microgramos/m^3	35.314×10^6

FACTORES DE CONVERSION PARA MEDIDAS GENERALES DE LA CONTAMINACION DEL AIRE. (760 mm H_y y 10° C) (continuación)

PARA CONVERTIR DE	A	MULTIPLICADO POR
	Microgramos/pies^3	1.0×10^6
	Libras/1000 pies^3	2.2046×10^6
Gramos/m^3	Miligramos/m^3	1000.0
	Gramos/pies^3	0.02832
	Microgramos/m^3	1.0×10^6
	Microgramos/pies^3	28.317×10^3
	Libras/1000 pies^3	0.06243
Microgramos/m^3	Miligramos/m^3	0.001
	Gramos/pies^3	28.317×10^{-9}
	Gramos/m^3	1.0×10^{-6}
	Microgramos/pies^3	0.02832
	Libras/1000 pies^3	62.43×10^{-9}
Miligramos/pies^3	Miligramos/m^3	35.314×10^{-3}
	Gramos/pies^3	1.0×10^{-6}
	Gramos/m^3	35.314×10^{-6}
	Miligramos/m^3	35.314
	Libras/1000 pies^3	2.2016×10^{-6}
Libras/1000 pies^3	Miligramos/m^3	16.018×10^3
	Gramos/pies^3	0.35314
	Microgramos/m^3	16.018×10^6
	Gramos/m^3	16.018
	Microgramos/pies^3	353.14×10^3

FACTORES DE CONVERSION PARA MEDIDAS GENERALES DE LA CONTAMINACION DEL AIRE. (760 mm H_y y 10 ° C) (continuación)

PARA CONVERTIR DE	A	MULTIPLICADO POR
	GASES ATMOSFERICOS	
Miligramos/m^3	Microgramos/m^3.	1000.0
	Microgramos/litro	1.0
	P.p.m. por volumen(20°c)	$\frac{20.04}{M}$
	P.p.m. por peso	0.0347
	Libras/$pies^3$	62.42×10^{-9}
Microgramos/m^3	Miligramos/m^3	0.001
	Microgramos/litro	0.001
	p.p.m. por volumen(20°c)	$\frac{0.02404}{M}$
	p.p.m. por peso	834.7×10^{-6}
	Libras/$pies^3$	62.43×10^{-12}
Microgramos/litro	Miligramos/m^3	1.0
	Microgramos/m^3	1000.0
	p.p.m. por volumen(20°c)	$\frac{24.04}{M}$
	p.p.m. por peso	0.8347
	Libras/$pies^3$	62.43×10^{-9}
p.p.m. por volumen (20° c)	Miligramos/m^3	$\frac{M}{24.04}$
	Microgramos/m^3	$\frac{M}{0.02404}$
	Microgramos/litro	$\frac{M}{24.04}$

FACTORES DE CONVERSION PARA MEDIDAS GENERALES DE LA CONTAMINACION DEL AIRE. (760 mm H_y y 10° c) (continuación).

PARA CONVERTIR DE	A	MULTIPLICADO POR
	p.p.m. por peso	$\frac{M}{28.8}$
	Libras/pies^3	$\frac{M}{385.1 \times 10^6}$
p.p.m. por peso	Miligramos/m^3	1.198
	Microgramos/m^3	1.198×10^{-3}
	Microgramos/litros	1.198
	p.p.m. por volumen(20°c)	$\frac{28.8}{M}$
	Libras/pies^3	7.48×10^{-6}
Libras/pies^3	Miligramos/m^3	16.018×10^6
	Microgramos/m^3	16.018×10^9
	Microgramos/litro	16.018×10^6
	p.p.m por volumen(20°c)	$\frac{385.1 \times 10^6}{M}$.
	p.p.m. por peso	133.7×10^3
	CALCULO DE PARTICULAS	
No./m^3	No./litro	0.001
	No./cm^3	1.0×10^{-6}
	No./pies^3	28.317×10^{-3}
No./litro	No./m^3	1000.0
	No./cm^3	0.001
	No./pies^3	28.316

RETURN TO KIMURA

RESEARCH APPLIANCE COMPANY
Route 8 and Craighead Road, Allison Park, Pa. 15101
Phone (412) 486-0500

MODEL 2343 STAKSAMPLR
DESCRIPTION, OPERATING INSTRUCTIONS AND PROCEDURES

2/24/70
dh

THE RESEARCH APPLIANCE COMPANY STAKSAMPLR

Stack sampling has been a difficult and disagreeable job until the present time. Before the development of the stack sampler by the National Center for Air Pollution Control in Cincinnati, Ohio and its further refinement and production by Research Appliance Company, stack sampling was limited to grab samples, simple and not very precise filters and the occassional use of impingers. However, now by using the RAC Staksamplr, dependable isokinetic particulate samples and representative gaseous samples may be taken easily and economically from any stack.

It is our intention within this paper to give you some idea of what must be done in order to stack sample. We are not attempting to set up a "cook book" type procedure since each stack has different characteristics; we are assuming some knowledge of stack sampling on the part of the user. We have, however, attempted to touch on the main points to be considered when using the RAC Staksamplr.

When stack sampling is being contemplated there are many factors to be considered. Not least among these is a survey of the process for which the stack is needed. This is quite important as peak loading times, peak temperatures, and peak humidity will all affect the sample. Therefore, one should be aware of what cycle the process is in and what the conditions are in this cycle so the samples can be regarded in light of these facts. It has been reported that inefficiencies and other problems related to process cycles have been determined by analysis of samples and their correlation with specific process cycles.

The next step in the preliminary survey is choosing the actual sampling site. Remembering that gas velocity, temperature, and humidity measurements, (which must be taken before sampling begins) are taken at the same location used in sampling the stack; one can plan on safety measures for the sampling crew and a method for getting the sample box and pitobe to the sampling point. Sampling points on the stack should be selected so that there is a uniformity of gas mixture and the stack gases should be as free as possible from turbulence. When selecting a site the usual rule is for measurements to be made five to ten diameters downstream from a disturbance or three to five diameters upstream. Disturbances are usually caused by inlets, outlets, bends or constrictions in a stack. This rule can not always be adhered to and in such cases compromises must be made. In doing this, flow measurements and sampling techniques must be carefully applied to minimize errors.

With the above information, complete with additions which may be necessary in any particular case, one is ready to begin preliminary velocity and temperature measurements for particulate sampling. A preliminary traverse is made with a pitot tube which is connected via an umbilical cord to an inclined/ vertical manometer.

The S pitot tube measures velocity head at the point in the gas stream where it is placed. Temperature, pressure, and humidity must also be measured at the sampling port since these factors significantly affect the flow of gas in cubic feet per minute. When making this preliminary traverse, the process cycle must be kept in mind since this seriously affects the velocity. Also, at this time a measurement is usually made with a Orsat Analyzer to determine the efficiency of combustion.. The acceptable level of CO_2 is 12%. It may be necessary to make many preliminary traverses in order to find an area which will conform to the preceding specifications. With the velocity information, and with the use of the nomograph (described elsewhere), the nozzle that will give isokenetic sampling at approximately 3/4 cubic feet per minute can be selected.

After the sampling site has been chosen, the problem of getting men and the Staksampler to this point becomes important. Duorail is supplied for attaching the Staksampler to the stack. Angled iron is attached to the sides of the sample box so that it may be moved either horizontally or vertically along two steel rails attached to the sides of the duct. The duorail is a long rectangle, the front of which is mechanically clamped to the sample port. The rear is supported by an angled iron brace, which is placed at an angle against the stack and held there by nylon cord tied around the duct and/or up the front of the duorail. That is, the duorail is one leg of a right triangle, the nylon cord (paralleling the stack) is the second leg, and the brace forms the hypotenuse. The duorail has proved very effective in attaching the sampler to the stack and has worked well with many ingenious plans on a variety of stacks.

With the sampling box located on the stack, the pitobe can be attached to it. The pitobe consists of a sampling nozzle (previously selected from information gathered in the preliminary survey), heated probe, and pitot tube. The ball joint from the pitobe connects directly to a glass cyclone located in the sampling box, which is designed to remove particles greater than 5 microns in diameter. The cylcone is followed by a glass holder with a coarse-porosity fritted glass filter. Both the cyclon and filter are positioned in the heated portion of the sampling box, which is maintained between 240° and 280°F. The filter is usually a 934 AH glass fiber filter. Next in line are four Greenberg-Smith impingers in an ice bath. Only the second impinger has the original tip, the other three have had the tip removed to decrease the pressure drop through them. The first and second impingers, during particulate sampling, are filled with 250 and 150 milliliters of deionized water, respectively. The third impinger is left dry to remove entrained water. The last impinger contains 175 grams of precisely weighed silica gel to remove any remaining water.

The front left compartment (viewing the sample box from the pitob) houses a blower and electrical circuitry. The blower circulates air through a thermostatically controlled heating element in the left rear compartment. The right side contains the ice bath and four impingers connected to the filter through an opening in the side of the enclosed heated compartment.

The umbilical cord connects the last modified Greenberg-Smith impinger, the pitot tube, and the heating element at the sampling box to the meter box which is located in a convenient place within 100 feet of the sample port. The umbilical cord consists of four parts:

1. A 3/8 inch vacuum hose with a ball-joint connection to the sample box and a quick disconnect connection to the meter box (connects impinger to meter box vacuum pump). A thermometer and check valve are built into the ball-joint connector.

2. Two 1/4 inch lines made of tygon tubing with quick disconnects on both ends of the tubing (connects pitot tube to the meter box manometer).

3. Four multistrand insulated conductors with amphenol connector on both ends (connects sample box circuit to meter box power supply).

4. Ground wire.

The umbilical cord attaches to the meter box, which contains a vacuum pump, regulating valves, instantaneous and intergrating flow meters, pitot tube manometers, vacuum gauge, and electrical controls.

The pitot tube lines of the umbilical cord connect through a quick-disconnect fitting to an inclined/vertical manometer.

A schematic of the meter box plumbing is shown in Figure 10. The umbilical cord sample line connects through a quick disconnect valve to the vacuum pump.

The pump intake vacuum, and indirectly the pressure drop across the collection apparatus, is monitored with a vacuum gauge just after the quick disconnect. The pressure drop across the sample apparatus is the gauge vacuum less the stack draft.

A bypass valve is in parallel with the vacuum pump to give fine flow control and to permit recirculation of gases at low sample rate so that the pump motor is not overloaded. Downstream of the pump and bypass valve are a thermometer, dry gas meter, another thermometer, and a calibrated orifice with an inclined/vertical manometer in parallel. The calibrated orifice and inclined/vertical water manometer are used to indicate the instantaneous sampling rate. The dry gas meter gives an integrated gas-sample volume. The average of the two temperatures on each side of the dry gas meter gives the temperature at which the volume is sampled. The meter pressure is the atmospheric pressure plus the orifice pressure drop.

The electrical circuitry for the meter box is shown schematically in Figure 11. Many of the electrical controls are shown in Figure 10. The meter box has a pilot light to indicate when the meter box is energized. Four toggle switches are located on the front of the meter box to control. They are as follows:

1. Vacuum pump, auxillary pump outlet, timer with buzzer, and a pilot light.

2. Fan in the sample box and a pilot light on the meter box.

3. Heating element in the sample box and a pilot light on the meter box, all in series with the toggle switch for the sample box fan. This prevents the heating element from operating without the fan; however, the fan can operate without the heating element.

4. Probe heating element controlled by a variable transformer and a pilot light.

The sample box fan and heating element, and the probe heating element along with a common ground are connected to a four-pronged female amphenol for ready connection to the umbilical cord.

Before sampling is begun the stack cross section selected as the site must be divided into sampling areas. In a circular duct a traverse is made by dividing the duct into equal concentric areas and sampling in the center of each area on four sides of center. No sample is taken in the exact center. The number of equal areas chosen depends on the size of the duct and accuracy desired. In a rectangular duct a sample traverse is made by dividing the duct into equal areas and sampling at the center of each area. The number of areas used depends on the flow pattern and the size of the stack. See Figure 6 for drawings and tables. Corrections for stack gas velocity are sometimes necessary between preliminary traverse and sample traverse because of changes in velocity head and temperature between these two intervals.

After the sampling train has been explored and confidance is gained in its operation, sampling may begin when the sample box temperature reaches 250°F. The sampling time at each traverse point depends upon the loading and moisture of the stack. These have been previously determined. The limiting factor here is the amount of particulate the cyclone and filtercan hold, the amount of condensate the impingers can accommodate, and the pressure drop that developes across the sampling equipment. Generally, five or ten minutes per traverse point is adequate. The pitobe is moved quickly from traverse point to traverse point without turning off the vacuum pump. The sample rate is maintained isokinetic at the meter box by observing the pitot tube manometer reading, performing the necessary computations on the nomograph, and correcting the sampling rate to comply. Recordings of temperature, manometer pressure, and dry gas meter volumes are made at the start and the end of each traverse point, and whenever a change occurs while at a traverse point.

The check-out procedure for the Staksamplr and the calibration procedure for the orifice and m ter are as follows. Equations one and two have application when using the nomograph, since their results are necessary for Figure 9 computations.

A preliminary check is made of the following for proper operation before trial test: pump, pump oil, quick connects, valves, manometers, dry test meter, thermometers, lights, buzzer, electrical check amphenol, variac, vacuum gauge, leakage at 27".

COVER OFF

PLUG IN POWER:	Bottom light on, solenoid click
PUMP OIL:	Minimum level
PUMP:	Provides sufficient suction when in operation
QUICK CONNECTS:	Proper locking operation making sure balls have been removed
VALVES:	Proper opening and closing
MANOMETER:	Fluid level and zeroing
DRY TEST METER:	Thermometers (inlet, outlet) do not hang up
THERMOMETERS:	Calibrate to a known temperature
LIGHTS:	Turn fan, heater, probe on; turn fan off and heater light also goes out. Turn fan on and heater off. Lights should indicate position
BUZZER:	Industrial timer set as desired with multiple CAMS for different timing. Set as desired. Light above power light should come on when buzzer sounds. Timer used noted on meter box
ELECTRICAL CHECK AMPHENOL:	Continuity check
VARIAC:	Connect neon bulb electrically to amphenol and turn variac up beyond 45 watching neon increase in brightness
VACUUM GAGE:	Turn selector valve (course) to "on" position, fine adj. to fully open; insert plug (plug input line); turn fine adj. until gage read "27" and hold for 15-30 seconds, observe dry meter for movement, check for leaks.

You are now ready to follow calibration procedures. After warmup and wetting, set wet meter at zero, start stop watch when dry meter reading is at a convenient position and record all information.

When 10 CF_w have gone through the meter stop the stop-watch and note dry meter for CF_d. Perform all calculations, and if readings are not within tolerance make adjustments as outlined on calibration procedures page.

TERMINOLOGY:

CFM	= Cubic foot/minute
H@	= Orifice pressure differential in inches of water that gives 0.75 CFM of air at 70°F and 29.92 in.Hg.
Y	= Dry meter differential (in. H_2O)
P_b	= Barometric pressure (in. Hg.)
CF_w	= Cubic feet (wet test meter)
CF_d	= Cubic feet (dry test meter)
T_w	= Temperature (west test meter)
IT_d	= Input temperature (dry) °F
OT_d	= Output temperature (dry) °F
T_d	= $(IT_d + OT_d)$ /2 °F
T	= Time (minutes)
WTM	= Wet Test Meter

With the meter and pump enclosed and a wet test meter attached (one cubic foot per revolution), allow the equipment to warm up and dry parts of WTM to become wetted (approximately 1/2 hour). Level the box by turning the adjusting screw in the lower right front corner. Then zero the manometer by placing the manometer switch in the up position and adjusting fluid level, if necessary. After the warmup period, run a trial test at an orifice manometer setting of 2 in. H_2O and CF_w of 10 to obtain H@ and Y.

ΔH@, which is calculated by using the formula

$$\Delta H@ = \frac{0.0317 \text{ (manometer orifice)}}{P_b \ (OT_d + 460} \left[\frac{(T_w + 460)t}{CF_w} \right]^2$$

is obtained by a trial test. If the value is not within 1.6 to 2.1 (1.84 nom desired) the orifice can be drilled in increments of 64ths to lower the value, or if the value is below 1.6, then the orifice should be replaced and the procedure repeated.

Y, which is calculated by using the formula

$$Y = \frac{CF_w P_b \ (T_{d\ avg.} + 460)}{CF_d \ (P_b + 0.147) \ (T_w + 460)}$$

is obtained during the trial run along with $\Delta H@$. The value should range between 0.99 and 1.01 (1.00 Nom. desired for operation).

The nomograph used in the preceding reduces calculation time to a few seconds. The following is the derivation of equation (5) which is represented by the nomograph with its three independent variables. At the end of this paper is a key to the symbols used in the equations.

For isokinetic sampling, the calibrated orifice manometer is made dependent on the pitometer manometer by combining the pitometer equation:

$$V_p = C_p \sqrt{\frac{2 g_c \Delta PRT}{P_s M_s}}$$

with an equation relating volumetric sampling rate to effluent velocity through the nozzle:

$$Q_m = \frac{\pi}{4} D^2 V_p \frac{T_m}{T_s} \frac{P_s}{P_m} M_c$$

When a calibrated orifice is used to measure Qm:

$$Q_m = JA \sqrt{\frac{T_m \Delta H 2 g_c R}{P_m M_m}}$$

Combining and rearranging equations one, two, and three give the dependency of the calibrated orifice manometer on the pitometer manometer:

$$\Delta H = K (\Delta P) D^4 T_s^{-1} \qquad K = \left(\frac{\pi C_p M_c}{4 JA}\right)^2 \frac{M_m}{M_s} \frac{P_s}{P_m} T_m$$

Stack velocities not only change between different traverse points, but also vary at a point because of variable flow conditions. The calculation of equation (4) presents an undesirable time lag between changes in stack velocity and sampling rate.

Figure 8 shows the nomograph. The K term in Equation (4) is usually a constant during sampling, but it may change for different sampling locations or processes. A four-independent-variable nomograph could be used; but

because this would make the nomograph that much larger and unwieldy and because K does not frequently vary, K is incorporated into the T scale. This is done by making th T scale movable and setting its position with a C scale. The C scale is a ratio of the true value of K to an assumed value. If the values for K vary from the assumed values, then a new value for C is obtained from a second nomograph (Figure 9). The nomograph of Figure 8 is based on the assumption that there is 5 percent water in the stack gas and 0 percent water passing through the orifice. It assumes a dry gas molecular weight of 29, atmospheric and stack pressures of 29.92 in. Hg. a meter temperature of 70°F and a $\Delta H@$ (the orifice pressure differential that gives 0.75 cubic feet per minute for dry air at 70°F and 29.92 in Hg) of 1.84. The nomograph of Figure 9 corrects for different stack and atmospheric pressures, different stack gas moistures, and different gas temperatures at the orifice. Figure 9 does not correct for moisture in the gas passing through the orifice nor molecular weight changes other than those due to water in the stack gas.

The following are instructions for the use of the nomograph (Figure 8):

1. Place C, which was found in Figure 9, in line with the Ref point, which is adjacent to the C scale.

2. Make a rough preliminary pitot, traverse, and determine the minimum, average, and maximum ΔP.

3. Measure the stack temperature, T, approximately.

4. Place the hair line of the slide on the temperature reading determined in step three. Using the ΔP's determined in step two, move the hair line from minimum to average to maximum, holding the T end of the hair line on the temperature. Note on the D scale the probe tip diameter, which is available and comes closest to the average. This is the probe tip to be used in this case. If, however, no probe tip is available in your particular ΔP range, use the next lowest diameter available.

5. Align the temperature, T, and the probe tip diameter, D, of step four to obtain a ΔP.

6. Align the ΔP from step five and the Ref point on the ΔH line with the slide to obtain a K factor setting.

7. Tighten the slide and keep this K factor setting as a pivot.

During sampling:

8. Determine ΔH for the ΔP's of the pitot traverse.

9. If T changes, repeat steps three through eight.

After sampling is complete, it is necessary to rinse the sampling train. When inorganic constituents are present, distilled water may be used as a wash. When organic constituents are present acetone or another suitable gas-sample flow to minimize the amount of liquid necessary for a rinse. The rinsing material should be led to a beaker and retained for analysis.

The cyclone and course prorsity filter collect particulate of different sizes, which are to be weighed. The weights of both sizes of particulate are determined by taring out the weight of the filter and the cyclone before sampling.

When only a particulate sample is taken, the first two impingers are filled with precisely 250 and 150 ml of deionized water, respectively. The liquid volume of water vapor in the stack is determined by subtracting these initial volumes from the final volumes. When one is sampling for a specific gas, the first impinger is left dry and the second is filled to 150 ml with the appropriate reagent. Here again, a precise volume is critical as condensation may occur in this impinger.

The third and fourth impingers are for entrapment of any moisture which may be picked up from the first two impingers. The silica gel must be precisely weighed, as the difference in its weight after sampling will be taken into account.

To determine the weight of solids, soluble and insoluble, from the liquid impingers it is necessary to evaporate the liquid in a tarred beaker. Then reweigh the beaker to find total solids. If volatile organic particulate matter is collected, an extraction in some organic reagent such as chloroform or carbon tetrachloride is necessary. This reagent is then evaporated with a stream of dry air in a preweighed beaker and the difference in beaker weight before and after evaporation is the organic's weight.

The total weight of particulate matter collected is the sum of the aqueous and solvent residues.

Reagents used for particular gaseous pollutants and their analysis procedures are beyond the scope of this paper; however, references are given which do include these and are much more complete than would be possible herein.

Figures one throughfive are examples of the method used by the County of Los Angeles for organization of data. The first samples made with the Staksamplr will give a base for comparison with future samples. Therefore, i' should be followed in all future samples.

AIR POLLUTION CONTROL DISTRICT -- COUNTY OF LOS ANGELES

TEST NO. _____ PAGE 31

SAMPLING STATION Inlet of Precipitator DATE June 6, 1960

GAS VELOCITY DATA

Point	12 30 - 1 30			1 30 - 2 30					
	Vel Head in H_2O	Temp ^oF	Velocity Ft/Sec	Vel. Head in H_2O	Temp ^oF	Velocity Ft/Sec	Vel Head in H_2O	Temp ^oF	Velocity Ft/Sec
R	0 36	740	60 3	0 34	790	59 8	0 38	830	64.3
1	0.26	800	52.5	0.22	850	49 3	0.22	840	42.1
2	0.26	780	52.1	0.26	800	52.5	0.21	850	48.2
3	0.28	800	54.6	0.25	820	52.0	0.26	820	53.0
4	0.34	810	60.3	0.33	850	60.5	0.31	780	56.8
R	0.34	860	61 5	0.35	810	61.2	0.37	830	63 5
5	0.36	860	63.3	0.35	800	60.9	0.37	850	63 9
6	0.40	850	66.5	0.36	790	61.6	0.37	830	63.5
7	0 43	860	69.1	0.38	840	64.5	0.38	790	63.2
8	0.40	880	67.3	0.38	750	62.2	0.34	800	60.1
R	0.38	880	65.5	0.38	760	62.5	0.37	850	63.9
Traverse	Av.	830	60.7	Av.	810	57.9	Av.	820	57.2
R	Av.	830	62.4	Av.	810	61.2	Av.	820	63.9

A Average velocity (traverse) Ft/Sec _____

B Average velocity (reference pt) Ft/Sec _____

C Flue factor A/B _____

D Pitot correction factor _____

E Gas density correction factor _____

F. Corrected velocity, A*D*E, Ft/Sec _____

or B*C*D*E, Ft/Sec _____

G Area of flue, sq ft _____

H. Average flue temperature, ^oF _____

J. Flow rate, F*G*60, CFM _____

K. Flow rate, 520*J/(H+460), SCFM _____

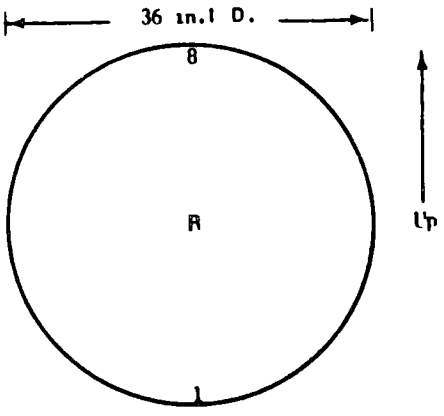


Figure 1

AIR POLLUTION CONTROL DISTRICT COUNTY OF LOS ANGELES

TEST NO _____ PAGE 35

SAMPLING STATION _____ Stack Outlet _____ DATE June 6, 1960

GAS VELOCITY DATA

Time	12 30			12 35			12 40		
POINT	VEL HEAD IN H_2O	TEMP °F	VELOCITY FT/SEC	VEL HEAD IN H_2O	TEMP °F	VELOCITY FT/SEC	VEL HEAD IN H_2O	TEMP °F	VELOCITY FT/SEC
1	0 03	290	13 6	0 03	340	14 2	0 02	360	11 7
2	0 055	290	18 7	0 04	340	16 4	0 03	360	14 4
3	0 07	290	21 1	0 06	340	20 1	0 05	360	18 6
4	0 02	290	11 2	0 03	340	14 2	0 06	360	20 4
B	0.05	290	17.8	0.045	340	17.1	0.03	360	14.4
5	0 04	300	16 0	0 04	340	16 4	0 05	360	14 4
6	0 045	300	16.9	0 035	340	15 4	0 03	360	14 4
7	0.06	300	19.6	0.04	340	14.4	0.04	360	16.7
8	0.08	300	22.6	0.06	340	20.1	0.06	360	20.4
B	0.05	300	17.9	0.04	340	16.4	0.0.	360	14.4
9	0.03	300	13.9	0.03	350	14.3	0 02	360	11 7
10	0 04	300	16 0	0 03	350	14.3	0.03	360	14.4
11	0.045	300	16 9	0 04	350	16 5	0 025	360	13 2
12	0 08	300	22 6	0 06	350	20 3	0 06	360	20 4
B	0 05	300	17 9	0 04	350	16 5	0 03	360	14 4
13	0 04	300	16 0	0 02	350	11 7	0 02	360	11 7
14	0 04	300	16.0	0 02	350	11 7	0 02	360	11 7
15	0 05	310	18 0	0 045	350	17 5	0 04	360	16 7
16	0.07	310	21 3	0 06	350	20.3	0.065	360	21 2
B	0.045	310	17.1	0.03	350	14.3	0.03	360	14 4
17	0.03	310	13.9	0.02	350	11.7	0.025	360	13 2
18	0.035	320	15.2	0.03	350	14.3	0.03	360	14 4
19	0 04	320	16.2	0.04	350	16.5	0.04	360	16 7
20	0 07	320	21 5	0 06	350	20 3	0 065	360	21 2
B	0 045	320	17 2	0 035	350	15 5	0 03	360	14 4
21	0.02	330	11.5	0.02	350	11 7	0 02	370	11 8
22	0 02	330	11 5	0 03	350	14 3	0 03	370	14 5
23	0 04	330	16 3	0 045	350	17 5	0 04	370	16 8
24	0.07	330	21.6	0.065	350	21 1	0 06	370	20 5
B	0 03	330	14 1	0 035	350	15 5	0 035	370	15 7

A. AVERAGE VELOCITY (TRAVERSE) FT/SEC _____

B AVERAGE VELOCITY (REFERENCE PT) FT/SEC _____

C FLUE FACTOR A/B _____

D PITOT CORRECTION FACTOR _____

E GAS DENSITY CORRECTION FACTOR _____

F CORRECTED VELOCITY, A×D×E, FT/SEC _____

OR B×C×D×E, FT/SEC _____

G AREA OF FLUE, SQ FT _____

H AVERAGE FLUE TEMPERATURE, °F _____

J FLOW RATE, F×G×60, CFM _____

K FLOW RATE, 520×J/(H+460), SCFM _____

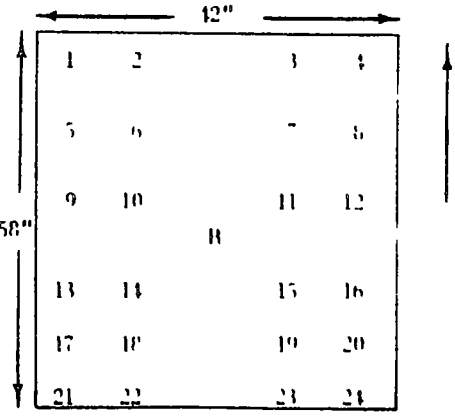


Figure 2

AIR POLLUTION CONTROL DISTRICT -- COUNTY OF LOS ANGELES

TEST NO. _____ PAGE 27

SAMPLING STATION Inlet of Precipitator - Test II DATE June 8, 1960

WATER VAPOR AND GAS DENSITY CALCULATIONS

PERCENT WATER VAPOR IN GASES

	Dust and Fumes Train	Particle Size Train
A. GAS PRESSURE AT METER, IN. HG (ABSOLUTE)	24.8	22.6
B. VAPOR PRESSURE OF WATER AT IMPINGER TEMP., IN. HG	0.504	0.580
C. VOLUME OF METERED GAS, CU.FT.	42.10	55.38
D. VOLUME OF WATER VAPOR METERED, B*C/A, CU.FT.	0.855	1.42
E. VOLUME OF WATER VAPOR CONDENSED, CU.FT.	3.2	4.7
F. TOTAL VOLUME OF WATER VAPOR IN GAS SAMPLE, D+E, CU.FT.	4.1	6.1
G. TOTAL VOLUME OF GAS SAMPLE, C+E, CU.FT.	45.3	60.1
H. PERCENT WATER VAPOR IN SAMPLED GAS, 100*F/G	9.1	10.1

GAS DENSITY CORRECTION FACTOR

COMPONENT	VOLUME PERCENT/100	x MOISTURE CORRECTION	x MOL. WT.	= WEIGHT PER MOLE WET BASIS
WATER		1.0	18.0	
CARBON DIOXIDE	DRY BASIS		44.0	
CARBON MONOXIDE	DRY BASIS		28.0	
OXYGEN	DRY BASIS		32.0	
NITROGEN & INERTS	DRY BASIS		28.2	
			AVERAGE MOLECULAR WEIGHT	

J. DENSITY OF GAS REFERRED TO AIR = $\frac{\text{Av. Mol. Wt.}}{28.95}$ = _____

K. GAS DENSITY CORRECTION FACTOR = $\sqrt{\frac{1.00}{J}}$ = _____

Figure 3

AIR POLLUTION CONTROL DISTRICT -- COUNTY OF LOS ANGELES

TEST NO _____ PAGE 19

SAMPLING STATION Inlet of Precipitator - Test 1 DATE June 8, 1960

SAMPLING TRAIN DATA AND CALCULATIONS

TIME	GAS METER READING CU FT V_M	GAS METER VAC IN HG P_M	GAS METER TEMP °F T_M	IMPINGER TEMP °F T_I	Sample Point
12 30	69.71				
12 35	77.5	9.0	78	68	7
12.40	83.5	9.2	78	72	7
12.45	90.0	9.2	78	72	7
12 50	96 4	9 4	80	72	7
12.55	103.0	9.4	80	72	6
1 00	110 0	9 4	83	72	6
1 05	115 7	9 4	83	72	R
1.10	122.2	9.4	83	70	R
1.15	129.2	9.4	83	64	4
1 20					4
1 25	141 5	9 6	85	62	3
1 30	148 22	9 6	85	62	3
60 min. Net	78.51 Net	9.3 Av	81 Av	68 Av.	

MATERIAL COLLECTED Particle Size

WEIGHT COLLECTED, GRAMS
- Decanted solids - 1.3825
- Filtered solids - 0 0032
- Solvent soluble - 0.0124
- Water soluble - 0.4114
- Whatman thimble - 0 075

A TOTAL WEIGHT 1 885

SAMPLING POINT 3, 4, R, 6, 7

SAMPLING NOZZLE DIAMETER 12 mm

Loss on Ignition
- Filtered solids 0 0017 grams
- Solvent soluble 0 0116
- Water soluble 0 1479

B STACK GAS FLOW RATE, SCFM 8,800

C CONDENSATE VOLUME, ML 46

D CONDENSATE VAPOR VOLUME, $.00267 \times C \times (460 + T_M)/(29\ 9 - P_M)$, CU.FT 3 2

E TOTAL SAMPLED VOLUME, $V_M + D$, CU FT 81 7

F SAMPLED VOLUME, $520 \times E \times (29\ 9 - P_M)/29\ 9 \times (460 + T_M)$, SCF 54 1

G CONCENTRATION, 15 43×A/F, GRAINS/SCF 0 54

H MATERIAL FLOW RATE, 60×G×B/7000, LBS./HR 41

Figure 4

AIR POLLUTION CONTROL DISTRICT---COUNTY OF LOS ANGELES

TEST NO. _____

PAGE 17

DATE June 8, 1960

SUMMARY OF TEST DATA

Test II - Second Hour

	Inlet		Outlet	
1. SAMPLING STATION				
2. MATERIAL COLLECTED	Dust & Fumes	Part. Size	Dust & Fumes	Part. Size
3 OPERATING CONDITION				
4. AV FLUE GAS VELOCITY, FT /SEC.	47.5	47.5	15.2	15.2
5. AV. FLUE GAS TEMP., ^{o}F	780	780	460	460
6 AREA OF FLUE, SQ. FT.	7.07	7 07	16.9	16.9
7. FLUE GAS FLOW RATE, SCFM	8,500	8,500	8,700	8,700
8. SAMPLING NOZZLE DIAM., MM	8.5	10	11	12
9. METER SAMPLING RATE, CFM	0.70	0.92	0.71	1.28
10. TESTING TIME, MIN.	60	60	60	60
11. AV. METER VACUUM, IN. HG	5.1	7.3	4.0	9.1
12. AV METER TEMP , ^{o}F	85	87	101	96
13. SAMPLE GAS VOL. - METER COND , CF	42.10	55.38	42.79	77.03
14. WATER VAPOR CONDENSATE, ML	54	73	36	71
VOLUME, CF, METER COND.	3.2	4.7	2.1	5.1
15. TOTAL SAMPLE GAS VOLUME, CF	45.3	60.1	44.9	82.1
16 TOTAL SAMPLE GAS VOLUME, SCF	35.8	43.2	36.1	53.4
17. WEIGHT COLLECTED, GRAMS A Insolubles	0.6984	0.8297	0.0178	0.0438
B. Solvent Sol.	0.1386	0.0076	0.0060	0.0077
C. Water Sol.	0.3015	0.4916	0.1144	0.1565
D. Filter	0.192	0.154	0.042	0.006
TOTAL WEIGHT, GRAMS	1.331	1 483	0 180	0 214
18. CONCENTRATION, GRAINS/SCF	0 57	0.53	0.077	0 062
19 CONCENTRATION, GRAINS/SCF @ 12% CO_2				
20. CONCENTRATION, PERCENT BY VOLUME				
21. CONCENTRATION, PPM BY VOLUME				
22, MATERIAL FLOW RATE, LBS/HR.	42	39	5 7	4 6

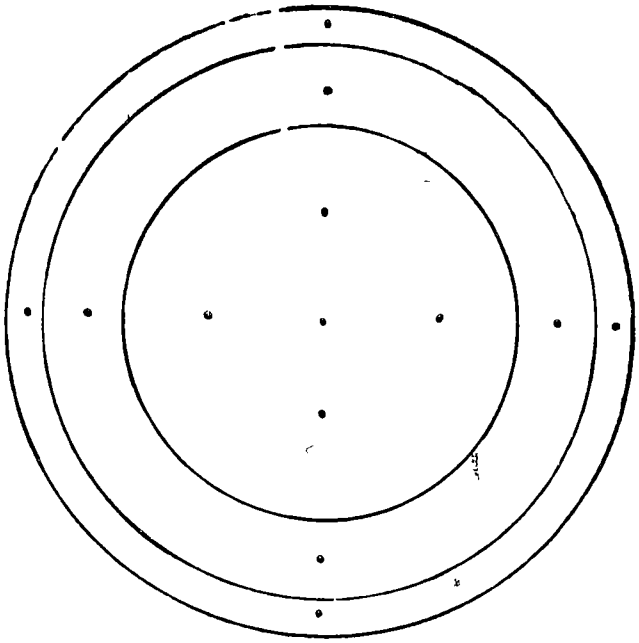
COLLECTION EFFICIENCY

23. MATERIAL TO COLLECTOR, LBS/HR.	42
24. LOSS TO ATMOSPHERE, LBS/HR	5.7
25. MATERIAL COLLECTED, LBS/HR.	36
26. EFFICIENCY, %	86

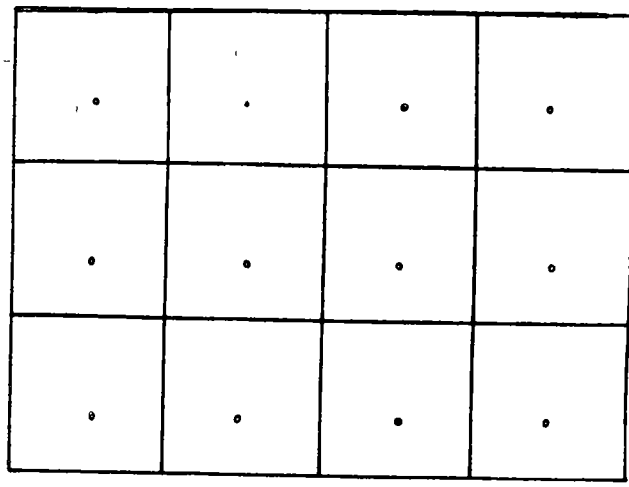
ORSAT ANALYSIS

DRY BASIS				
CO_2, %			8.1	
O_2, %			12.2	
CO , %			0.03	
N_2, %			79.7	
WET BASIS				
CO_2, %			7.6	
O_2, %			11.4	
CO , %			0.03	
N_2, %			74.3	
H_2O, %	9.1	10.1	6.7	8.8

Figure 5



Cross section of a circular stack divided into three concentric equal areas, showin location of traverse points.. The location and number of such points for a stack of given diameter can be determined by referring to Table II.



Cross section of rectangular stack divided into 12 equal areas, with traverse points located at the center of each area.

TABLE I

Suggested Number of Equal Areas for Velocity Measurement in Circular Stacks

Stack Diameter (feet)	Number of Equal Areas
1 or less	2
1 - 2	3
2 - 4	4
4 - 6	5
over 6	6 or more

TABLE II

Percent of Circular Stack Diameter From Inside Wall to Traverse Point

Point Number	Number of Areas Selected				
	2	3	4	5	6
1	6.7	4.4	3.3	2.5	2.1
2	25.0	14.7	10.5	8.2	6.7
3	75.0	29.5	19.4	14.6	11.8
4	93.3	70.5	32.3	22.6	17.7
5		85.3	67.7	34.2	25.0
6		95.6	80.6	65.8	35.5
7			89.5	77.4	64.5
8			96.7	85.4	75.0
9				91.8	82.3
10				97.5	88.2
11					93.3
12					97.9

Figure 6

NOMENCLATURE

V = Face velocity

C = Pitot calibration coefficient including unit balance

T = Absolute temperature

P = Absolute pressure

M = Molecular weight

ΔP = Differential pressure

Q = Volumetric flow rate

A = Area

N = Mole fraction of non-condensibles or non-reactables

B = Orifice calibration coefficient including unit balance

H = Differential pressure of orifice

d = Diameter of nozzle

Subscripts

s = in stack

n = in nozzle

m = in meter

Special Case

Isokinetic Equation

1) $V_s = V_n$ when isokinetic

2) Pitot Equation

$$V_s = C \frac{T_s}{P_s} \frac{P}{M_s}$$

Figure 7

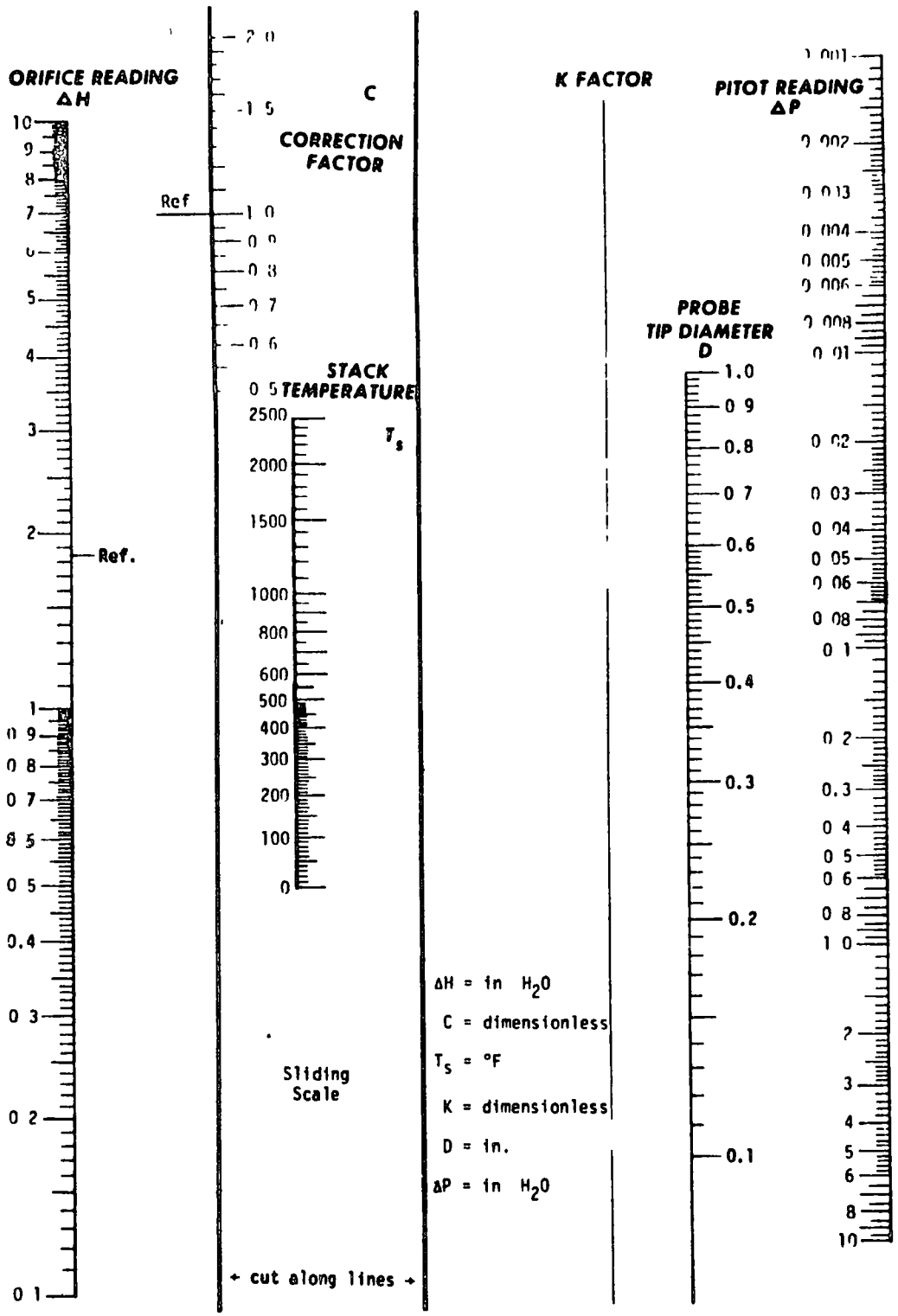
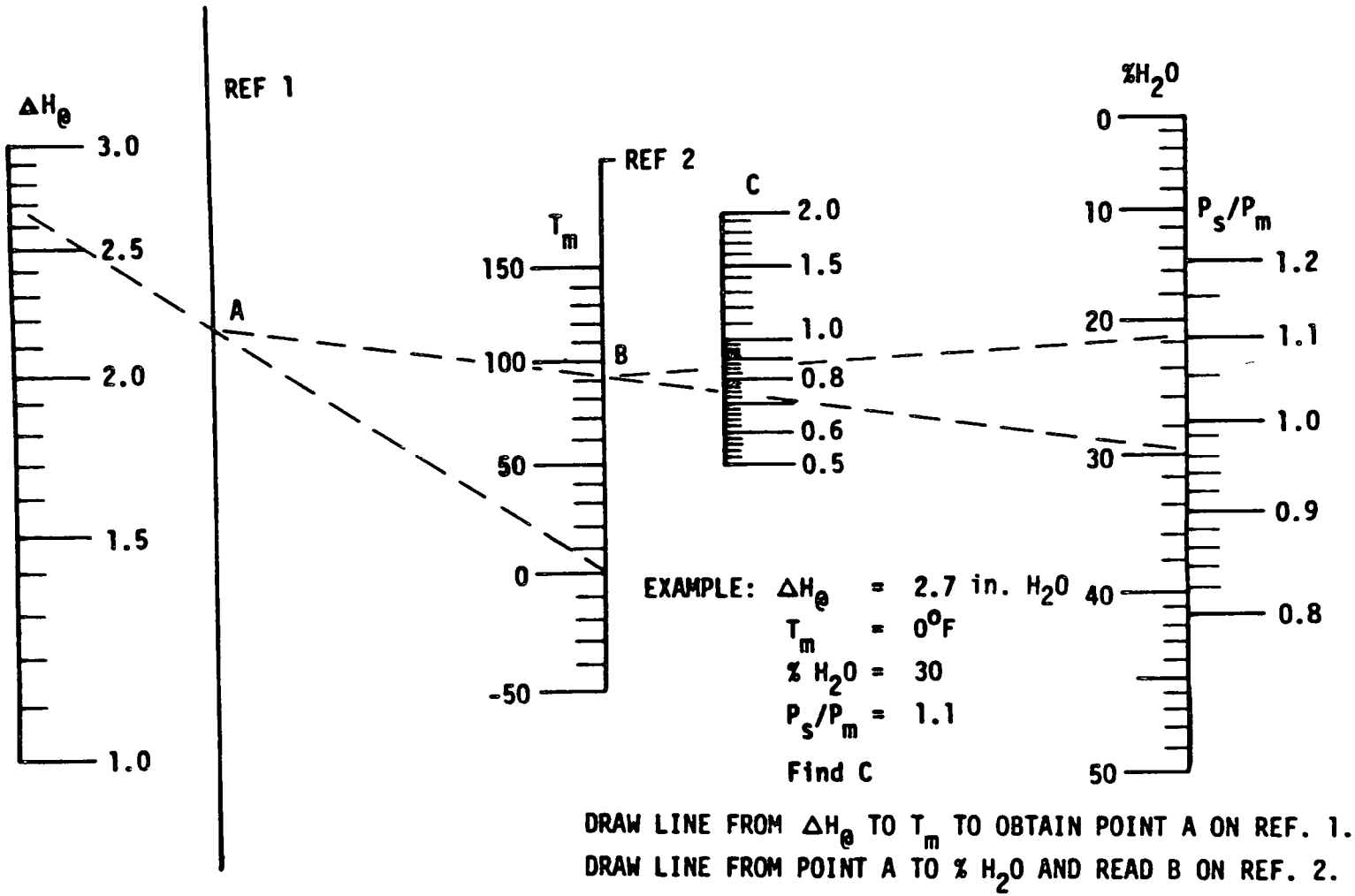
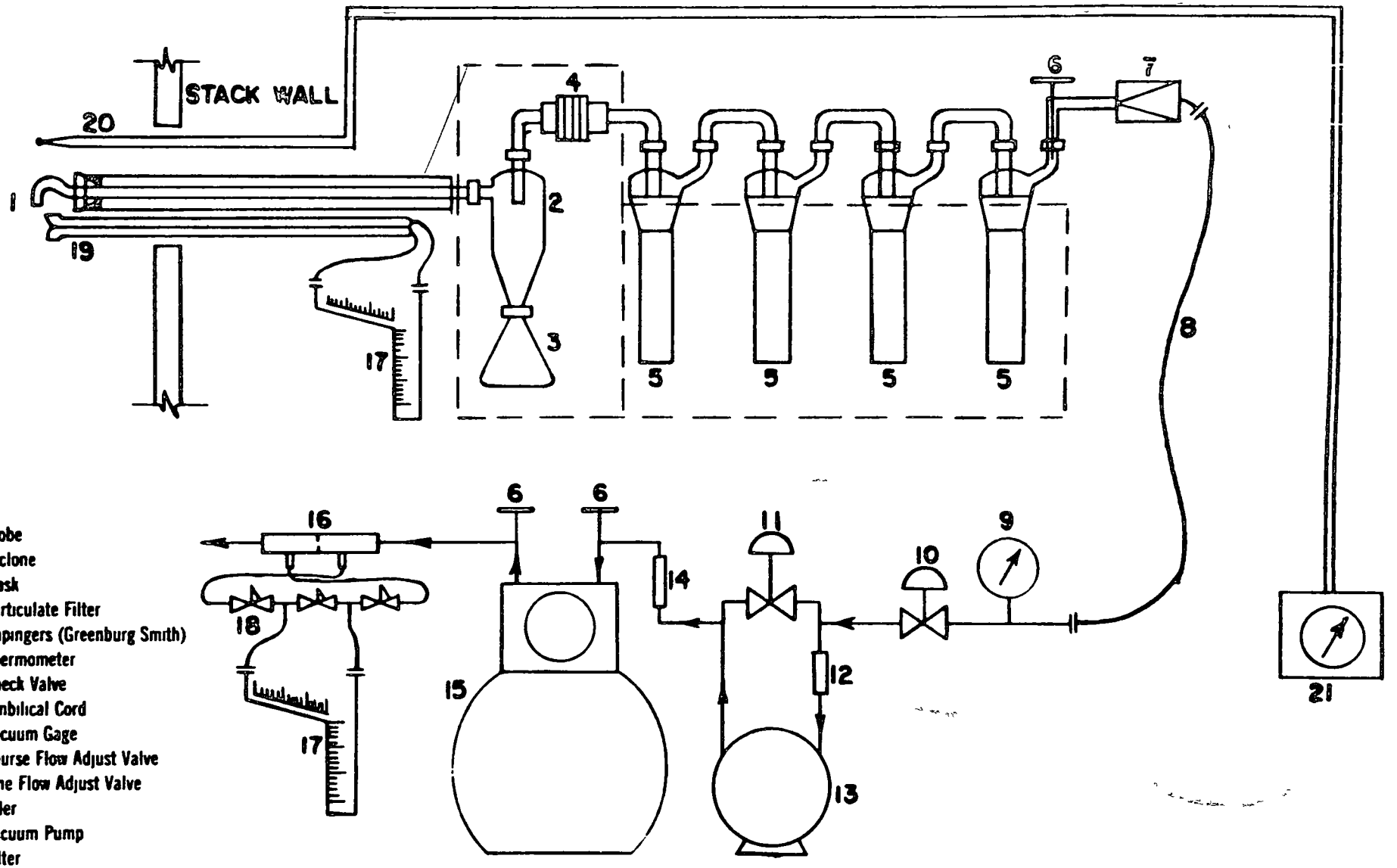


Figure 8. Operating nomograph.



DRAW LINE FROM ΔH_e TO T_m TO OBTAIN POINT A ON REF. 1.
DRAW LINE FROM POINT A TO % H_2O AND READ B ON REF. 2.
DRAW LINE FROM POINT B TO P_s/P_m, AND OBTAIN ANSWER OF 0.85 FOR C.

Figure 9. Correction factor C for Figure 8.



1) Probe
2) Cyclone
3) Flask
4) Particulate Filter
5) Impingers (Greenburg Smith)
6) Thermometer
7) Check Valve
8) Umbilical Cord
9) Vacuum Gage
10) Course Flow Adjust Valve
11) Fine Flow Adjust Valve
12) Oiler
13) Vacuum Pump
14) Filter
15) Dry Gas Meter
16) Orifice Tube
17) Incline Manometer
18) Solenoid Valves
19) Pitot
20) Thermocouple
21) Pyrometer

FIGURE 10

PROPERTY OF
RESEARCH APPLIANCE Co. ALLISON PARK, PA.

TOLERANCES DEC ± FRACT ±	TITLE STAKSAMPLER FLOW SYSTEM		
	DWG NO 1748	MAT'L	SCALE
NO REQ'D	DRAWN BY R.G.	APPR.	DATE 6-23-69
FINISH		JIG NO	PART NO

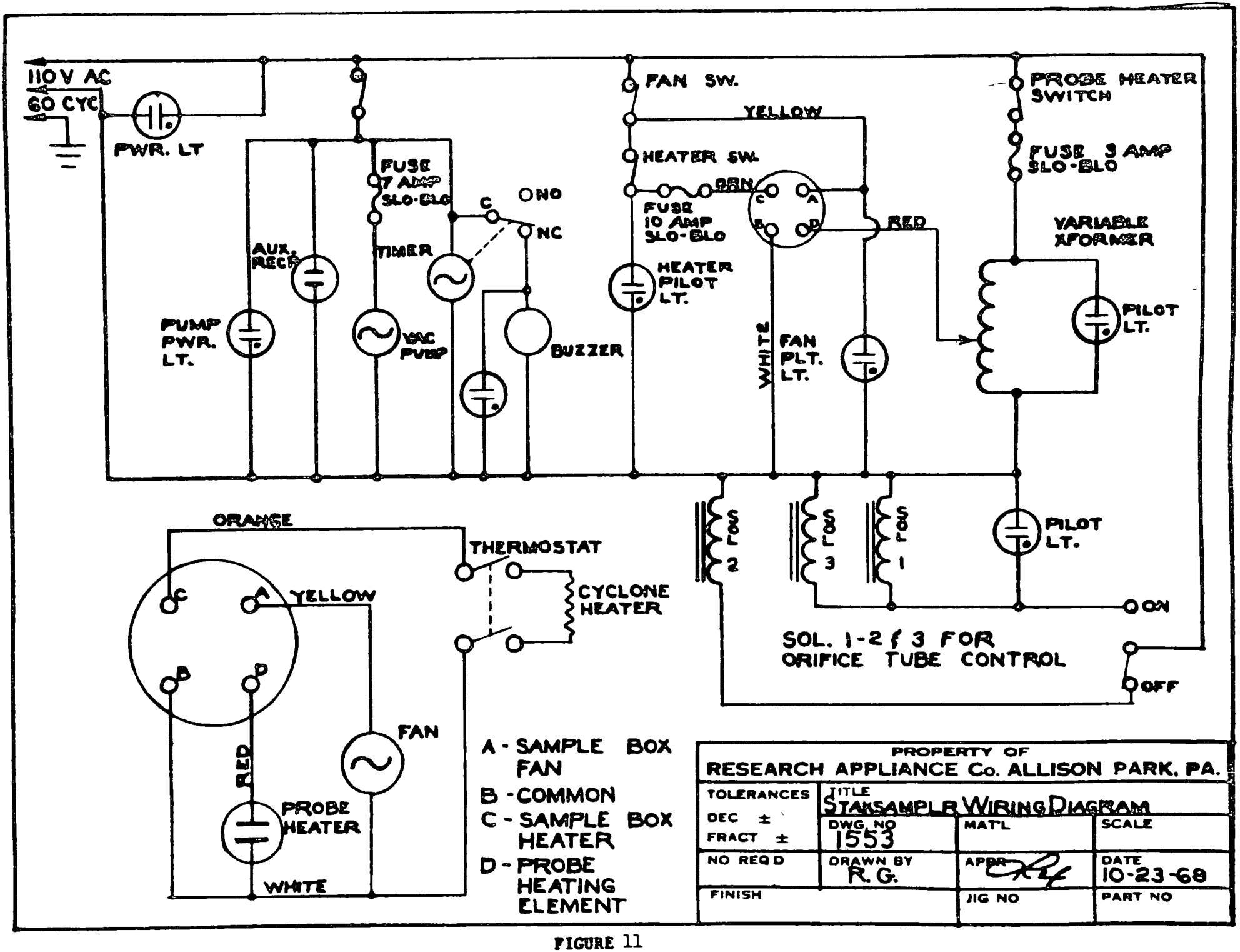
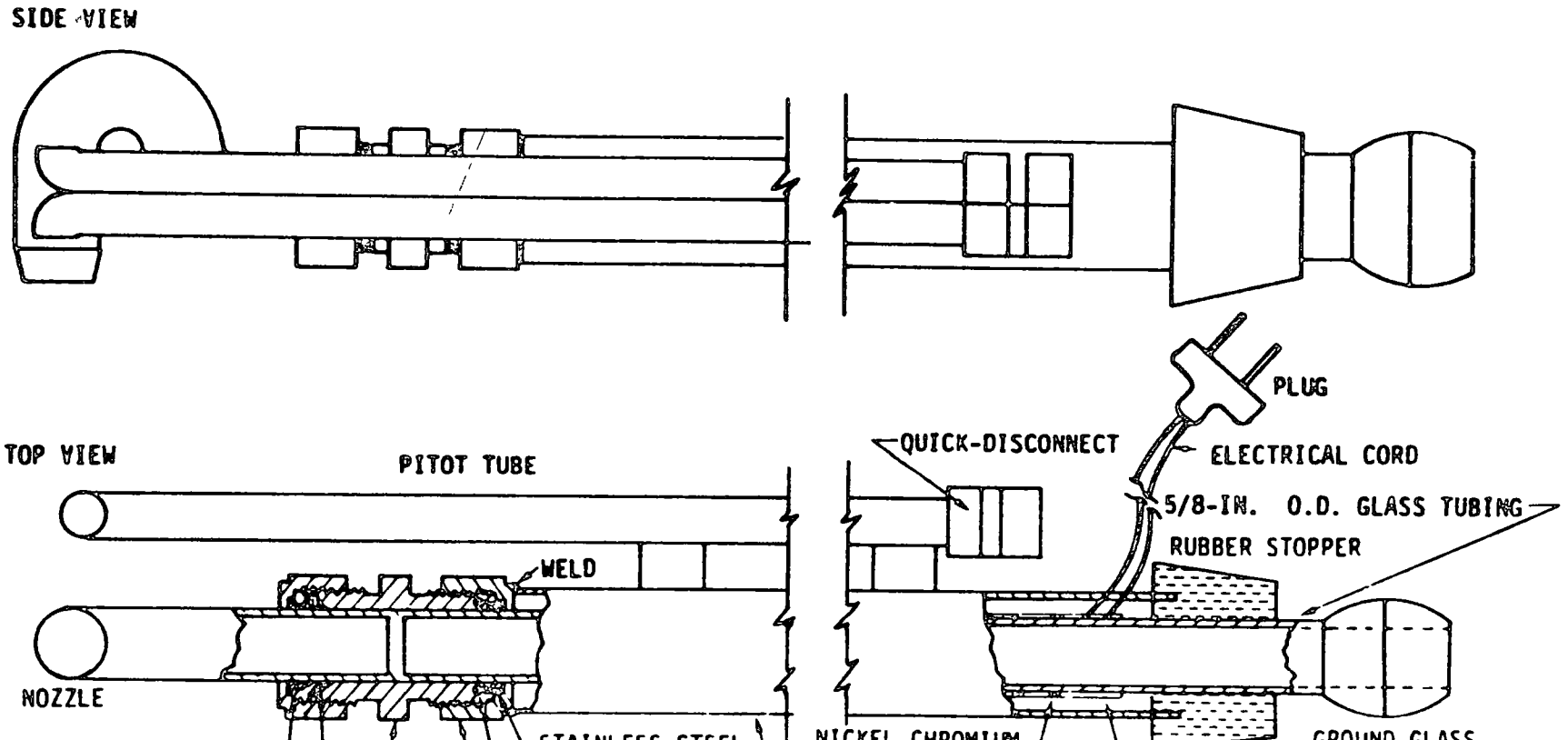

110 V AC
60 CYC
PWR. LT
FUSE 7 AMP SLO-BLO
AUX. RECT.
TIMER
C
NO
NC
PUMP PWR. LT.
VAC PUMP
BUZZER
FAN SW.
YELLOW
HEATER SW.
ORN
FUSE 10 AMP SLO-BLO
HEATER PILOT LT.
RED
WHITE
FAN PLT. LT.
PROBE HEATER SWITCH
FUSE 3 AMP SLO-BLO
VARIABLE XFORMER
PILOT LT.
SOL 2
SOL 3
SOL 1
PILOT LT.
ON
OFF
SOL. 1-2 & 3 FOR ORIFICE TUBE CONTROL
ORANGE
THERMOSTAT
CYCLONE HEATER
YELLOW
FAN
RED
PROBE HEATER
WHITE
A - SAMPLE BOX FAN
B - COMMON
C - SAMPLE BOX HEATER
D - PROBE HEATING ELEMENT
PROPERTY OF
RESEARCH APPLIANCE Co. ALLISON PARK, PA.
TOLERANCES
DEC ±
FRACT ±
TITLE
STAKSAMPLER WIRING DIAGRAM
DWG NO
1553
MAT'L
SCALE
NO REQ'D
DRAWN BY
R. G.
APPR
DATE
10-23-68
FINISH
JIG NO
PART NO

FIGURE 11



NOTE: 1. PITOBE LENGTH CAN BE ANY SUITABLE SIZE.

2. NOZZLE DIAMETER AND CONFIGURATION CAN BE A VARIETY OF SIZES, BUT IT MUST HAVE A 5/8-IN. SHANK.

Figure 12. Pitobe.

CUSTOMER TO MODIFY ANGLE TO FIT THEIR STACK

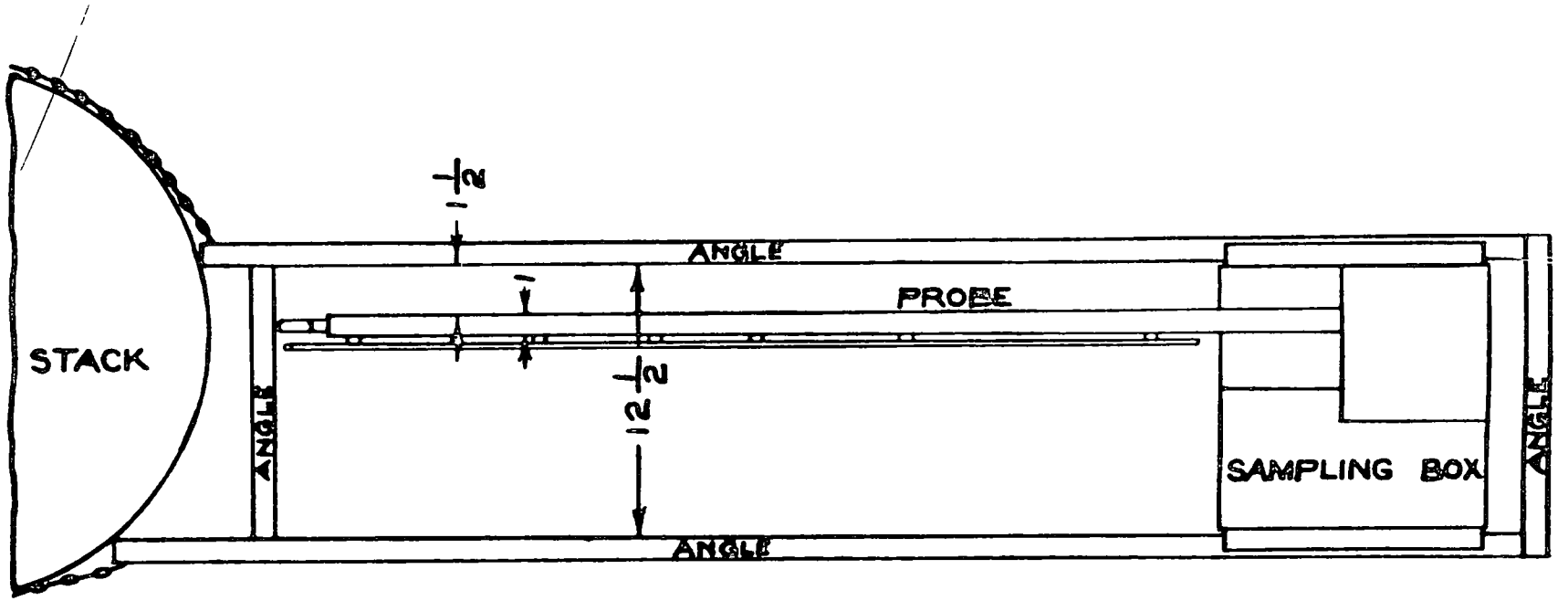


FIGURE 14

PROPERTY OF
RESEARCH APPLIANCE Co. ALLISON PARK. PA.

TOLERANCES DEC ± FRACT ±	TITLE STAK SAMPLER MOUNTING (TOP VIEW)		
NO REQ'D	DWG NO 1532	MAT'L —	SCALE —
	DRAWN BY R.G	APPR	DATE 9-25-68
FINISH		JIG NO	PART NO

NOMECLATURE

A = orifice area, ft^2

C = $(K_{actual})/(K_{assumed})$, dimensionless

C_p = pitometer calibration factor, dimensionless

D = Nozzle diameter, ft.

g_c = gravitational constant, $32.17 \cdot (lb_{mass})(ft)/lb_{force})(sec^2)$.

ΔH = orifice pressure differential, $(lb_{force})/(ft^2)$

$\Delta H_@$ = orifice pressure differential that give 0.75 cfm of air at 70°F and 29.92 in Hg, $(lb_{force})/(ft^2)$

J = orifice coefficient, dimensionless

K = defined by Equation 5

M_c = mole fraction of dry gas in stack effluent, dimensionless

M_m = dry effluent molecular weight, $(lb_{mass})/(lb\text{-mole})$

M_s = effluent molecular weight, $(lb_{mass})/(lb\text{-mole})$

P_m = meter pressure, $(lb_{force})/(ft^2)$

P_s = stack pressure, $(lb_{force})/(ft^2)$

ΔP = pitometer pressure differential, $(lb_{force})/(ft^2)$

Q_m = volumetric flow rate, $(ft^3)/(sec)$

R = gas-law constant, 1545 $(ft)(lb_{force})/(°R)(lb\text{-mole})$

T_m = effluent temperature at the meter, °R

T_s = stack gas temperature, °R

V_p = stack velocity at a traverse point, ft/sec

Figure 15

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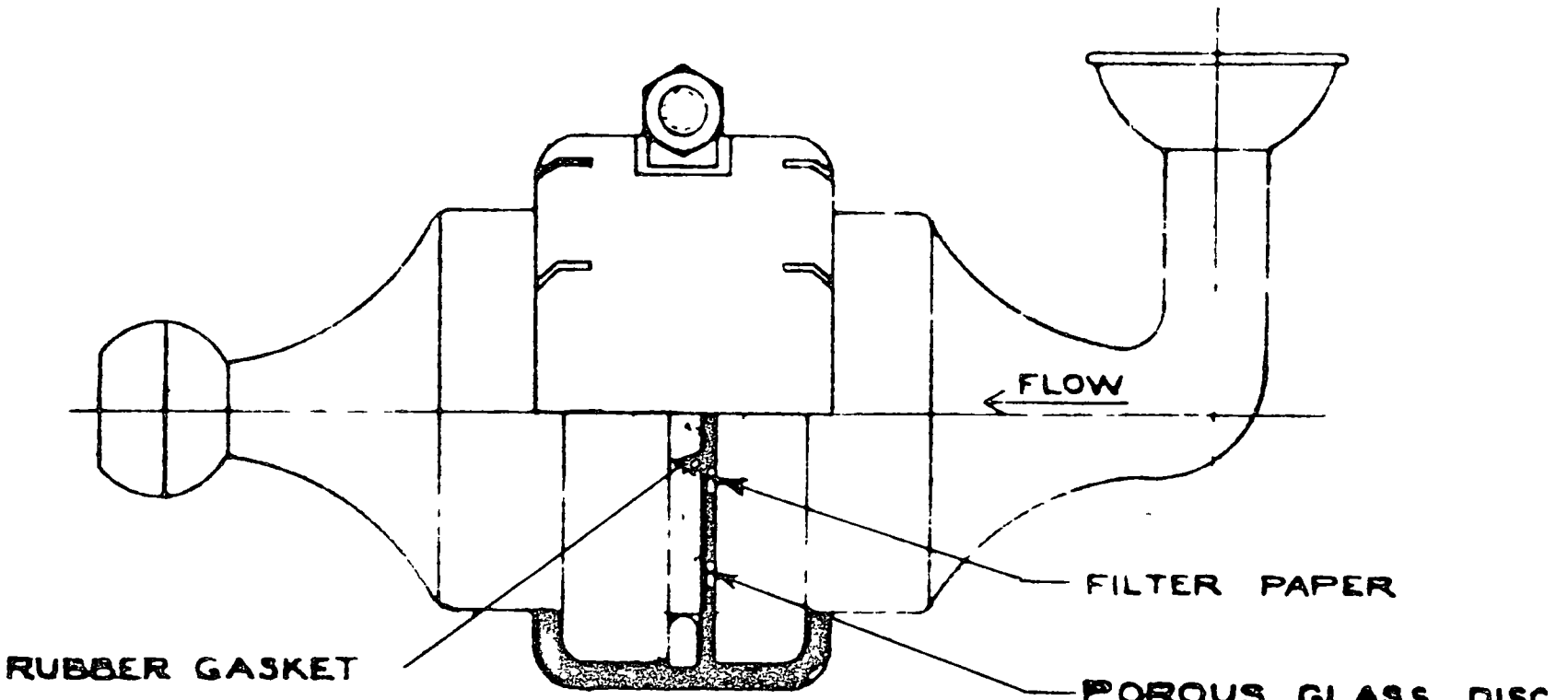

PROPERTY OF
RESEARCH APPLIANCE Co. ALLISON PARK, PA.

TOLERANCES DE ? FRACT ± NO R[illegible]	TITLE STAKSAMPLER FILTER ASSEMBLY		
	DWG NO 1914	MATL —	SCALE FULL
	DRAWN BY R.G.	APPR	DATE 3-18-70
FINISH		JIG NO	PART NO

Research Appliance Co. Rt. 8 & Craighead Road, Allison Park, Pa. 15101

SUBJECT: Staksamplr Model 2343 Your P.O._____

Dear Customer:

Before acknowledging your purchase order for "Staksamplr" components we wish to make clear the operating limits of the unit.

1. Maximum operating temperature of the 3' and 5' pitobes with Pyrex glass inner tubing -- 800°F.

2. Maximum operating temperature of the 3', 5' and 10' pitobes with stainless steel inner tube -- 1200°F.

3. Maximum pitobe length 10 ft. (effective length).

4. Type 304 stainless steel used on all probes.

5. 1000 FPM minimum, 10,000 FPM maximum velocity on stack.

6. 50% maximum moisture content in stack gas.

7. Maximum length of umbilical cord (distance from sampling probe to control case 100 ft.)

8. Sampling is done Isokenetically. The sample is drawn through the pitobe in to the glass sampling train where the particulate and gases are collected. The control case should be conveniently located somewhere no further than a maximum distance of 100' from the sampling port.

9. Grain loading with a variation of flow rate by a factor of 2 will give you 5% accuracy with Isokenetic sampling.

10. Nomograph is supplied with unit for field calculations.

11. Sampling probe tips come in 3 sizes 1/4", 3/8" and 1/2" diameters. Sampling port diameter should be no less than 2-1/2" minimum. Temperature range of stack gas should be known to determine type of probe to be used.

12. 3 sets of glass elements should be used to run a complete sampling test. Cyclone removes particles greater than 5 microns. Glass filter removes particles down to .3 microns.

13. Fluoride 95% Accuracy, Chloride 95% Accuracy, Chlorine 95% Accuracy, SO_2 with peroxide in 2 Greenburg-Smith Impingers will give you 95% Accuracy, Hydrochloric Acid 95% Accuracy, Measurement of wet phosphoric acid, furnace phosphoric acid, phosphate fertilizer, titanium, incineration and coal combustion have also proven successful.

14. Analysis of samples is made at laboratory.
A. Particulate is expressed as weight per standard cubic foot or weight per unit.
B. Gaseous emissions are expressed in the units or parts per million (Volume ratio) or weight per unit time.
C. Combustion processes measurement of Carbon Monoxide is usually made with an Orsat Analyzer.
D. The water content of the sampling gas is calculated from the vapor removed in the impinger.

Research Appliance Company manufactures and makes available commercially this apparatus which has been developed and used by the National Air Pollution Control Administration in their stack sampling program. Research Appliance Company does not have the trained personnel to teach the art of stack sampling. This is something the purchaser must be knowledgeable in or acquire through training.

Training courses in this field are offered by the National Air Pollution Control Administration at Durham, North Carolina. Description and operating instructions are included with the apparatus, however.

Research Appliance Company
Sales Department

2/6/70

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A SYSTEMATIC PROCEDURE FOR DETERMINING THE COST OF CONTROLLING PARTICULATE EMISSIONS FROM INDUSTRIAL SOURCES

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The increasing concern about the air quality of our nation has created a similar concern in the costs associated with reducing emissions to desirable levels. The information available on such costs is not only scarce but is further complicated by reporting inconsistency. The purpose of this paper is to bridge this inadequacy by presenting a methodology for assessing the cost of controlling particulate emissions from industrial sources. Basic equipment costs were collected and evaluated for dry centrifugal and wet collectors, fabric filters, electrostatic precipitators, and afterburners. Manufacturers, installers, users, and operators of air pollution control equipment were contacted to obtain the necessary cost data for the year 1968. A basic premise of the procedure developed is that the most meaningful approach to the evaluation and comparison of air pollution control costs is based on the total cost of control annualized over the expected economic life of the equipment. Items such as capital charges and expenditures for operation, maintenance, and collected waste disposal are generally more significant in cost accounting than the depreciated value of the initial investment. By defining the size and efficiency of collection required, the degree of difficulty in installing the equipment, and knowledge of some of the characteristics of the involved process, gas stream, and pollutant characteristics, the cost of control can be estimated with the assistance of cost factors and guidelines presented.

A new dimension of intensified interest and investigation was added to the field of air pollution control with the passage of The Air Quality Act of 1967. For the first time, comprehensive economic investigations were to be undertaken to determine the cost of reducing air pollutant emissions and to assess the related economic and welfare benefits to be derived from various levels of required control effort. Accommodating such comprehensive studies requires detailed information on the cost incurred from the application of air pollution control system alternatives.

This paper presents basic collection equipment costs and estimating factors for assessing the total cost of control. In addition, a procedure is outlined for calculating the total cost of various devices for the collection of particulate matter from industrial processes. Such information enables the implementers of air quality-oriented control programs to consider air pollution problems from an economic, as well as a technical viewpoint, which will result in more effective control decisions. This concept of air quality–oriented control programs provides an economically defensible and scientifically sound course of action for reducing the burden on our air resources.

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The technology and art of applying devices for cleaning particulate laden gas is well defined, after years of research and practical experience. Historically most control efforts have been directed toward nuisance abatement and visible plume reduction. The advent of air quality standards and increasingly stringent emission standards will require many users and operators of control devices to install more efficient gas cleaning devices. Achievement of higher efficiencies within reasonable cost limits demand that attention be directed toward integration of control equipment into the industrial process and plant layout. Figure 1 illustrates this concept in the selection of gas cleaning equipment for removing particulate matter (dust, fume, mist, aerosol) from gas streams of industrial processes.

As shown in Figure 1, initial consideration in control equipment selection must be given to air quality and emission standards, from which collection efficiency may be ascertained. Attention should be given not only to existing but also to anticipated control requirements. The overlapping of collection efficiency ranges for various types of control equipment, as shown in Table I, allows a certain amount of flexibility in equipment selection. For example, to achieve 99% collection efficiency, a theoretical choice may be made from among electrostatic precipitators, fabric filters, and wet collectors.

Consideration should also be given to gas stream and particle characteristics. The most important factor here is the gas volume, which determines the size of collection equipment. Other characteristics may present problems or conditions that not only affect equipment selection, but also its operation, durability, and service. For example, the danger of a flash fire may preclude fabric filters altogether. In another situation, a corrosive gas stream will shorten the life of a wet collector unless the collector is constructed of corrosion-resistant materials.

Further consideration in equipment selection, as shown in Figure 1, should be given to the accommodations. For example, wet collectors require large amounts of water and space for waste disposal. Electrostatic precipitators, because of their size, may require considerable space and elaborate structural support.

Economics should also be considered in selection of control equipment. The cost of control items listed in Figure 1 should be evaluated to select the most economic gas cleaning system that is adaptable to the process and other requirements.

Estimating Control Costs

There are several procedures available for estimating the cost of an air pollution control system. The accuracy of the estimate depends on the amount of work done on problem assessments and system design, and the degree of component accounting undertaken. Usually, the more laborious the procedure, the more accurate the estimate. Estimates prepared for competitive situations are developed through such procedures, and are usually considered to be of poor quality if they deviate by more than 5-8% from true costs. Besides being extremely time consuming, such detailed estimation is beyond the requirements of most air pollution control program needs. For these reasons a simplified approach may be taken.

The procedure presented in this paper is a compilation of cost aggregations derived from the most definable cost component - the cost of "flange-to-flange" control hardware. Only those accounting items most directly associated with control costs and definable for general application to all industries are included in the cost aggregations. Costs of such items as engineering studies, land, and site preparation, which are extremely variable from one location to another, were excluded from the procedures described.

The costs developed in this paper are accurate to within ±20% of specific equipment costs and to within ±30% of total capital investment. Such cost ranges take into account cost differences caused by variation in engineering design among similar coll ction types, labor rates, taxes, freight, construction codes, and gas stream characteristics.

Additional problems are encountered in estimating the cost of operating and maintaining control equipment. Records of comprehensive operating and maintenance costs are usually not available as they are considered impractical, too costly to maintain, and insignificant in terms of overall production cost. In the absence of such information, cost equations were developed on the basis of the assumption that control equipment is operated and maintained so that it functions at its designed collection efficiency.

Source of Cost Data

The cost information presented in this paper is based on careful study of the literature, and survey of many suppliers, installers, and operators of air pollution control equipment. The cost information was reviewed by experts from the gas cleaning equipment industry for reasonableness of data and methodology. In acquiring this cost information, care was exercised to assure completeness and consistency. The cost data reflect 1968 prices.

Categorization of Costs

The total cost of installing and operating air pollution control equipment is the function of three major definable cost categories: (1) capital investment, (2) operating and maintenance costs, and (3) capital charges.

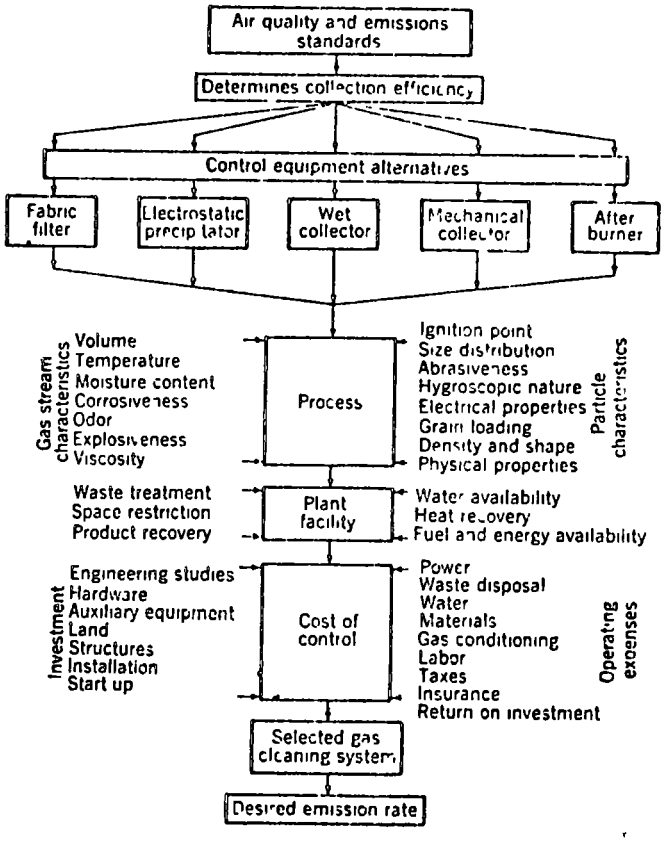


Figure 1. Criteria for selection of gas cleaning equipment.

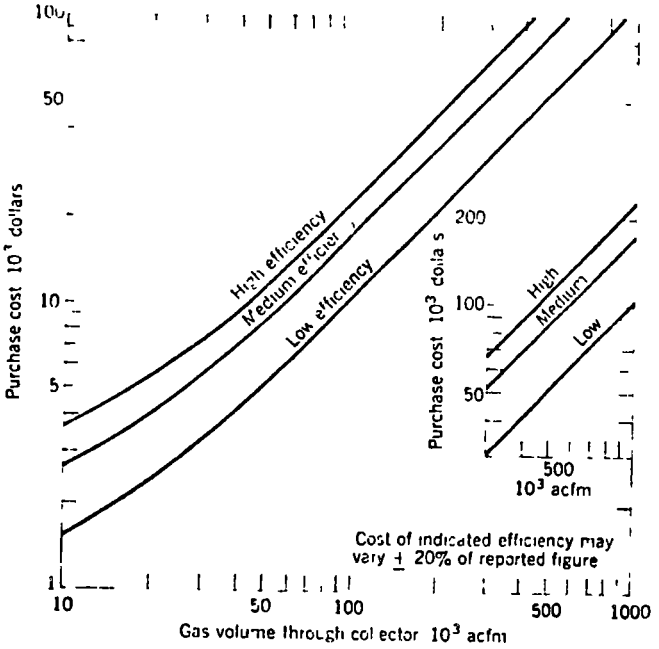


Figure 2 Purchase cost of dry centrifugal collectors

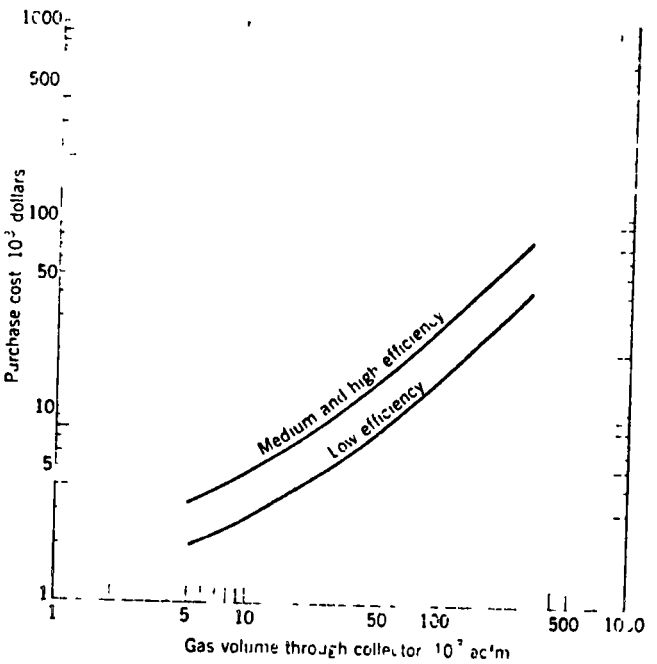


Figure 3 Purchase cost of wet collectors

Capital Investment

The "installed cost" quoted by a manufacturer of air pollution control equipment is usually based on an engineering study of the actual emission source. The cost includes three items: (1) control hardware costs, (2) auxiliary equipment costs, and (3) costs for field installation. Other costs incurred in a control installation include engineering studies, land, site preparation, operating supply inventory, structural modification, and start-ups. The variance of these cost items is beyond the limits of general consideration.

The purchase cost curves presented in Figure 2 through 6 illustrate the control hardware costs for dry centrifugal collectors, wet collectors, electrostatic precipitators, fabric filters, and afterburners. These purchase costs are the amounts charged by manufacturers for equipment of standard construction materials. Equipment fabricated with special materials (e.g., stainless steel 316 or ceramic coatings) to withstand high-temperature or corrosive gas streams will cost considerably more than reported in the figures.

Table I Air pollution control equipment collection efficiencies [1,2,3]

Equipment type	Typical efficiency ranges (on a total weight basis) (%)
Electrostatic precipitator[a]	80–99.5+
Fabric filters[b]	95–99.9
Mechanical collector	50–95
Wet collector	75–99+
Afterburner	
Catalytic[c]	50–80
Direct flame	95–99

[a] Most electrostatic precipitators sold today are designed for 98–99.5% collection efficiency.
[b] Fabric filter collection efficiency is normally greater than 99.5%.
[c] Not normally applied in particulate control, has limited use because most particulate matter poisons or desensitizes the catalyst.

Purchase cost varies with the size and collection efficiency for equivalent types of control devices. These costs are reported for nominal high, medium and low efficiencies. As indicated in the figures, the costs may vary from the plotted curve by ±20%. Reporting in this manner was necessary because of the wide range of process applications to which these curves relate. For example, electrostatic precipitators designed to reduce emission to 0.05 gr/scf are considered high-efficiency electrostatic precipitators even though resulting collection efficiencies may range from 95% in one installation to 99.9% in another because of inlet grain loading differences.

Auxiliary equipment and installation, the remaining capital investment items, are aggregated with the purchase cost to comprise the total installed cost. Total installed costs for all generic types of control devices, expressed as a percentage of purchase cost are presented in Table II. These installed costs include a reasonable increment for the following items: (1) erection, (2) insulation materials, (3) transportation of equipment, (4) clarifiers and liquid treatment systems for wet collectors, and (5) auxiliary equipment such as fans, normal ductwork, and motors. The low values listed in the table are for minimal transportation and simple layout and installation of control devices. The high values are for higher transportation cost and more difficult layout and installation. The extremely high values are for unusually complex installations, such as may be encountered with existing process situations. Ranges of installed costs for electrostatic precipitators were calculated for each collection efficiency cost curve in Figure 4 and are presented in Figure 7.

Table III lists the major cost categories and related conditions that establish the installed cost range for all categories of collection equipment.

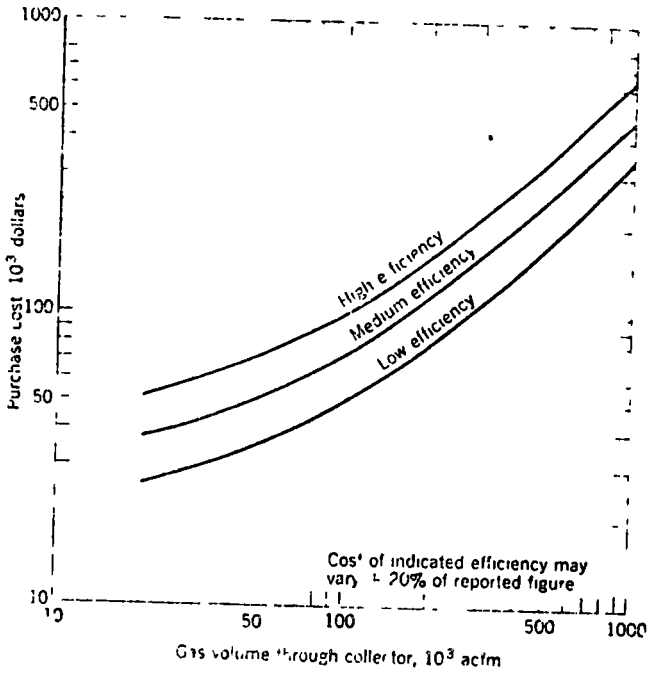
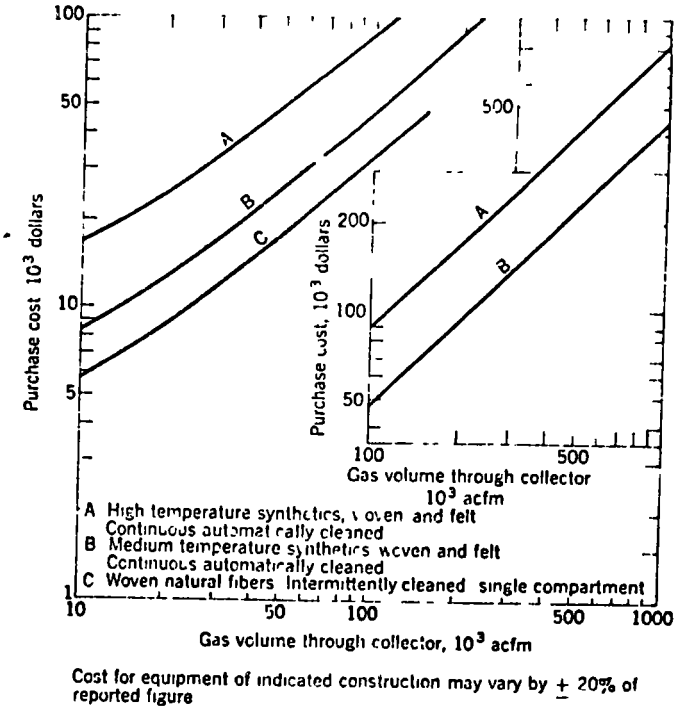


Figure 4 Purchase cost of high voltage electrostatic precipitators



Cost for equipment of indicated construction may vary by ± 20% of reported figure

Figure 5 Purchase cost of fabric filters

Maintenance and Operation

The cost of operating and maintaining control equipment depends on such factors as the quality and suitability of the control equipment and the user's understanding and vigilance in its operation. Management policies and attitudes also play a role in this area of cost.

Maintenance and operating costs are difficult to assess, but are frequently a significant portion of the overall annual cost of controlling air pollutant emissions. Although combined operating and maintenance costs may be as low as 15% of the annualized total cost for dry centrifugal collectors and electrostatic precipitators, they may be as high as 90% for a high-efficiency wet collector.

The annual operating cost is the expenditure incurred in operating a control device at its designed collection efficiency for a period of one year. This cost depends on and accounts for the following factors: (1) gas volume cleaned, (2) the pressure drop across the system, (3) the total time the device is operated, (4) the consumption and costs for electricity, fuel, and scrubbing liquor, and (5) the mechanical efficiencies of the fan and the pump. Table IV gives the theoretical cost equations developed to reflect these factors.

Maintenance cost is defined as the expenditure required to sustain the operation of a control device at its designed efficiency. This is best accomplished with a scheduled maintenance program and proper replacement of defective and worn parts. The maintenance cost as indicated in Table V is assumed to be proportional to the gas flow rate of the device. Maintenance cost is an estimate based on present knowledge and understanding of control system applications. These costs are expressed as average annual values computed over the useful life of the devices. Actually, maintenance costs, as in any mechanical device, will increase with the age and wear of the equipment. Formulas for calculating maintenance costs are presented in Table IV.

Costs of electricity, fuel, and water are presented in Table VI. Engineering data are also given in Table VI for operational requirements of (1) make up water, (2) electricity for electrostatic precipitators, (3) power for wet collectors, and (4) pressure loss for all applicable control devices.

Capital Charges

The capital charges (interest, taxes, and insurance) vary considerably depending on local tax structure, type of industry, industry financial position and ability to borrow money, and the existing money market. The capital charge rate will range from 6 to 12% per year. For the purposes of presentation and ease of calculation a rate of 7% per year of the capital investment (total installed costs) was assumed.

Table II Installed cost expressed as a percentage of purchase cost for all generic types of control devices

Generic type	Cost range (%) Low	Typical	High	Extreme high
Dry centrifugal	135	150	200	500
Wet scrubber				
Low, medium energy	150	200	300	500
High energy[a]	200	300	500	600
Electrostatic precipitators	140	170	200	500
Fabric filters	150	175	200	500
Afterburners	110	125	200	500

[a] High energy scrubbers usually require more expensive fans and motors

Table III Conditions affecting purchase and installation costs

Cost category	Low to typical costs	High to extreme high costs
Equipment transportation	Minimum distance, simple loading and unloading procedures	Extensive distance, complex procedure for loading and unloading
Plant age	Hardware designed into new plant as an integral part of process	Hardware installed into confines of old plant requiring structural or process modification or alteration
Available space	Vacant area for location of control system	Little vacant space, extensive steel support construction and site preparation required
Instrumentation	Little required	Complex instrumentation required to assure reliability of control or constant monitoring of gas stream
Guarantee on performance	None required	Guaranteed high collector efficiency to meet stringent control requirements
Degree of assembly	Control hardware shipped completely assembled	Control hardware to be assembled and erected in the field
Degree of engineering design	Standard "package type" control system	Control system requiring extensive integration with process, insulation to correct temperature and moisture problem, noise abatement
Utilities	Electricity, water, waste disposal facilities readily available	Electrical and waste treatment facilities must be expanded, water supply must be developed or expanded
Collected waste material handling	No special treatment facilities or handling required	Special treatment facilities and/or handling required
Labor	Low wages in geographical area	Overtime and/or high wage geographical area
Auxiliary equipment	Simple draft fan, minimal ductwork	Extensive cooling equipment, ductwork, large motors
Corrosiveness	Noncorrosive gas	Acidic emissions requiring high alloy accessory equipment using special handling and construction techniques

Table IV Equations for calculating annual operation and maintenance costs

Control device	Operation costs: Electrical costs (A)	Operation costs: Liquor consumption costs (B)	Operation costs: Fuel costs (C)	Maintenance costs (D)
Centrifugal collectors	$S \frac{0.7457\ PHK}{6356\ E}$	—	—	SM
Wet collector	S (0.7457) HKZ	SWHL	—	SM
Electrostatic precipitators	S (JHK)	—	—	SM
Fabric filters	$S \frac{0.7457\ PHK}{6356\ E}$	—	—	SM
Afterburners	$S \frac{0.7457\ PHK}{6356\ E}$	—	SHF	SM

Note: annual cost (dollars) for operating and maintenance, G = (A) + (B) + (C) + (D) where

S = design capacity of the unit in actual cubic feet per minute (acfm)
P = pressure drop in inches of water
H = hours of operation annually
K = cost of electricity in dollars per kilowatt hour
E = fan efficiency expressed as decimal
M = maintenance cost per acfm in dollars per acfm
F = fuel costs in dollars per actm per hour
W = make up liquor rate in gallons per hour per acfm
L = cost of liquor in dollars per gallon
Z = total power input required for a specified scrubbing efficiency in horsepower per acfm
J = kilowatts of electricity per acfm

Annualization of Costs

The capital investment for an air pollution control installation can represent a sizable expenditure and have a significant impact on the economic position of an industrial firm. What is more important, however, is the recurring annual cost of control, which is the aggregation of all associated cost items. The annualized cost of control is computed by depreciating the capital investment (total installed cost) over the expected or feasible life of the control equipment and adding the capital charges (taxes, interest, and insurance). The recurring cost of maintenance and operating expenditures are then added to the annualized capital cost figure to give the total annualized cost of control.

The straight line method of depreciating capital investment is a frequently used procedure because it has the simplicity of a constant annual write-off. This procedure was used in the annualized cost calculation presented in this report. The depreciation period varies considerably from industry to industry and is based on factors such as obsolescence and useful life of the equipment. The Standard Internal Revenue Service guidelines[4] for depreciation periods varies from 8 years for the aerospace and electronic industries to 28 years for the steam electric generating industry. A depreciation period of 15 years (6⅔% per year) can be considered typical for most control equipment installations. For ease of calculations a depreciation rate of 7% per year was used in this report.

Sample Calculations

The following procedure can be used to determine the capital investment and annual cost of control for an average application. A careful investigation of the industrial process will determine the selection of applicable control devices, as was discussed earlier. For purposes of illustration, the evaluations of three collectors are presented in Table VII.

The calculations shown in Table VII are for a new plant requiring high-efficiency collectors to comply with an emission regulation. Control efficiency is required to be greater than 98 percent. The volume of gas handled is 100,000 actual cubic feet per minute (acfm) for a temperature of 300°F; no conditioning of gases is required. Only a minimum of ductwork, valving, and hooding is required to fit the collector onto the process. The step-by-step procedure is as follows:

1. Electrostatic precipitators, fabric filters, and high-energy wet collectors have been assumed as applicable control devices.
2. Determine purchase cost for high-efficiency electrostatic precipitators, high-energy wet collectors, and fabric filter of medium temperature filter material from Figures 3, 4, and 5.
3. Calculate low, typical, and high installed cost using the installation factors from Table II.
4. Calculate low, typical, and high maintenance costs for 8000 hr. Maintenance cost factors are presented in Table V. Since maintenance costs may vary widely, low, typical, and high costs are calculated.
5. Calculate operating expenses for high-efficiencies associated with the individual collectors. Typical costs for electricity and water are assumed. All such related values for calculating operating expenses are taken from Table VI. Since costs for electricity and for water are easily established in any geographical area, single estimates can be determined for operating expenses. (Note Table VII.)
6. Calculate the total annual control costs by adding the annual depreciation costs and capital charges to operating and maintenance expenditures.

In the example presented here, an electrostatic precipitator requires approximately twice as much capital outlay for installation as either a fabric filter or a wet collector. However, the precipitator is a good choice economically on an annual cost basis.

In another situation requiring cooling and conditioning of hot gases, the wet collector would be a better choice. For

Table V. Annual maintenance cost factors for all generic types of control devices

Generic type	Cost ($/acfm)		
	Low	Typical	High
Dry centrifugal	0.005	0.015	0.025
Wet collectors	0.02	0.04	0.06
Electrostatic precipitators	0.01	0.02	0.03
Fabric filters	0.02	0.05	0.08[a]
Afterburners			
Thermal	0.03[b]	0.06[c]	0.10[c]
Catalytic	0.07	0.20	0.35

[a] Exotic materials can result in higher maintenance.
[b] Metal liner with outside insulation.
[c] Refractory lined.

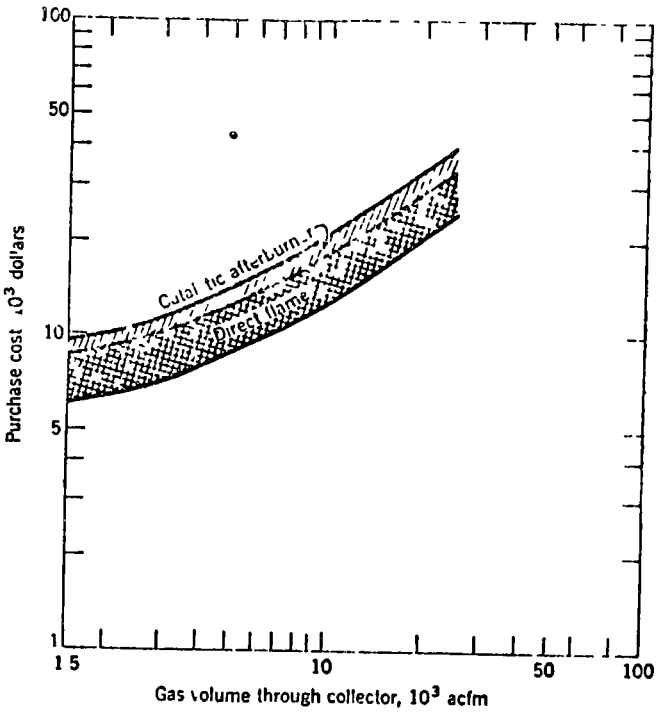


Figure 6. Purchase cost of afterburners.

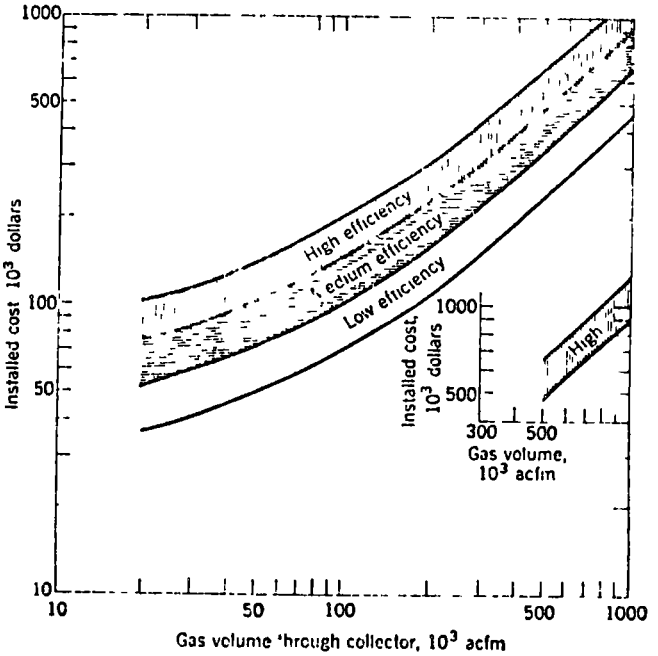


Figure 7. Installed cost of high voltage electrostatic precipitators.

Table VI Engineering and cost factors for determining operating cost

Cost of electricity, $/kw-hr

	Low	Typical	High
All devices	0.009	0.011	0.020

Cost of liquor in 10^{-3} dollars per gallon (assume H$_2$O for make up)

	Low	Typical	High
Wet scrubber	0.10	0.25	0.50

Hourly fuel costs for afterburners

Device (source temperature @ 380°F)	Inlet temperature (°F)	Outlet temperature (°F)	ΔT°F	Fuel cost[b] ($/acfm hr)
Direct flame	380	1400	1020	0.00057
DF with heat exchanger	1000	1400	400	0.00023
Catalytic afterburner	380	900	520	0.00028
CAB with heat exchanger	650	900	250	0.00014

Watts of electricity per acfm based on efficiency for electrostatic precipitators (10^{-3} kw/acfm)

Low	Medium	High
0.19	0.26	0.40

Special data for wet collectors

	Low efficiency	Medium efficiency	High efficiency
Scrubbing (contact) power, horsepower/acfm[c]	0.0013	0.0035	0.008
Make up liquor rate, gal/acfm hr	0.03	0.03	0.03

Pressure losses through equipment (in H$_2$O)

	Low	Typical	High
Dry centrifugal	—	2–3	4
Fabric filters	2–3	4–5	6–8
Afterburners	0.5	1.0	2
Electrostatic precipitators	—	Considered insignificant	0.5
Wet collectors			
Fan losses	1	10	20–60
Pump losses	1–3	1–5	1–10

[a] Based on national average for large consumers
[b] Includes the cost of heating an additional 50% excess air and assumes no heat value content in the material or pollutant being consumed
[c] Data do not include requirements for pumping water through system. Such requirements may range from 0.0 to 0.5 horsepower per 1000 acfm

example, in basic oxygen furnace installations, high-energy wet collectors with high power costs are competitive with electrostatic precipitators and are sometimes cheaper than the latter on an annual basis. In these installations, electrostatic precipitators and fabric filters must be large enough to cope with the volume of gases generated by combustion of carbon monoxide withdrawn from the furnace. In addition, precautionary gas conditioning has to be undertaken to prevent explosions within the electrostatic precipitator or spark carry-over into the fabric filter. These additional requirements of greater collector capacity and of gas conditioning may make dry collectors more expensive than wet collectors.

Summary

Air quality control program officials should consider the associated costs for various control strategies in their decision-making processes. The estimation of these costs in some simplified, logical manner has been the purpose of this presentation. Cost data have been illustrated for basic control devices, and installed costs and annual control costs have been estimated. In addition, due consideration has been given to the specific industrial process and to individual engineering parameters, which affect the selection of the ultimate control system.

Acknowledgments

The authors wish to acknowledge the efforts and contributions of Ernst and Ernst, Washington, D. C., for the development of background material under National Air Pollution Control Administration Contract No. PH 86-68-7. Credit is also given to the Industrial Gas Cleaning Institute for its review and contribution of basic equipment cost data and estimating procedures.

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4. Depreciation Guidelines and Rules, U. S. Treasury Dept. Internal Revenue Service publication No. 456. U. S. Government Printing Office, Washington, D. C., July 1962.

Table VII Calculation of investment and annual costs for three collectors at 100,000 acfm and 8000 operating hours

	Electrostatic precipitator (99.5% efficiency)			High energy wet collector			Medium temperature fabric filter		
Purchase cost		$100,000			$27,000			$48,000	
Installation charge	40%	70%	100%	100%	200%	400%	50%	75%	100%
Installation costs	$ 40,000	$ 70,000	$100,000	$27,000	$54,000	$108,000	$24,000	$36,000	$48,000
Total installed costs	$140,000	$170,000	$200,000	$54,000	$81,000	$135,000	$72,000	$84,000	$96,000
Depreciation (7%)	$ 9,800	$ 11,900	$ 14,000	$ 3,780	$ 5,670	$ 9,450	$ 5,040	$ 5,880	$ 6,720
Capital charges (7%)	9,800	11,900	14,000	3,780	5,670	9,450	5,040	5,880	6,720
Annual capital costs	$ 19,600	$ 23,800	$ 28,000	$ 7,560	$11,340	$ 18,900	$10,080	$11,760	$13,440
Maintenance	$ 1,000	$ 2,000	$ 3,000	$ 2,000	$ 4,000	$ 6,000	$ 2,000	$ 5,000	$ 8,000
Electrical costs	3,520	3,520	3,520	52,500	52,500	52,500	7,740	7,740	7,740
Water	—	—	—	6,000	6,000	6,000	—	—	—
Total operating and maintenance	$ 4,520	$ 5,520	$ 6,520	$60,500	$62,500	$ 64,500	$ 9,740	$12,740	$15,740
Total annual cost	$ 24,120	$ 29,320	$ 34,520	$68,060	$73,840	$ 83,400	$19,820	$24,500	$29,180

TEST CONDUCTED AT
NALCO CHEMICAL COMPANY
4001 W. 71st Street
CHICAGO, ILLINOIS

REPORT ON THE PARTICULATE EMISSIONS TO THE ATMOSPHERE FROM KATALCO ELECTROSTATIC PRECIPITATOR,

Test Personnel

George Kimura	Environmental Control Engineer
Robert Malec	Environmental Sampling & Equipment Technician
Joseph Stoklosa	Environmental Sampling & Equipment Technician
James Turano	Environmental Sampling & Equipment Technician

Department of Environmental Control
Technical Services
City of Chicago

OCTOBER 1971

INTRODUCTION:

This report presents the results of tests made to determine particulate emissions to the atmosphere from five stacks located at the Nalco Chemical Company, 4001 W. 71st Street.

All five stacks tested already contained sampling port holes put there by Nalco. These same port holes were used for these tests.

All the processes tested were continuous in operation- that is, streams of materials entered the processes and a stream of product was discharged from the processes. The processes were shut down only for maintenance or as products were not required.

Witnessing the tests for Nalco Chemical Company were Mr. Hugo Manini and, at times, Mr. Martin C. Mazurk.

Process flow rate data were provided by Nalco.

SUMMARY OF RESULTS

Company _ Nalco

Equipment tested Katalco Electrostatic Precipitator

TEST NO.	PARTICULATE EMISSIONS TO ATM Grains per SCF
1	0.13 *
2	0.12 *
3	0.17 *

SCF = Standard cubic foot @ 60° F and 30 inches Hg.

Code Limitation - Particulate Emissions: 0.10 grains/SCF per Section 17-2.4-1 of the Environmental Control Ordinance.

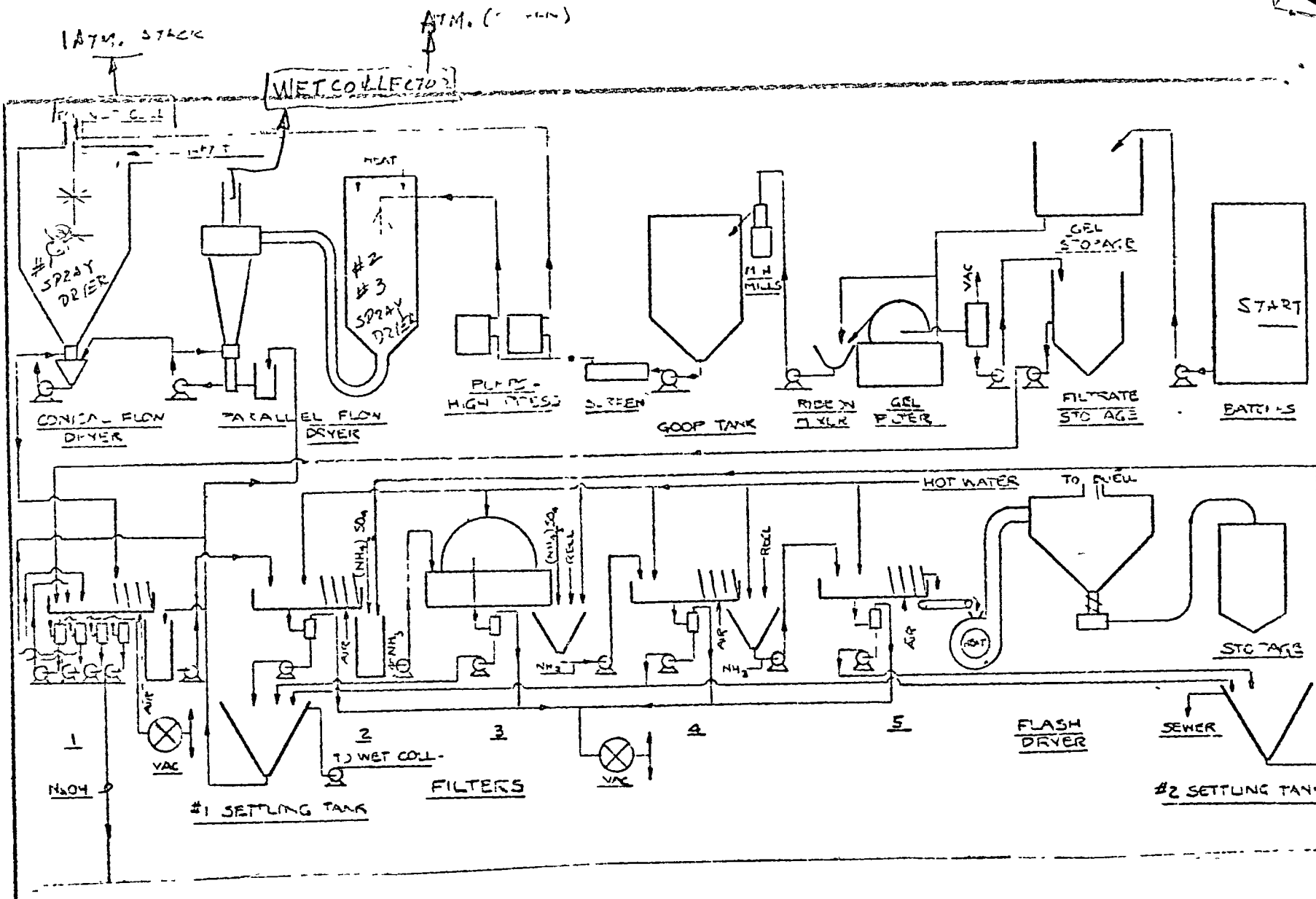
TEST NO.	MASS RATE OF EMISSIONS Pounds per hour
1	7.2
2	6.2
3	9.0

* VIOLATION

Company Nalco Location

Equipment tested Katalco Electrostatic Precipitator

SAMPLING DATA	TEST NO. 1	2	3
Date of test.	Aug 13 1971	Aug 16 1971	Aug 16 1971
Time of test	11:58	11:27	12:42
Duration of test run, minutes	64	64	64
Total sampled volume, SCF	56.36	53.49	56.35
Total number of sampling points	8	8	8
Probe nozzle dia., inches	.25	.25	.25
PARTICULATE DATA			
Particulates caught -			
in filter, grams	.3245	.2545	.4171
in probe, grams	.1384	.1440	.1979
in impingers - benzene soluble			
- dehydrated solids			
Total particulates caught, grams	.4629	.3985	.6150
STACK GAS DATA			
Gas volume flow, ft^3/min, stack condition	8470	8330	8220
Gas volume flow, SCFM	6630	6340	6230
Gas temp. at sampling point, °F, average	203	228	231
% moisture in stack gas	6.9	5.8	12.0
MATERIAL FEED RATE OF PROCESS lb/hr	600	600	600



NALCO CHEMICAL COMPANY 180 N. MICHIGAN AVE., CHICAGO, ILL. 60601

FLUID CRACKING CATALYST PROCESS PLANT 2

DWN FHJ	SCALE	DATE 2-11-69	REV.	DWG. NO 1125-A

Drawing by courtesy of Nalco Chemical Co.

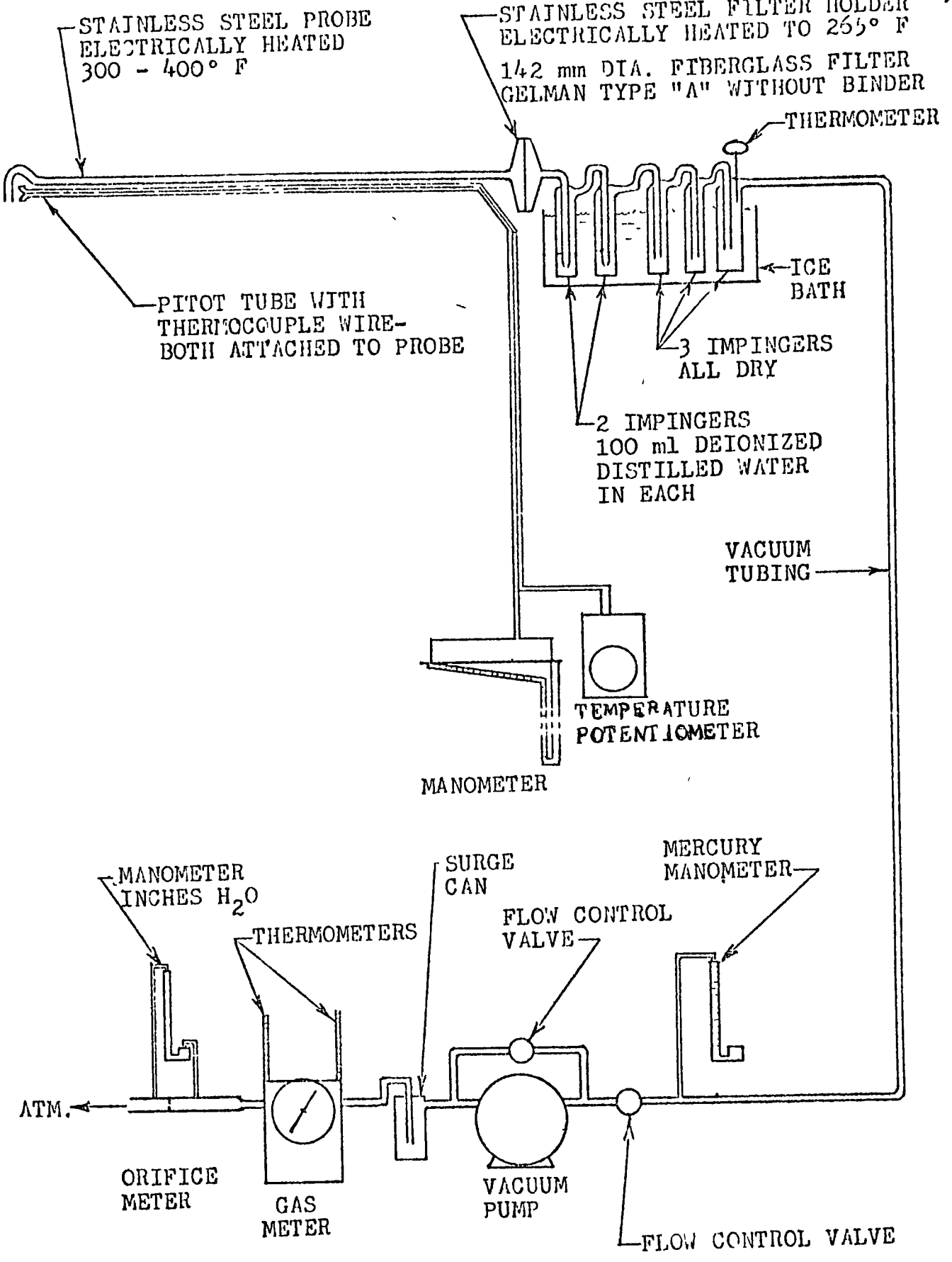
NALCO CHEMICAL COMPANY 180 N MICHIGAN AVE, CHICAGO, ILL 60601

KATALCO PRODUCTS 52 PROCESS

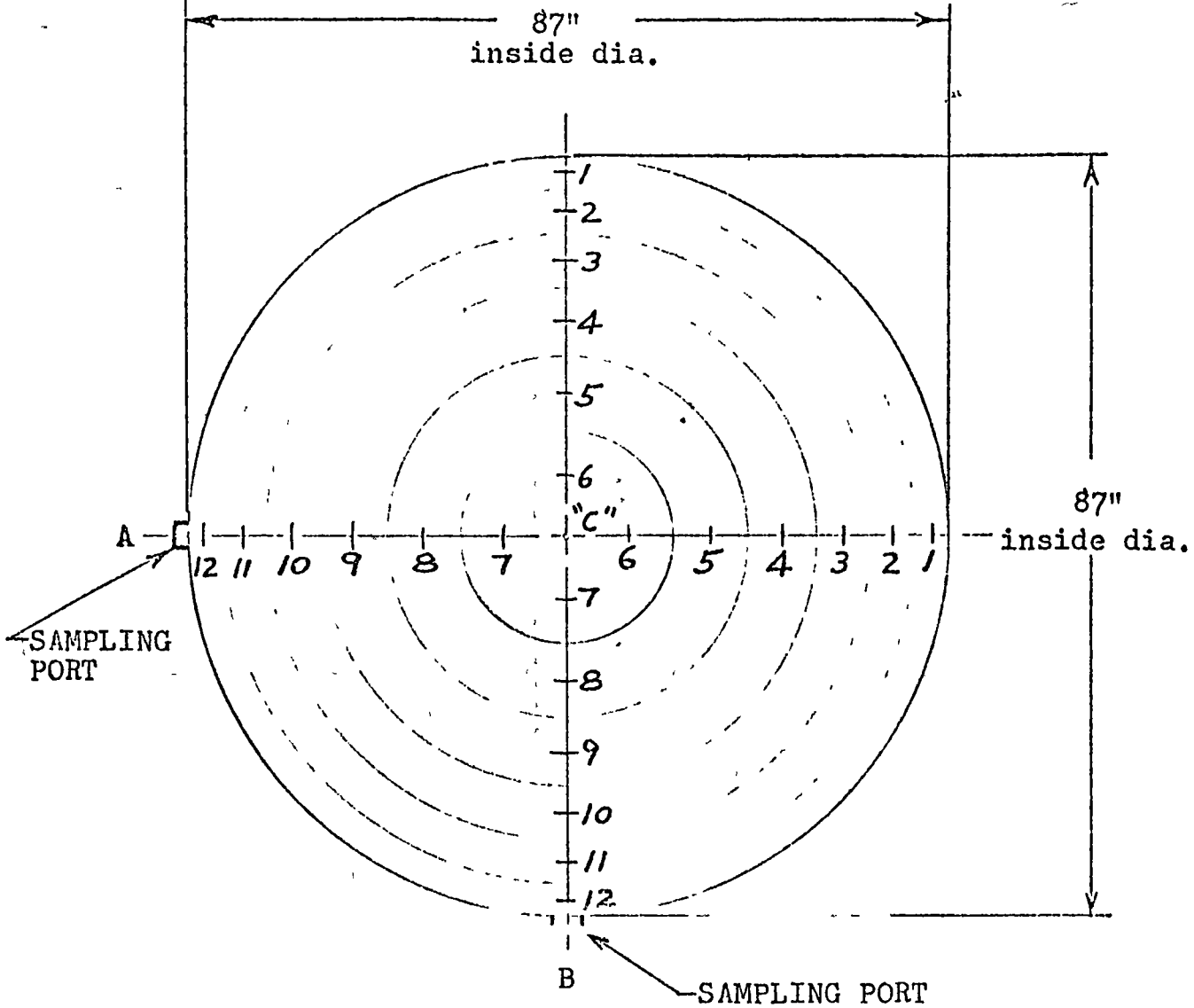
22-6-35

DWN	SCALE	DATE	REV	DWG NO

Drawing by courtesy of Nalco Chemical Co.



PARTICULATE SAMPLING TRAIN



DISTANCE TO NUMBERED POINTS FROM CENTER "C" OF STACK

POINT NO.	TRAVERSE "A"	TRAVERSE "B"
1	41 5/8	41 5/8
2	37 5/8	37 5/8
3	33 1/8	33 1/8
4	28	28
5	21 3/4	21 3/4
6	12 1/2	12 1/2
7	12 1/2	12 1/2
8	21 3/4	21 3/4
9	28	28
10	33 1/8	33 1/8
11	37 5/8	37 5/8
12	41 5/8	41 5/8

Number of sampling points per traverse 12

Total number of sampling points per test 24

Name of Company Nalco

Equipment Tested Spray Dryer No. 1 Wet Collector

passed through the meter.

The condensate was analyzed as described in another section of this report.

The filter holders and impingers were charged with filters and de-ionized distilled water at the laboratory and then taken to the test site. They were brought back, at the conclusion of the tests, to the laboratory intact. These procedures were followed to minimize sample loss or contamination.

GRAVIMETRIC ANALYSES

The filters with impacted particulate sample from the tests were removed from the filter holders and placed into weighing foils and then placed into a gravity convection oven for two hours. The samples were removed from the oven and placed immediately into a desiccator. After about 24 hours, the samples were weighed. In weighing, the samples were removed one at a time from the desiccator and immediately weighed and immediately put back into the desiccator. Weighings were repeated at about 24 hour intervals until no significant weight changes occurred.

The amount of particulates collected by the filter was calculated from the difference between the weight of the filter before and after the test.

The inside surface of the sampling probe containing deposited particulate sample from a test run was removed by attaching a filter holder containing a pre-weighed filter to the probe as per the sampling train set-up. A vacuum pump attached to the downstream end of the filter holder induced air flow through the probe and filter. A tubing brush was inserted into the probe to dislodge particles adhering to the probe. The particulates were swept and trapped onto the filter. The filters were processed as described above.

The liquid from the impingers were placed into tared drying dishes. The dishes were then placed into a gravity convection oven set at 105° C. The oven was contained in a dehumidified room to facilitate drying. After all the water had evaporated, the dishes were immediately placed into a desiccator for about 24 hours before weighing. The dishes were removed one at a time from the desiccator and immediately weighed. Weighings were repeated at 24 hour intervals until no significant weight changes occurred.

All sample handling and weighings were conducted in in a controlled low humidity enclosed room.

Gravimetric analyses were performed by George Kimura.

SENSITIVITY CHECK ON ANALYTICAL BALANCE

	1st Try	2nd Try	3rd Try
WEIGHT OF EMPTY BEAKER, gm	144.4352	144.4354	144.4355
ADD SMALL PIECE OF PAPER, gm	144.4385	144.4387	144.4385
WEIGHT OF PAPER BY DIFFERENCE, grams	.0033	.0033	.0030
WEIGHT OF PAPER BY WEIGHING PAPER ALONE, grams	.0033	.0032	.0032

DESCRIPTION OF BALANCE

TORBAL Model EA-1 APO

Serial No. 100777

Capacity 160 grams

Single Pan Substitution Type Analytical Balance

GRAVIMETRIC ANALYSES

Nalco Katalco

PARTICULATES CAUGHT IN FILTER *

	TEST NO. 1	2	3
Weighing foil, filter & residue, grams	4.0495	4.2277	4.0585
Weighing foil, grams	2.3178	2.5711	2.2474
Filter, grams	1.4072	1.4021	1.3940
Residue, grams	.3245	.2545	.4171

PARTICULATES CAUGHT IN PROBE *

	TEST NO. 1	2	3	4
Weighing foil, filter & residue, grams	3.6653	3.7521	3.6607	
Weighing foil, grams	2.2249	2.3521	2.1602	
Filter, grams	1.3020	1.2560	1.3026	
Residue, grams	.1384	.1440	.1979	

PARTICULATES CAUGHT IN PROBE

	TEST NO. 1	2	3	4
Weighing dish + residue, grams				
Weighing dish, grams				
Residue, grams				

* Samples dried at 190° C.

DERIVATION OF EQUATIONS

Determination of stack gas velocity.

$$V = \sqrt{2gh} \quad \text{for any gas}$$

Where V = velocity in ft/sec
G = gravitational constant, 32.2 ft/sec^2
H = velocity head of gas, ft

Let $V = \sqrt{2gh_a}$ for air at 60°F and 29.9 "Hg

Where h_a = velocity head of air at 60°F and 29.9 "Hg
The corresponding velocity head in inches of water would be:

$$Z = \frac{\text{density of water in lb per cubic feet}}{(\text{density of air in lb/ft}^3) \times (\frac{12 \text{ inches}}{1 \text{ foot}})}$$

$$= \frac{62.37 \text{ lb/ft}^3 \text{ for water at 60°F and 29.9 "Hg}}{(0.07636 \text{ lb/ ft}^3 \text{ for air at 60°F and 29.9 "Hg}) \quad (\frac{12 \text{ inches}}{1 \text{ foot}})}$$

$$V = \sqrt{2g Z h_a} = \sqrt{2g \left(\frac{62.37}{.07636}\right) \left(\frac{1}{12}\right) \quad hw}$$

Where hw = velocity head in inches of water

For any gas at any temperature and pressure the following equation results utilizing gas law relationships:

$$V = \sqrt{2gh_w \left(\frac{1}{12}\right) \frac{62.37}{0.07636 \left(\frac{460+60}{460+T}\right) \left\{\frac{P_b - P_s}{29.9}\right) \left(\frac{M \text{ gas}}{M \text{ air}}\right)}}$$

Where h_w = velocity head in inches of water

T = temperature of gas, °F

P_s = pressure of gas in stack, inches Hg

P_b = barometric pressure

M gas = molecular weight of gas

M air = molecular weight of air

For convenience, factor out constants

$$V = 2.90 \sqrt{\frac{29.9}{P_b - P_s} \times \frac{M\ air}{M\ gas} \times h_w \times (460 + T)}$$

For a type "S" pitot tube, apply correction factor supplied by the manufacturer of the pitot tube:

$$V = (C_p)(2.90) \sqrt{\frac{29.9}{P_b - P_s} \times \frac{M\ air}{M\ gas} \times h_w \times (460 + T)}$$

Conversion of Condensate Collected in Impingers to Vapor Volume at Meter Conditions

$$V_v = (ml)_{CONDENSATE} \left(0.0022 \frac{lb\ H_2O}{ml\ H_2O}\right) \left(19.9 \frac{ft^3\ water\ vapor}{lb\ water}\right) \left(\frac{29.92"Hg}{P_b - P_m}\right) \left(\frac{460 + T_m}{460 + 32}\right)$$

at 32°F and 29.92 "Hg

Where T_m = average meter temperature

P_m = average gage pressure at meter

P_b = barometric pressure

For convenience, factor out constants thus:

$$V_v = (ml)\ (0.00267)\ \left(\frac{460 + T_m}{P_b - P_m}\right)$$ = that volume of water vapor condensed out of the sampled stack gas in the impingers, therefore, not read by the meter, ft^3 at meter conditions of temperature and pressure.

$$M_c = \frac{V_m}{V_m + V_v}$$ = that decimal portion of stack gas that is actually read by meter.

Where V_m = actual meter reading, ft^3.

V_v = that volume of water vapor condensed out of stack gas not read by the meter, ft^3 at meter conditions of temperature and pressure.

$$V_{vm} = (V_m)\ \left(\frac{P_{H_2O}}{P_{baro} - P_{impinger}}\right)$$ = volume of water vapor in metered gas - ft^3 at meter conditions.

Where P_{H_2O} = vapor pressure of water at impinger exit temperature, inches Hg

$P_{impinger}$ = gage (negative) pressure in impingers, inches Hg

$$W.V. = (100)\left(\frac{V_v + V_{vm}}{V_m + V_v}\right)$$ = water vapor content in stack gas, % by volume

Where:

V_v = that volume of water vapor condensed out of stack gas not read by meter - ft^3 at meter conditions of temperature and pressure.

V_m = volume of water vapor in metered gas- ft^3 at meter conditions of temperature and pressure.

STACK GASES CONTAINING ENTRAINED DROPLETS OF WATER AT TEST POINT

$$W.V. = \frac{(V.P.)\,(R.H.)}{P_s} = \frac{(V.P.)\,(100)}{P_s} = \% \text{ moisture by volume}$$

Where: V.P. = vapor pressure of water at stack temperature in inches of Hg.

P_s = absolute pressure in stack - inches Hg.

R.H. = relative humidity

$$\frac{W.V.}{100} = \frac{V_v + V_{vm}}{V_v + V_m}$$

$$\left(\frac{W.V.}{100}\right) V_v + \left(\frac{W.V.}{100}\right) V_m = V_v = V_{vm}$$

$$V_{vm} = \left(\frac{W.V.}{100}\right) V_v - V_v + \left(\frac{W.V.}{100}\right) V_m$$

$$V_{vm} = V_m \frac{P_{H_2O}}{(P_a - P_{imp})}$$

$$V_m \frac{P_{H_2O}}{(P_a - P_{imp})} - \left(\frac{W.V.}{100}\right) V_m = V_v \left[\left(\frac{W.V.}{100}\right) - 1\right]$$

$$V_v = \frac{V_m \left[\dfrac{P_{H_2O}}{(P_a - P_{imp})} - \left(\dfrac{W.V.}{100}\right)\right]}{\dfrac{W.V.}{100} - 1} = \text{volume in } ft^3 \text{ at meter conditions of water condensed out of stack gas and therefore not read by meter}$$

Where: V_m = volume of metered gas at meter conditions, ft^3

V_{vm} = volume of water vapor in metered gas - ft^3 at meter conditions

P_{H_2O} = vapor pressure of water at impinger exit temp., inches Hg.

P_{imp} = gage (negative) pressure in impingers, inches Hg.

P_a = atmospheric pressure, inches Hg.

Determination of Molecular Weight of Stack Gas using Orsat Data

Fractional % by volume, dry.

Co_2 _____

O_2 _____

Co _____

N_2 _____
(by diff.)

% moisture in gas _____

Conversion to wet basis

Co_2 _____ x (1 - .(fractional % water) _____) = _____

O_2 _____ x (1 - .(fractional % water) _____) = _____

CO _____ x (1 - .(fractional % water) _____) = _____

N_2 _____ x (1 - .(fractional % water) _____) = _____

Determination of Isokinetic Sampling Rate:
This is best determined by reference to prepared graphs, however, the graphs are prepared by the following type of calculations:

$Q_s = (V)\ (60)\ (A)$

Where: Q_s = isokinetic sampling rate of stack gas, ft^3/min

V = velocity of stack gas at nozzle location, ft per second

60 = seconds per minute

A = area of sampling nozzle, ft^2

$$Q_m = Q_s \left(\frac{460 + T_m}{460 + T_s}\right) \left(\frac{P_b - P_s}{P_b - P_m}\right)$$

M_c = metering rate for isokinetic sampling, ft^3/min

Where Q_s = isokinetic sampling rate of stack gas, ft^3/min

T_m = temperature of gas at meter, °F

T_s = temperature of gas in stack, °F

P_b = barometric pressure, inches Hg

P_s = pressure in stack, inches Hg

P_m = pressure of gas at meter, inches Hg

M_c = that decimal portion of satck gas that is actually read by meter.

Calculations of grain loading

$V_{tm} = V_m + V_v$ = total sampled gas volume, ft^3 at meter conditions of temperature and pressure.

Where V_m = actual meter reading in ft^3

V_v = that volume of water vapor condensed out of stack gas by the impingers not read by meter -

ft^3 at meter conditions of temperature and pressure.

$$V_{scf} = (V_{tm})\left(\frac{P_b - P_m}{30.0'}\right)\frac{(460 + 60)}{(460 + T_m)}$$ = total ft^3 of sampled volume corrected to standard conditions of 60°F and 30.0"Hg.

Where: V_{tm} = total sampled volume at meter conditions, ft^3

P_b = barometric pressure, inches Hg

P_m = pressure of gas at meter, inches Hg

T_m = temperature of gas at meter, °F.

$C_m = (15.43)\frac{W}{V_{scf}}$ = grains per standard cubic foot

Where: 15.43 = that amount of grains per gram

W = weight of particulates in grams

V_{scf} = total sampled volume of stack gas corrected to standard conditions of 60°F & 30.0 inches Hg.

NALCO - KATALCO CALCULATIONS TEST #1

$V_V = (.00267)(73)\left(\frac{460+105}{29.94}\right) = 3.68\ ft^3$

$V_{TM} = 57.690 + 3.68 = 61.37\ ft^3$

$V_{STD} = (61.37)\left(\frac{29.94-0}{30}\right)\left(\frac{520}{460+105}\right) = 56.36\ SCF$

$C_H = (15.43)\left(\frac{.4629}{56.36}\right) = 0.127\ grains/SCF$

$V_{VM} = (57.690)\left(\frac{.2677}{29.94-2.9}\right) = .571\ ft^3$

$M.V = (100)\left(\frac{3.68 + .571}{57.690+3.68}\right) = 6.9\ \%$

Molecular Wt of gas

$28.95 \times .93 = 26.92$

$18 \times .07 = \underline{1.26}$

28.18

$V = (2.9)(.825)\sqrt{\left(\frac{28.95}{28.18}\right)(460+203)}(.905) = 56.5\ ft/sec$

Area of stack $= \frac{(18)(20)}{(144)} = 2.5\ ft^2$

$Q_S = (2.5)(56.5)(60) = 8470\ ft^3/min$

$Q_{STD} = (8470)\left(\frac{29.94}{30}\right)\left(\frac{520}{460+203}\right) = 6630\ SCFM$

Mineral Emissions $= \frac{(6630)(.127)(60)}{7000} = 7.2\ lb/hr$

NALCO - KATALCO CALCULATIONS TEST #2

$V_V = (.00267)(57)\left(\frac{460+91}{30.22}\right) = 2.77\ ft^3$

$V_{TM} = 53.489 + 2.77 = 56.263\ ft^3$

$V_{STD} = (56.263)\left(\frac{30.22-0}{30}\right)\left(\frac{520}{460+91}\right) = 53.487\ SCF$

$C_M = (15.43)\left(\frac{.3985}{53.487}\right) = 0.115\ grains/SCF$

$V_{VM} = (53.489)\left(\frac{.2478}{30.22-2.9}\right) = 0.48\ ft^3$

$W.V = (100)\left(\frac{2.77+0.48}{53.489+2.77}\right) = 5.0\ \%$

$V = (2.9)(.825)\sqrt{\left(\frac{28.95}{28.18}\right)(460+228)(.872)} = 55.5\ ft/sec$

$Q_S = (2.5)(55.5)(60) = 8330\ ft^3/min$

$Q_{STD} = (8330)\left(\frac{30.22}{30}\right)\left(\frac{520}{460+228}\right) = 6340\ SCFM$

Mass Rate of Emissions $= \frac{(6340)(.115)(60)}{7000} = 5.2\ lb/hr$

NALCO – KATALCO CALCULATIONS TEST #3

$V_V = (.00267)(136)\left(\frac{460+125}{30.22}\right) = 6.67\ ft^3$

$V_{TT} = 53.035 + 6.67 = 59.71\ ft^3$

$V_{STD} = (59.71)\left(\frac{30.22-0}{30}\right)\left(\frac{520}{460+45}\right) = 56.35\ SCF$

$C_{TT} = (15.43)\left(\frac{.6150}{56.35}\right) = 0.168\ grains/scf$

$V_{VM} = (53.035)\left(\frac{.7491}{30.22-3.1}\right) = .56\ ft^3$

$M.V. = (100)\left(\frac{6.67+.56}{53.035+6.67}\right) = 12.1\ \%$

$V = (2.9)(.825)\sqrt{\left(\frac{28.95}{28.18}\right)\left(\frac{1}{460+2\ldots}\right)(.80\ldots)} = 54.8\ ft/min$

$Q_S = (2.5)(54.8)(60) = 8220\ ft^3/min$

$Q_{STD} = (8220)\left(\frac{30.\ldots}{30}\right)\left(\frac{\ldots}{\ldots}\right) = 6230\ SCFM$

Mass Rate of Emissions $= \frac{(\ldots)(\ldots)(60)}{7000} = 9.0\ lb/hr$

COMPANY Naico Chemical
LOCATION Joliet 71st St
EQUIPMENT TESTED Totalco Stack

DATE: 8-18-71
TEST PERSONNEL:
1. G Kimura
2. R Malec
3. J Turpin
4. J Sorlook

FILTER NO. 1 FILTER BOX NO. _____
PROBE NOZZLE DIA. .250
ORIFICE (X) ROTAMETER ( ) NO. 6
METER I.D. 1091-3.5-A MAKE Rockwell
METER READING:
AFTER TEST 786.703 Ft³
BEFORE TEST 729.013 57.690 Ft³
BARO. PRES. 29.94 IN. HG.
OUTDOOR TEMP. _____ °F
TIME TEST START 11:58 (AM) PM

DATA CHECKED BY _____
METER READING CHECKED BY _____
AFTER TEST _____ Ft³
BEFORE TEST _____ Ft³
TOTAL LIQUID IN IMPINGERS
BEFORE TEST 200 ml
AFTER TEST 273 ml

POINT Pit South	ELAPSED TIME MINUTES	STACK TEMP °F	STACK PITOT ΔP INCHES H_2O	SAMPLING TRAIN FLOW METER READ	IMPINGER OUTLET TEMP. °F	IMPING. VACUUM INCHES HG.	TEMP. METER INLET °F	TEMP. METER OUTLET °F
1	0	203°	1.0	1.9	36°	3.2	93°	90°
2	8	202°	.85	1.65	40°	2.75	110°	91°
3	16	202°	.70	1.35	40°	2.5	115°	94°
4	24	202°	.66	1.3	41°	2.9	114°	91°
	32	202°	.68	1.3	42°	2.4	114°	91°
N.Port								
1	32	202°	1.1	2.1	43°	3.1	111°	78°
2	40	203°	.91	1.7	45°	2.4	116°	97°
3	48	206°	.86	1.55	45°	2.1	119°	100°
4	56	206°	.72	1.35	45°	2.7	119°	101°
	64	205°	.71	1.35	45°	2.7	119°	102°
		same	Same		6	same		same
		203°	.70		42°	2.9		105

LOCATION 400 [illegible]

EQUIPMENT TESTED [illegible]

TEST PERSONNEL:
1. G. Kyriacou
2. [illegible]
3. E. [illegible]
4.

FILTER NO. 2 FILTER BOX NO.

PROBE NOZZLE DIA. .250

ORIFICE(X) ROTAMETER( ) NO. 6

METER NO. (1) 9635257 MAKE ROOTS-NELL

DATA CHECKED BY

METER READING:

AFTER TEST 871.729 Ft³

BEFORE TEST 818.240 Ft³
53.489

METER READING CHECKED BY

AFTER TEST Ft³

BEFORE TEST Ft³

BARO. PRES. 30.22 IN. HG.

OUTDOOR TEMP. °F

TOTAL LIQUID IN IMPINGERS 1 NPT 2

BEFORE TEST 200 ml

TIME TEST START 1127 AM PM

AFTER TEST 257 ml

POINT S. PLT	ELAPSED TIME MINUTES	STACK TEMP °F	PITOT ΔP INCHES H_2O	FLOW METER READ	SAMPLING TRAIN IMPINGER OUTLET TEMP. °F	IMPING. VACUUM INCHES HG.	TEMP. METER INLET °F	TEMP. METER OUTLET °F
1	0	225°	.88	1.6	34.5°	2.85	82°	82°
	4	227°	.88	1.6	37.5°	2.9	85°	83°
2	8	227°	.70	1.3	38°	2.6	90°	82.5°
	12	228°	.71	1.3	38°	2.65	93°	84°
3	16	228°	.62	1.15	38.5°	2.5	95°	84°
	20	224°	.62	1.15	39.5°	2.5	95°	84°
4	24	224°	.58	1.15	39°	2.5	95°	85°
	28	224°	.58	1.15	39°	2.5	96.5°	85°
	32	224°	.59	1.15	39°	2.5	99°	85°
N. PLT								
1	32	230°	1.0	1.8	41°	3.55	97°	86°
	36	224°	1.0	1.8	41.5°	3.55	98°	86°
2	40	230°	.91	1.15	41.5°	3.4	100°	87°
	44	230°	.91	1.15	41°	3.4	100°	87°
3	48	232°	.79	1.5	41.5°	3.2	101°	89°
	52	230°	.82	1.5	42°	3.2	101.5°	91°
4	56	230°	.74	1.4	42°	3.15	102°	91°
	60	230°	.74	1.4	42.5°	3.15	102°	91°
	64	230°	.74	1.4	43°	3.15	103°	91°
		230°	.812		42.5°	2.9		91°

LOCATION [illegible]
EQUIPMENT TESTED [illegible]

DATE: 8-16-71
TEST PERSONNEL:
1. [illegible]
2. [illegible]
3. [illegible]
4.

FILTER NO. 3 FILTER BOX NO.
PROBE NOZZLE DIA. .250
ORIFICE (X) ROTAMETER ( ) NO. 6
METER NO. CA96 3539 MAKE Rockwell
METER READING:
AFTER TEST 924.826 Ft³
BEFORE TEST 871.791 Ft³
53.935
BARO. PRES. 30.22 IN. HG.
OUTDOOR TEMP. °F
TIME TEST START 12.42 AM PM

DATA CHECKED BY
METER READING CHECKED BY
AFTER TEST Ft³
BEFORE TEST Ft³
TOTAL LIQUID IN IMPINGERS IMP #3
BEFORE TEST 200 ml
AFTER TEST 336 ml

POINT / Sq Point	ELAPSED TIME MINUTES	STACK TEMP °F	PITOT Δ P INCHES H_2O	FLOW METER READ	SAMPLING TRAIN IMPINGER OUTLET TEMP. °F	IMPING. VACUUM INCHES HG.	TEMP. METER INLET °F	TEMP. METER OUTLET °F
1	0	233°	.83	1.55	44°	2.95	93°	89°
	4	238°	.83	1.55	43°	3.0	94°	89°
2	8	235°	.74	1.4	43°	2.95	98°	89°
	12	232°	.74	1.4	43°	3.0	99°	90°
3	16	237°	.63	1.15	43°	2.65	100°	90°
	20	232°	.63	1.15	43°	2.65	99.5°	89°
4	24	226°	.55	1.1	43°	2.65	100°	89°
	28	221°	.55	1.1	43°	2.60	100°	89°
	32	221°	.55	1.1	43°	2.60	100°	88°
1 Point								
1	32	229°	1.0	1.9	44°	3.75	95°	88°
	36	235°	.99	1.9	44°	3.85	99.5°	90°
2	40	235°	.83	1.6	44°	3.45	101°	89°
	44	231°	.80	1.6	44°	3.50	103°	87°
3	48	236°	.79	1.55	44.5°	3.45	104°	87.5°
	52	237°	.78	1.55	44.5°	3.45	105.5°	90°
4	56	232°	.73	1.35	45°	3.2	107°	91.5°
	60	230°	.73	1.35	45°	3.2	107°	91.5°
	64	230°	.73	1.35	45°	3.2	107°	91.5°
		Ave. 231°	Ave. .860		Ave. 43.7°	Ave. 3.1	°	90.5°

CONTROL BY COMBUSTION

I INTRODUCTION

Many organic compounds released from manufacturing operations can be converted to innocuous carbon dioxide and water by rapid oxidation -- combustion. Three rapid oxidation methods are used to destroy combustible contaminates 1) furnaces, 2) flares and 3) catalytic combustion. The furnace and flare methods are characterized by the presence of a flame during combustion. Whereas, catalytic combustion utilizes a metallic catalyst to promote rapid oxidation. Catalytic combustion is a flameless-type combustion.

II PRINCIPLES OF COMBUSTION

To achieve complete combustion, i.e., the combination of the combustible elements and compounds of a fuel with all the oxygen which they can utilize, sufficient space, time, turbulence, and a temperature high enough to ignite the constituents must be provided.

The "three T's" of combustion -- time, temperature, turbulence -- govern the speed and completeness of the combustion reaction. For complete combustion, the oxygen must come into intimate contact with the combustible molecule at sufficient temperature, and for a sufficient length of time, in order that the reaction be completed. Incomplete reactions may result in the generation of aldehydes, organic acids, carbon and carbon monoxide.

The factors influencing completness of combustion are evaluated in more detail below.

A Temperature

Every combustible substance has a minimum ignition temperature, which must be attained or exceeded, in the presence of oxygen, if combustion is to ensue under the given conditions. This ignition temperature may be defined as the temperature at which more heat is generated by the reaction than is lost to the surroundings.

The ignition temperature for flame combustion of combustible substances cover a large range, as indicated in Table 1.[1]

The ignition temperatures of the gases volatized from coal vary considerably and are appreciably higher than the ignition temperatures of the fixed carbon in the coal. The gaseous constituents in the coal are usually distilled off, but not ignited, before the ignition temperature of the fixed carbon is attained. Therefore if complete combustion of the gases is to be achieved it is necessary that the temperature of the effluent gases be raised to the ignition temperature of the gases.

The same principle applies to the complete combustion of any mixture of combustible substances. A sufficiently high temperature must be achieved which will burn all the combustible compounds. To achieve such a temperature it may be necessary to add auxilliary heat to the combustible-laden gas stream (e.g., via a gas fired burner).

Since the reaction rate increases with temperature, temperatures considerably above the ignition temperatures of the combustible may be necessary to accomplish complete combustion in a reasonable amount of time.

B Oxygen

Oxygen is necessary for combustion to occur. The end products of combustion depend on the supply of oxygen. When methane, for instance, is burned with too little oxygen, solid carbon results thus:

$$CH_4 + O_2 = C + 2H_2O + Q \text{ (heat of reaction)}$$

The solid carbon agglomerates forming particles of soot and smoke. If enough oxygen is supplied, the carbon is burned to carbon dioxide, thus:

Table 1. FLAME IGNITION TEMPERATURE IN AIR*
(At Pressure of One Atmosphere)

Combustible	Formula	Temperature, °F
Sulfur	S	470
Charcoal	C	650
Fixed carbon (bituminous coal)	C	765
Fixed carbon (semibituminous coal)	C	870
Fixed carbon (anthracite)	C	840 - 1115
Acetylene	C_2H_2	580 - 825
Ethane	C_2H_6	880 - 1165
Ethylene	C_2H_4	900 - 1020
Hydrogen	H_2	1065 - 1095
Methane	CH_4	1170 - 1380
Carbon monoxide	CO	1130 - 1215
Kerosene	-	490 - 560
Gasoline	-	500 - 800

* Rounded-out values and ranges from various sources, a guide only.

$$CH_4 + 2O_2 = CO_2 + H_2O + Q$$

Here, then it is completely burned, no solid is set free, and hence there is no smoke.

When carbon is burned with an insufficient supply of oxygen, carbon monoxide results

$$2C + O_2 = 2CO + Q$$

If enough oxygen is available, then carbon dioxide results

$$C + O_2 = CO_2 + Q$$

The chemical reactions which occur during the combustion of many gaseous compounds are shown in Table 2.(1)

To achieve complete combustion of a combustible compound with air, a Stoichiometric (theoretical) quantity of oxygen must be available. The quantity of air which must be furnished to obtain theoretical complete combustion for many combustible compounds is shown in Table 3.(1)

It is necessary, however, to use more than the theoretical air required to assure sufficient oxygen for complete combustion. Excess air would not be required if it were possible to have every oxygen molecule combine with the combustibles. The amount of excess air added to insure complete combustion must be held at a practical minimum to reduce the stack heat losses. Realistic values of excess air necessary to burn various fuel are given in Table 4.(1)

C Time

A fundamental factor in the design and performance of combustion equipment is the

Table 2. COMMON CHEMICAL REACTIONS OF COMBUSTION

Combustible	Reaction
Carbon (to CO)	$2C + O_2 = 2CO + Q$
Carbon (to CO_2)	$C + O_2 = CO_2 + Q$
Carbon monoxide	$2CO + O_2 = 2CO_2 + Q$
Hydrogen	$2H_2 + O_2 = 2H_2O + Q$
Sulfur (to SO_2)	$S + O_2 = SO_2 + Q$
Sulfur (to SO_3)	$2S + 3O_2 = 2SO_3 + Q$
Methane	$CH_4 + 2O_2 = CO_2 + 2H_2O + Q$
Acetylene	$2C_2H_2 + 5O_2 = 4CO_2 + 2H_2O + Q$
Ethylene	$C_2H_4 + 3O_2 = 2CO_2 + 2H_2O + Q$
Ethane	$2C_2H_6 + 7O_2 = 4CO_2 + 6H_2O + Q$
Hydrogen sulfide	$2H_2S + 3O_2 = 2SO_2 + 2H_2O + Q$

where Q = the heat of reaction

time required for combustion of a particle in relation to the residence time in the equipment at combustion conditions. The residence time (at conditions conducive for complete combustion) should be greater than the time required for combustion of the particle.

The time of residence depends primarily on aerodynamic factors including size which are arbitrarly set in the design of the unit. The time of combustion is controlled by the temperature and aerodynamic factors. The time of residence, then, becomes a question of economy, namely size versus temperature. The smaller the unit, the higher the temperature must be to oxidize the material in the time of contact.

D Turbulence

Not only must the oxygen be supplied, but it must be intimately mixed with the material being burned so that it is available to the combustion substance at all times. When burning solids, without turbulence, the initial products of combustion act as a screen for the incoming oxygen and thereby slow down the rate of surface reaction. The burning of gases requires a thorough mixing of them with air otherwise separate zones between the gases and air will form and they will escape unchanged or incompletely burned.

Through the proper regulation and control of these four factors, complete combustion can be attained.

2 Blue flame

A burner utilizing the same fuel, but arranged to premix the air and fuel prior to delivery to the burner nozzle, will produce a short, intense, blue flame, permitting complete oxidation within a confined space

In any fuel-fired burner, whether it is of the luminous (yellow flame) or permixed (blue flame) type, sustained combustion depends upon maintaining the air-gas supply to the burner within the flammable range

B Flare Combustion

All process plants which handle hydrocarbons, hydrogen, ammonia, hydrogen cyanide, or other toxic or dangerous gases are subject to emergency conditions which occasionally require immediate release of large volumes of such gases for protection of plant and personnel In many petrochemical process, hydrocarbons present with inert gases, such as nitrogen and carbon dioxide, must be continuously released in variable volume and concentration. Where these gases are released at energy concentrations constantly within or above the flammable range, their disposal can be handled most economically and safely by application of flares However, smokeless burning of hugh quantities of gases by flares presents some serious design problems First, the flare must be sufficiently elevated above ground level for heat and flame protection of adjacent buildings and personnel Flame must be sustained at varying rates exceeding by many times to operating range of industrial burners. These physical demands prevent the employment of combustion chambers.

Flare combustion is often characterized by a luminous (yellow) flame. The luminous flame results when oxygen in the air surrounding the flame comes in contact with the hydrocarbons by diffusion only. The luminous color results from incandescent carbon which result from the cracking of the hydrocarbon molecules.

Blue-flame flare combustion can be accomplished by adding water vapor, under proper temperature conditions, as the gas is burned. A water-gas reaction is set up, generating carbon monoxide and hydrogen which assists in the production of blue flame burning by removing the unburned carbon. Combustion of carbon monoxide and hydrogen results in carbon dioxide and water [2]

$$C + H_2O = CO + H_2 \quad \text{(water-gas reaction)}$$

$$CO + \tfrac{1}{2}O_2 = CO_2$$

$$H_2 + \tfrac{1}{2}O_2 = H_2O$$

One design of a steam injected flare is illustrated in Figure 1.[2]

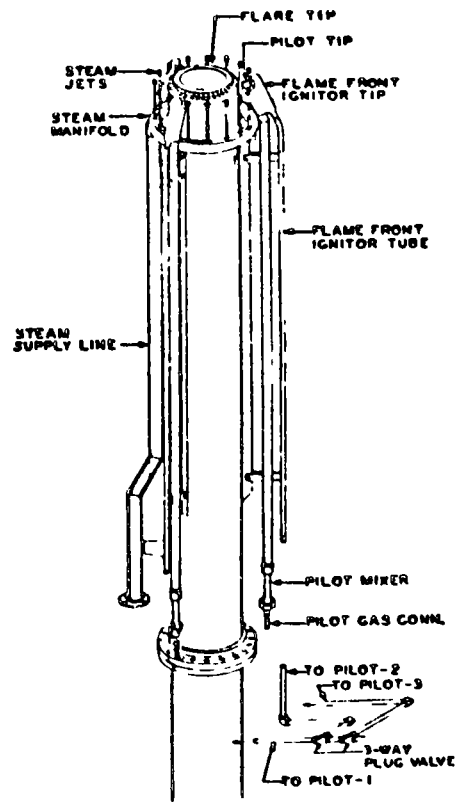


Figure 1. STEAM INJECTION TYPE FLARE

C Furnace Combustion

Whereas flares are effective in destroying waste gase which are released continuously or periodically at concentrations above the lower limit of flammability, gases vented from industrial processes are generally exhausted at concentrations far below the lower flammable limit At these concentrations of gases, combustion in an enclosed chamber is necessary.

Furnace combustion is commonly called "direct flame incineration" since a separately fired burner is normally employed to sustain rapid oxidation The flame, per se, has no influence on the reaction except as it provides the time - temperature - turbulence factors.

Since "the three T's" allow considerable latitude in design, numerous combinations of the "three T's" will result in complete combustion Generally, however, furnace construction costs required a practical limit on holding time of less than 0 5 to 0 75 seconds Residence temperature may vary from 950°F for naphtha vapors to 1600°F for methane and somewhat higher for some aromatic hydrocarbons (2) Higher percentages of inerts in the gas stream which act as oxidation depressants will demand higher temperatures.(3)

A diagram of a waste gas and odor incinerator is shown in Figure 2.

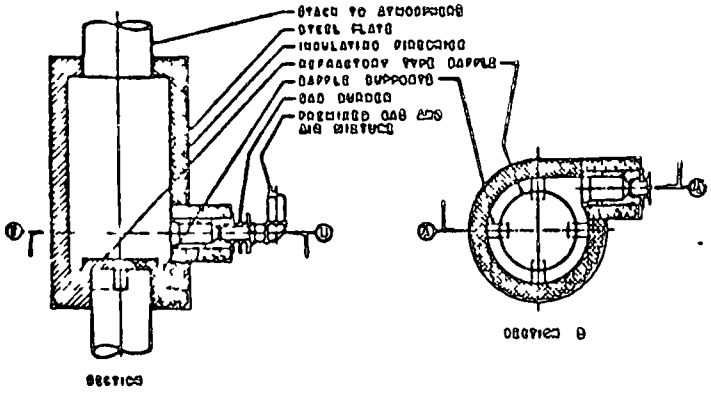


Figure 2. DIAGRAM OF A WASTE GAS AND ODOR INCINERATOR

D Catalytic Combustion

Catalytic combustion is the lowest temperature method of rapidly oxidizing combustible gases and vapors Many substances exhibit catalytic properties, but metals in the platinum family are recognized for their ability to produce the lowest catalytic ignition temperatures and are therefore conventionally used.

Since catalytic oxidation is a surface reaction, relatively small amount of platinum are used in a way which exposes the maximum surface area to the gas stream This is accomplished by coating a high surface area substance with the catalyst and arranging the catalyst coated substances in catalyst beds

Sufficient surface area must be supplied to permit the oxidation reaction to be completed within the bed, since "the three T's" still apply if "exposed catalyst surface" is substituted for "time " Turbulence is achieved in the passage of the contaminated gases through the bed. Catalyst temperature results from the oxidation reaction itself, plus burner or electric preheating where necessary With platinum alloy catalysts, oxidation of hydrogen will be initiated at ambient temperature, naphtha at 450°F, and methane at 750°F.(2)

The temperatures required to catalytically oxidize many organic compounds are given in Table 5 (4)

Catalytic combustion is generally applicable where the following conditions apply 1) where the gas stream to be handled contains vaporized or gaseous combustible materials, and 2) where there is no large amount of dust, fly ash, or other solid inorganic material in the gas stream

Catalytic systems are designed to prevent condensate formation in exhaust equipment. The exhaust fan in a catalytic system is located on the hot side of the system so that all vapors passing through it are above the condensation temperature

Table 5. INDUSTRIAL APPLICATIONS OF CATALYTIC COMBUSTION

Industrial process	Contaminating agents in waste gases	Approximate temperature required for catalytic oxidation
Asphalt Oxidizing	Aldehydes, Anthracenes, Oil Vapors, Hydrocarbons	600° - 700°F
Carbon Black Mfg.	H_2, CO, CH_4, Carbon	*1200° - 1800°F
Catalytic Cracking Units	CO, Hydrocarbons	650° - 800°F
Core Ovens	Wax, Oil Vapors	600° - 700°F
Formaldehyde Mfg.	H_2, CH_4, CO, HCHO	650°F
HNO_3 Mfg.	NO, NO_2	** 500° - 1200°F
Metal Lithography Ovens	Solvents, Resins	500° - 750°F
Octyl-phenol Mfg.	C_6 H_5OH	600° - 800°F
Phthalic Anhydride Mfg.	Maleic Acid, Phthalic Acid, Naphthaquinones, Carbon Monoxide, Formaldehyde	600° - 650°F
Polyethylene Mfg.	Hydrocarbons	500 - 1200°F
Printing Presses	Solvents	600°F
Varnish Cooking	Hydrocarbon Vapors	600° - 700°F
Wire Coating and Enameling Ovens	Solvents, Varnish	600° - 700°F

* Temperatures in excess of 1200°F required to oxidize carbon,
** Reducing atmosphere required.

A typical catalytic combustion system employing a preheat burner is shown in Figure 3.[2]

Heat evolved by the catalytic oxidation can also be used to preheat the gas stream. Figure 4[4] shows a heat exchanger and preheat burner arrangement to heat the gas stream to the catalytic ignition temperature.

IV SELECTED APPLICATION OF COMBUSTION TO AIR POLLUTION CONTROL

A Flare Combustion

1 Dimethylamine odor control during the manufacture of soaps and detergents[5]

New and improved products for the consumer requires new processes and new chemical raw materials The manufacture of new products by a soap and detergent company required the use of dimethylamine as a raw materia

Dimethylamine $\left[NH(CH_3)_2\right]$ is a gaseous material at 40°F and atmospheric pressure The material is a first cousin of ammonia (NH_3) and at concentrations in excess of 100 ppm the odor of this amine is nearly identical to that of ammonia As the amine concentration becomes diluted it takes on an odor resembling fish which has been in the sun too long. As the concentration falls below 100 ppm the fish odor becomes predominant over the ammonia odor

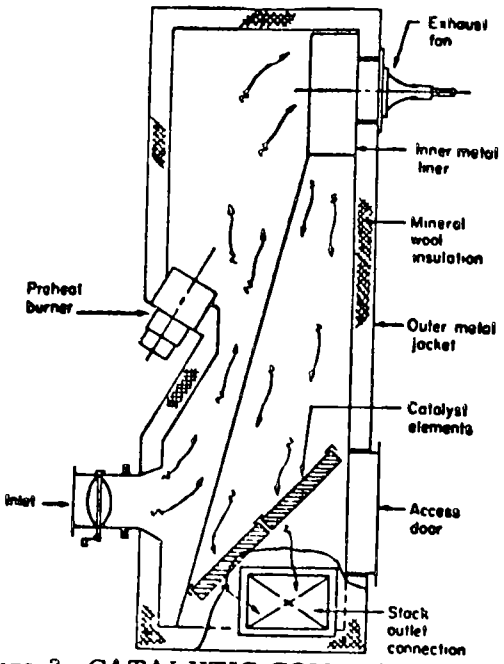


Figure 3. CATALYTIC COMBUSTION SYSTEM INCLUDING PREHEAT BURNER AND EXHAUST FAN

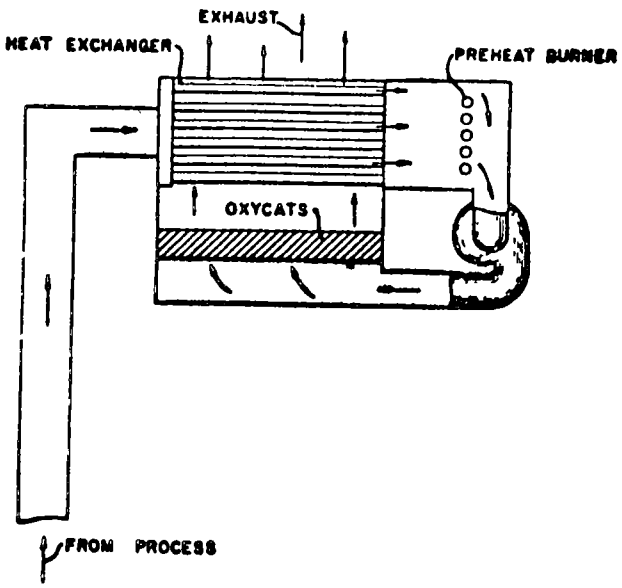


Figure 4. CATALYTIC COMBUSTION SYSTEM INCLUDING HEAT EXCHANGER, PREHEAT BURNER AND HEAT FAN

In order to protect residence 2500 feet from the plant from this fishy odor a method was needed to destroy the dimethylamine emissions The solution to this odor problem was obtained through the use of a 100-foot flare stack. The amine-laden waste gases are vented to a holding tank for storage A continuous flow of the amine-laden gases enters the base of the flare stack, passes through a flame arrestor and are incinerated at the top of the flare stack. The stack is equipped with four natural gas pilot lights to assure ignition of all combustibles released from the stack. The result has been a smokeless flare which reduces the odor problem several orders of magnitude.

B Furnace Combustion

1 Methyl mercaptan, hydrogen sulfide and methyl sulfides odor control from the Kraft Pulping Process (6)

Odors resulting from the Kraft (sulfate) pulping process have been reduced by rapid oxidation of the non-condensable gases emitted from the black liquor. Gaseous emissions from the black liquor contain the odorous compounds, methyl mercaptan, hydrogen sulfide and methyl sulfide. The oxidation of these compounds results in sulfur compounds which are less volatile and therefore less odorous than the original contaminants.

Several west coasts pulp and paper mills have installed equipment to incinerate these odorous sulfur gases One mill utilizes an integral part of the Kraft process, the lime kiln, to incinerate the odors. Another method of reducing the odors has been the oxidation of the black liquor itself.

Emissions of gaseous sulfur compounds may be as high as 100 pounds per ton of pulp from an uncontrolled Kraft process.

2 Vapor control from paint and varnish cookers(7)

In the burning of combustible vapors from paint and varnish cookers, adequate consideration must be given to prevent

fire or explosion in the kettle as a result of flashback through the vapor. Safeguards can be achieved by diluting the vapor concentration to less than 25 percent of the lower explosive limit and by maintaining gas velocities in the ducts well in excess of 20 feet per second, the rate at which flame could propagate along the duct.

A fume (vapor) combustion system for incinerating vapors from paint and varnish cookers is shown in Figure 5.

A correctly proportioned and well insulated furnace requires a fuel input between 600 and 1200 BTU per hour per gallon of processed batch. In some processes, enough vapors are produced to appreciably supplement the regular fuel

3 Odor control from coffee roasters[8]

The combustibles in coffee roasting effluent gases may be present in concentration ranging from 0.17 to 0.27 grains per cubic feet, depending upon the type of roaster and the rate of exhaust flow

The roaster exhaust gases include the following compounds· formic acid, high fatty acids, furfural, methylamine, pyrole, acetic acid, acetone, ammonia pyridine and hydroquinone

Furnace combustion is presently being employed to incinerate the combustible gases from coffee roasters and to reduce the odor per se.

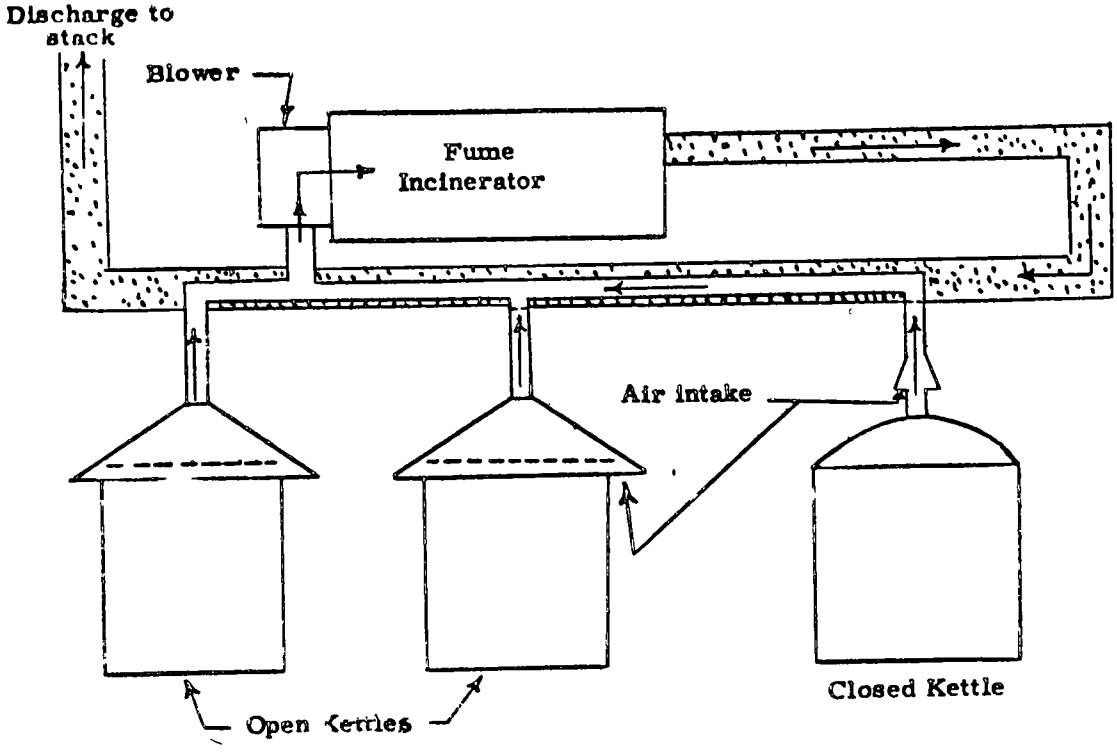


Figure 5. LAYOUT OF FUME COMBUSTION SYSTEM FOR PAINT AND VARNISH COOKING

4 Vapor and particulate control from a flue-fed (apartment house size) incinerator[9]

Flue-fed incineration is a batch-type operation. To effect complete combustion requires that the correct amount of combustion air (Stoichiometric air plus some excess air) be supplied during each segment in the combustion cycle. Normally, however, batch-type incineration results in a deficiency of air after the refuse is charged and too much excess air during the burn-down portion of the cycle The result is incomplete combustion of combustible gases and particulates (solids).

Afterburners are used to effect complete combustion of the incinerator effluent gases. Normally an afterburner built into the incinerator or a roof-type afterburner is used to incinerate the effluent gases. A diagram of a roof afterburner is shown in Figure 6.

C Catalytic Combustion

1 Catalytic oxidation of lithographic oven vapors[4]

Catalytic combustion is used in many industrial processes to destroy odors and contaminant gases Among the processes in which catalytic oxidation is used includes varnish cooking, carbon black manufacture and metal lithographic ovens.

Figure 7 shows a catalytic oxidation system used on a metal lithographic oven. Here a portion of the process effluent, after having been catalyzed and cleaned, is channeled back to a lithographying oven. The returned exhaust, split among several zones in the oven, provides all or a part of the oven heat requirements. Excess exhaust over that needed to heat the oven is vented directly to the atmosphere.

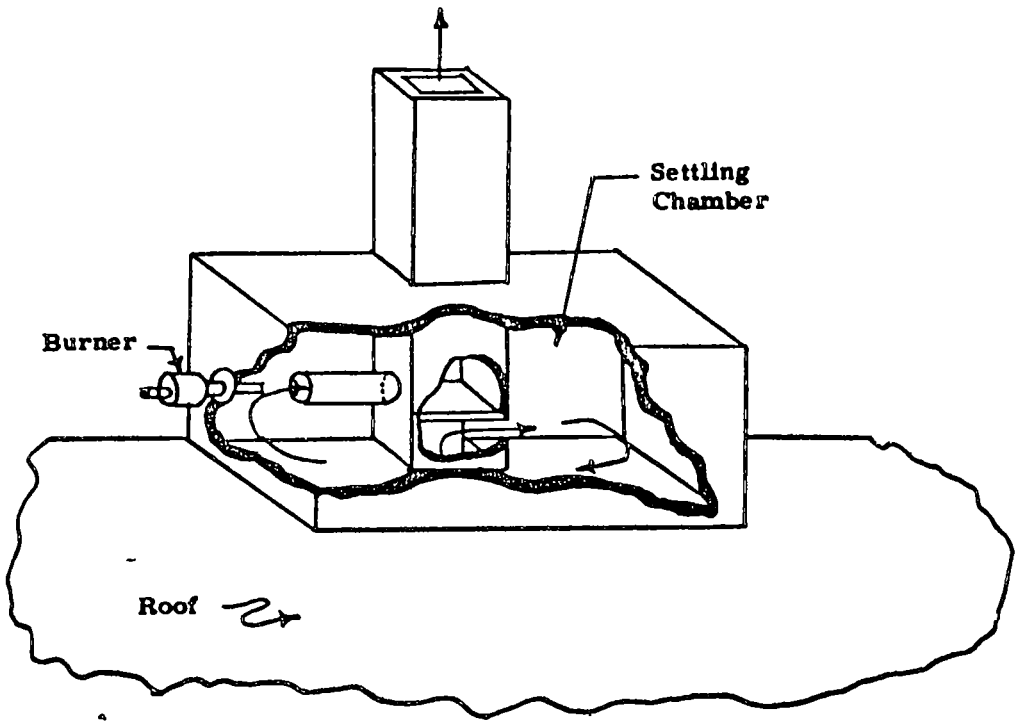


Figure 6. ROOF AFTERBURNER

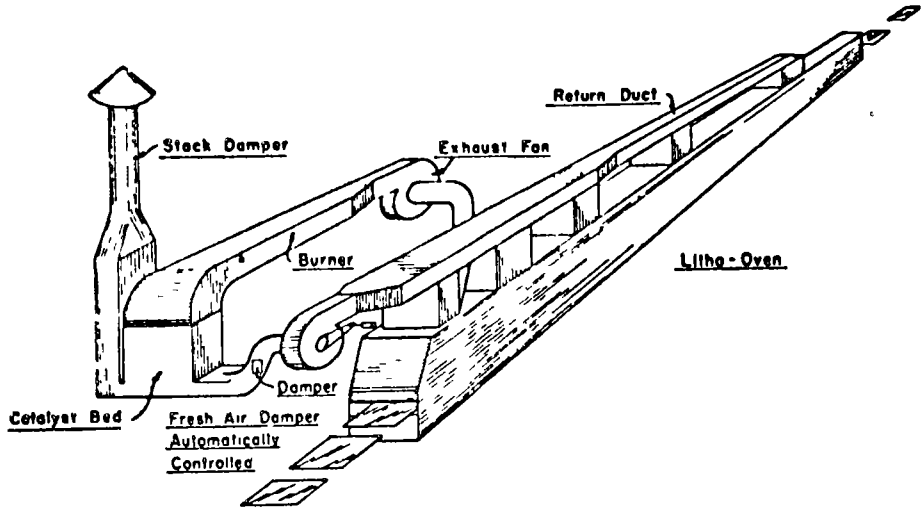


Figure 7. CATALYTIC OXIDATION OF SOLVENT FROM METAL LITHOGRAPHIC OVENS

2 Catalytic reduction (deoxidation) of nitrogen oxides in waste gases from nitric acid manfacture[10]

Catalytic combustion is also used to reduce contaminants to lower oxidation-state compounds. Waste gases (tailgas) from the manufacture of nitric acid contain NO, NO_2 and nitric acid vapors. Concentrations of nitrogen oxides in these waste gases range from less than 0.1 per cent to almost 50 per cent by volume. By mixing a hydrocarbon (e.g., methane) or reactive fuel (e.g., carbon monoxide) with the waste gases and passing the gases through a catalyst, the following reaction takes place if the reaction goes to completion.

$$(n_1)\ NO_x + (n_2)\ HC = (n_3)\ H_2O + (n_4)\ CO_2 + (n_5) N_2$$

This reaction can be made to proceed at comparatively low temperature (500 - 1200°F).* The amount of free oxygen contained in the waste gas stream presumably influences the ease with which the reaction can be completed. Obviously, when the waste gas stream is entirely devoid of free oxygen, then oxidation of the hydrocarbons can occur only through simultaneous reduction of the nitrogen oxides to a lower oxidation state or free nitrogen

A schematic of a catalytic reduction system for nitric acid waste gases is shown in Figure 8

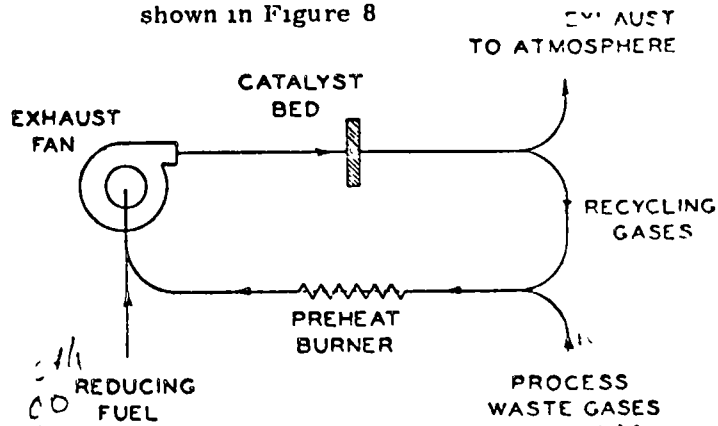


Figure 8. SCHEMATIC OF CATALYTICAL REDUCTION SYSTEM FOR NO_x

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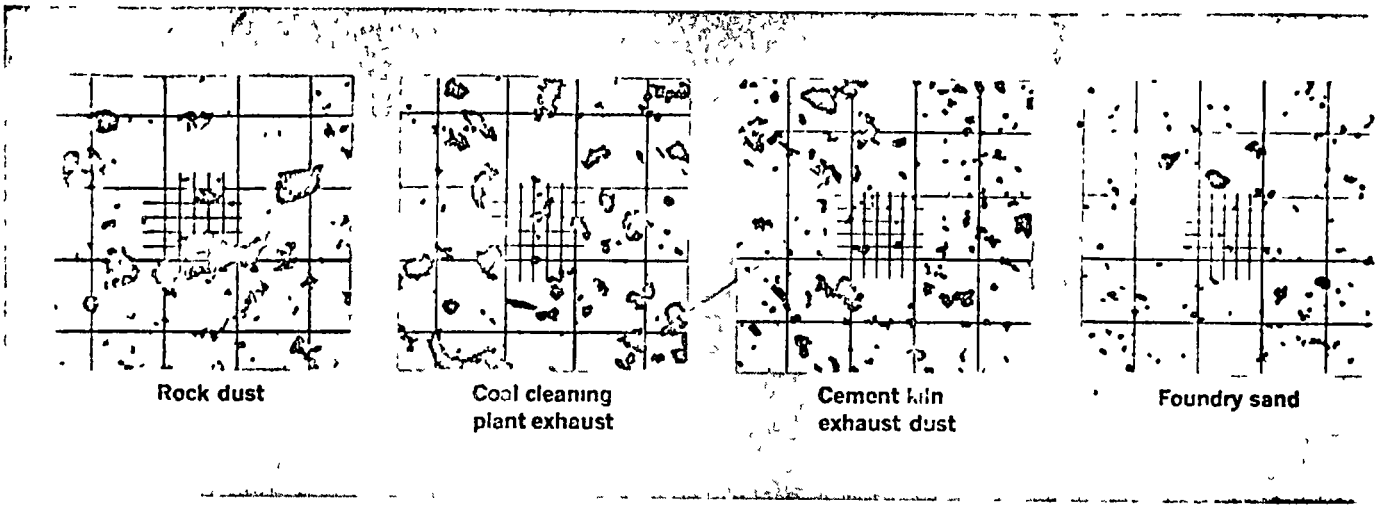
1 Babcock and Wilcox Co. Steam -- Its Generation and Use 37th Edition, Chapter 4 1963.

2 Stern, A.C. Air Pollution Academic Press, New York City, Vol II, Chapter 32

3 Coward, H.F. et al. U.S. Bureau of Mines - Bulletin 503, Vol 4, 1952

*Table 5



PHOTOMICROGRAPHS of various dusts

Dust Collection Equipment

GORDON D SARGENT, Nopco Chemical Div, Diamond Shamrock Chemical Co

In solving a dust collection problem, an engineer must first evaluate his own situation in order to select the most promising types of collectors This article puts together the available facts and sources that the engineer needs for background information After making a preliminary equipment selection, suitable vendors can be contacted for help in developing the final answer An early and complete definition of the problem can reduce the false starts that lead to wasted pilot trials or costly, inadequate installations

Selecting a dust collector for cleaning a process gas stream can be a challenge Some engineers may try to find shortcuts, and quick estimates put on both gas flow and collection efficiency may be the entire extent of the collector specification. The result can be an ineffective installation that has to be replaced.

Treating a gas stream, especially to control pollution, may not be a money-maker, but costs can be minimized, not by buying the cheapest collector but by thoroughly engineering the whole system, as is normally done in other process design areas

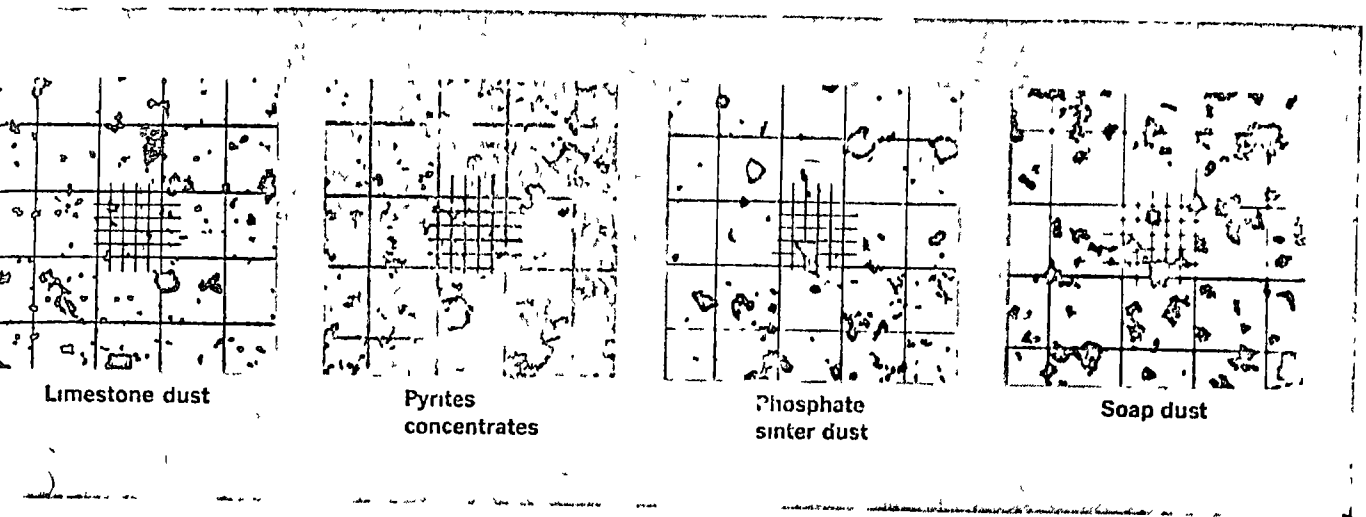
What data are needed? What equipment might be suitable? The usual questions that immediately arise in the choice of a pump or heat exchanger have well-established routes to the answers By contrast, the extremely heterogeneous nature of particulates in gas streams has led to a wide variety of equipment for which engineering principles are either lacking or not available to the practicing engineer, equipment manufacturers must be relied upon for proprietary designs and for performance guarantees

Gas-cleaning equipment discussed here will handle dust particle sizes between 0 1 and 100 microns and concentrations from 0 1 to 100 grains/cu ft The micron (μ) is the commonly used unit of particle-size measurement and is defined as 1/1,000 mm or 1/25,400 in

Dust concentrations are usually given in terms of grains/cu ft of gas (7,000 grains = 1 lb)

Air cleaners for fumes with much smaller particle size and loadings are beyond the scope of this article, as are combustion or catalytic incinerators, gas or odor absorbers or adsorbers, ventilation-air cleaners and mist eliminators

The need for gas cleaning may be either for process, protection or profit A collector may be an integral part of a process such as spray-drying or an auxiliary to recover valuable byproduct The main requirement may be safety, as by reducing toxic or combustible dust. People and property in the plant or neighborhood may need to be protected by a good dust collection system, or the requirement may be to



(large squares = 100 microns, small squares = 20 microns) American Standard

Selecting a dust collection system is not as straightforward a procedure as choosing a pump or heat exchanger. Here is a guide to the complexities of the numerous kinds of equipment available, the jobs that they do, and the way to select wisely.

meet air pollution laws and to clean up an unsightly stack plume

Equipment Applications

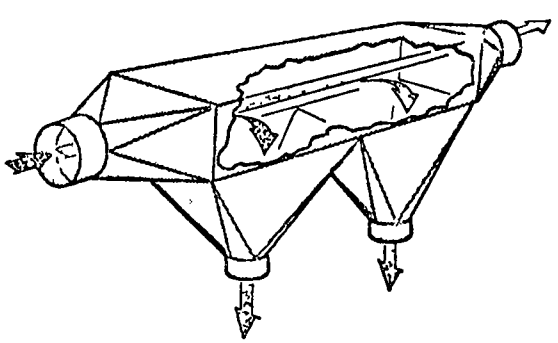
The many different dust collectors available today are summarized in Table I, Equipment Application Table, which simplifies a review of the whole collector field. The table is intended to be used along with descriptions, illustrations, and efficiency curves that follow Ranges and limits tabulated are typical values but naturally may vary widely for unusual applications More background is available in the publications listed under "General Equipment" in the references at the end of this article Suppliers can be found listed in the Environmental Engineering Deskbook (*Chem Eng*, Oct. 14, 1968) and should be consulted especially for integrated systems, packaged units and air cleaners.

Performance of the different types of collectors can be roughly compared by means of the curves showing grade or fractional-size efficiency, Fig. 20. The data were obtained by Stairmand[11] on one standard test-dust with characteristics as shown in Table V.

Other performance curves cannot be compared to these for several reasons. Obviously, equipment design may affect efficiency. We must also consider that different test procedures give widely differing results on the same dust, dust loadings tested may have been different, particle characteristics and even particle size may be different. Efficiency curves must be used with caution and are discussed more fully in a later section of this report

DRY INERTIAL COLLECTORS

A dry collector has certain advantages compared to a wet collector. If the dust is a useful product, dry collection saves the cost of reprocessing Han-



GRAVITY settling chamber—Fig 1

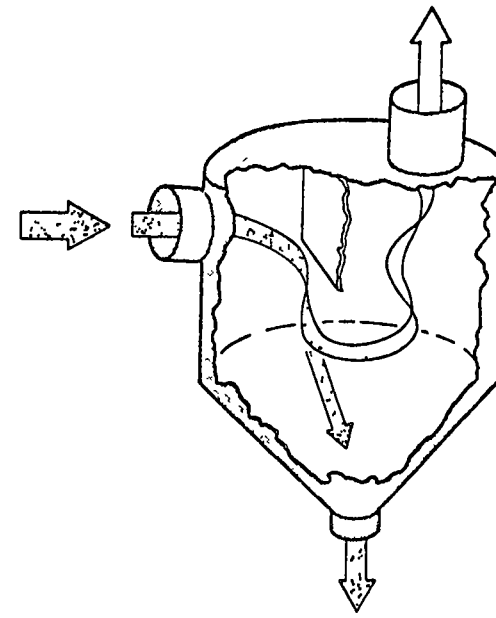
dling the collected material can give rise to additional dust problems Dry, dusty material has the disadvantage of requiring ventilation and if hygroscopic, caking can be a problem The cleaned gas will not be cooled or completely free of fines Without cooling, the temperature limits of equipment will have to be considered Corrosion will be minimum unless the fumes contain corrosive mists Equipment generally is bulky

Inertial or mechanical collectors are best suited for medium or coarse particulates High dust-loadings can be handled at moderate pressure drops and power consumption Simple construction of this type of collector results in lower cost and maintenance than other types Efficiency is not very high; hence, for a really clean effluent, some other type of collecting device must be used in combination with or in place of the inertial collector The inertial or mechanical collectors depend on particle inertia in a gravity or centrifugal force field

Gravity Settling Chamber

Principle—Dirty gas is directed through an oversized duct where velocity drops low enough to let large particles settle out by gravity (Fig. 1)

Comments—Flow may be horizontal or vertical. Dust separation suffers from reentrainment from eddy currents In the Howard dust chamber, horizontal shelves or trays have been added to shorten the settling path of the particle, improving collection efficiency, but making cleaning much more difficult



BAFFLE CHAMBER uses direction change—Fig. 2

The gravity settling chamber is seldom used today, but can be designed for a specific application—ventilation contractors seem to be familiar with them Space requirement is large and efficiency low, which

Equipment application table—Table I

Types of Dust Collecting Equipment	Particle Size Microns	Loading Grains/ Cu Ft	Collection Efficiency Weight %	Pressure Loss Gas, In W G.	Pressure Loss Liquid Psi.	Utilities Per 1,000 Cfm.	Gas Velocity, Fpm	Size Range Limits, 1,000 Cfm.	Space Required, (Relative)
Dry inertial collectors									
Settling chamber	>50	>5	<50	<0 2	——	——	300-600	None	Large
Baffle chamber	>50	>5	<50	0 1-0 5	——	——	1,000-2,000	None	Medium
Skimming chamber	>20	>1	<70	<1	——	——	2,000-4,000	50	Small
Louver	>20	>1	<80	0 5-2	——	——	2,000-4,000	30	Medium
Cyclone	>10	>1	<85	0 5-3	——	——	2,000-4,000	50	Medium
Multiple cyclone	>5	>1	<95	2-6	——	——	2,000-4,000	200	Small
Impingement	>10	>1	<90	1-2	——	——	3,000-6,000	None	Small
Dynamic	>10	>1	<90	Provides head		1-2hp	——	50	
Wet scrubbers									
Gravity spray	>10	>1	<70	<1	20-100	0 5-2 gpm	100-200	100	Medium
Centrifugal	>5	>1	<90	2-6	20-100	1-10 gpm.	2,000-4,000	100	Medium
Impingement	>5	>1	<95	2-8	20-100	1-5 gpm	3,000-6,000	100	Medium
Packed bed	>5	>0 1	<90	1-10	5-30	5-15 gpm.	100-300	50	Medium
Dynamic	>1	>1	<95	Provides head	5-30	1-5 gpm, 3-20 hp	3,000-4,000	50	Small
Submerged nozzle	>2	>0 1	<90	2-6	None	No pumping	3,000	50	Medium
Jet	0 5-5	>0 1	<90	Provides head	50-100	50-100 gpm	2,000-20,000	100	Small
Venturi	>0 5	>0 1	<99	10-30	5-30	3-10 gpm	12,000-42,000	100	Small
Fabric filters	>0 2	>0 1	<99	2-6	——	——	1-20	200	Large
Electrostatic precipitators	<2	>0 1	<99	0 2-1	——	0 1-0 6 kw	100-600	10-2,000	Large

Note The terms expressing concentration, or loading, can be defined as light = ½ 2, moderate = 2 5, and heavy = 5+ grains/cu ft Particle size fine, 50% in ½ 7 micron size range, medium, 50% in 7 15 micron size range, coarse, 50% over 15 microns

Data required for equipment selection—Table II

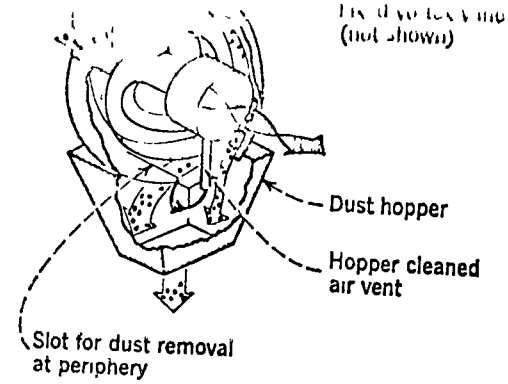
Particle characteristics
- *1. Particle size distribution
- *2. Concentration—average and extreme values
- 3. Particle density (and viscosity)
- 4. Bulk density
- 5. Moisture content
- 6. Electrical resistivity and sonic properties
- 7. Handling characteristics—erosion, abrasion, frangible, flocculent, adhesive, sticky, linty, bridging
- 8. Composition
- 9. Recovery value
- 10. Flammability or explosive limits
- 11. Toxicity limits
- 12. Solubility

Gas characteristics
- *1. Flowrate—average and extreme values
- 2. Pressure
- 3. Temperature
- 4. Moisture content, condensable vapors
- 5. Composition and reactivity
- 6. Corrosive properties

Effluent
- *1. Desired emission of contaminant in clean gas
- 2. Method of disposal or recovery of collected contaminant

* Required for preliminary equipment selection

limits this type to precleaning gas to be fed to a more efficient collector A combination of settling chambers and radiant-cooling connecting ducts is cited in one text[2] as being used in the metal refining industry.

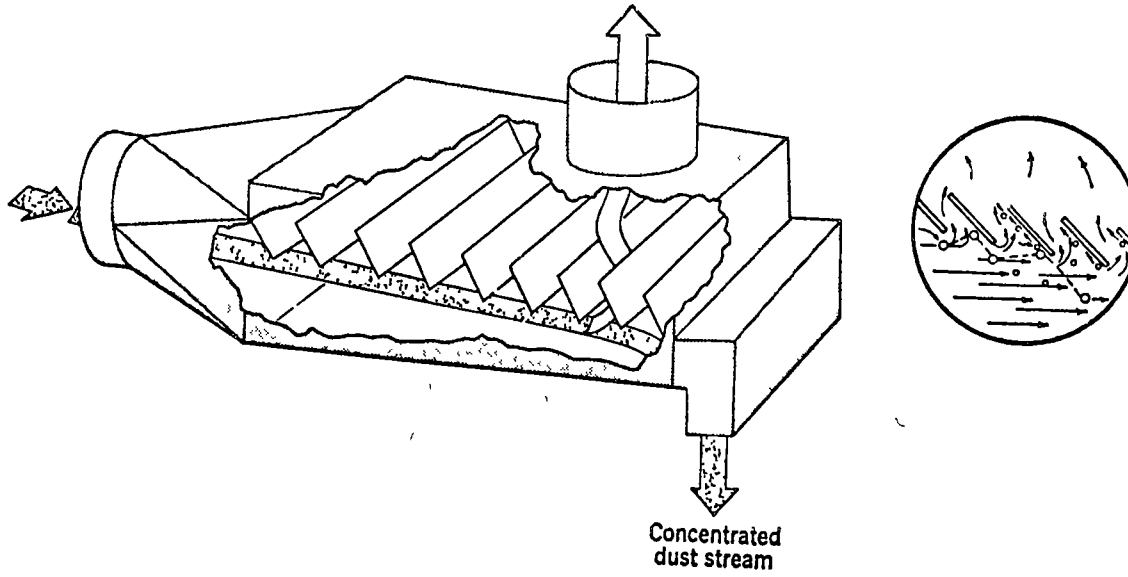


SKIMMING CHAMBER employs scroll—Fig 3

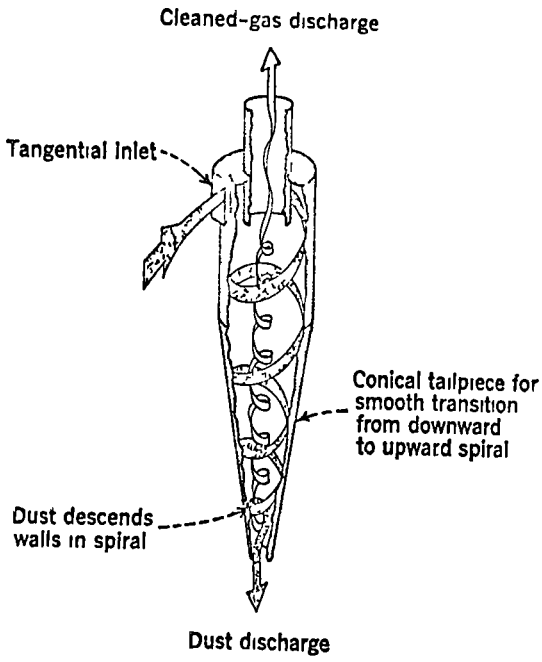
Baffle Chamber

Principle—Settling is aided by using momentum from a direction change Gas flow is directed downward through a chamber containing a baffle around which the gas is deflected, meanwhile the larger dust particles tend to continue moving downward to be collected in a hopper for later use or removal (Fig 2)

Comments—This collector takes less space than the straight-through settling chamber and has similar efficiency One chip-trap design[2] (intended to protect downstream fans from very coarse materials) has dimensions given in terms of the inlet duct diameter.



LOUVER TYPE collector, with detail showing method of dust removal—Fig. 4



CYCLONE removes larger particles—Fig 5

Skimming Chamber

Principle—The dirty gas stream enters a scroll tangentially, the dust is carried to the periphery by inertia Concentrated dusty gas is skimmed by slots and led to a dust hopper or secondary collector. The cleaned gas stream from the hopper is combined with that leaving axially from the skimming chamber (Fig 3.)

Comments—Dry collectors of medium efficiency such as this one have an exit-gas stream that will probably not satisfy most requirements of dust collecting A secondary collector may well be required, the skimming chamber being used to reduce the load of coarser particles that are carried into the secondary collector

Louver-Type Collector

Principle—Gas passes into the wide end of a wedge or cone and must take a sharp bend in order to escape through slots or louvers in the walls The larger particles are carried by inertia to the narrow end of the chamber where they are purged with a small fraction of the gas stream (Fig 4)

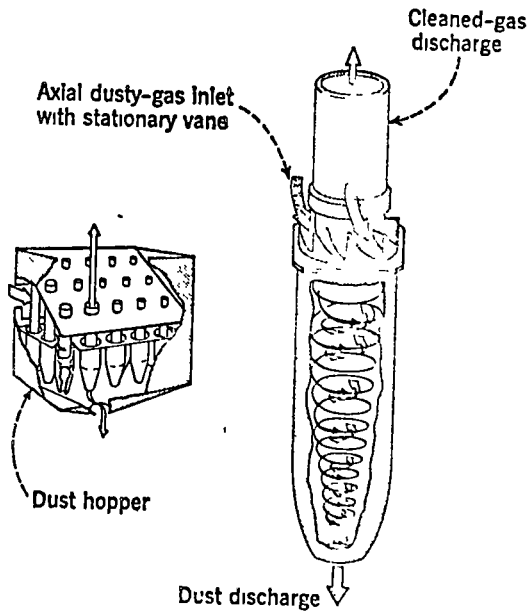
Comments—This collector must be followed by a second collector, such as a high-efficiency cyclone, to separate the dust from the gas. One author (Strauss)[14] shows cone-shaped louvered collectors followed by a baffle chamber for coarse dust, followed in turn by a cyclone for fine dust The gas purged, usually less than 10%, is returned to the inlet of the louvered collector and recycled.

Cyclones

Principle—In the most common arrangement, the gas enters the cyclone tangentially at the top of the cylindrical section and spirals downward into the bottom section, which is usually conical in shape. Dust particles, which have a greater applied centrifugal force than the gas molecules, accumulate at the wall and are carried down, held against the wall by the gas velocity At the bottom of the cyclone the gas separates from the dust, flows back up in a smaller spiral and exits at the top Solids are collected in a hopper and removed by a rotary valve, screw conveyor, or other such means (Fig. 5.)

Comments—Cyclones are one of the most widely used collectors The unit is low cost, has no moving parts and can be constructed with refractory linings for high temperature, up to 1,800 F. The common arrangement with tangential inlet, and axial outlets for dust and clean gas is shown in the schematic diagram, Fig 1. Units can be designed for high dust capacity at medium efficiencies and medium pressure drop. High efficiencies are obtained with smaller diameters and higher velocities, which in turn take higher pressure drops Efficiencies of the high-throughput and high-efficiency cyclones can be compared in Fig 19. Units may be installed in parallel for large gas flows and in series for higher efficiencies (or for both advantages, in combined series-parallel).

Cyclones may have various configurations and still operate on the same basic principle of centrifugal



MULTIPLE CYCLONE (and single element)—Fig 6

separation. Gas entry may be tangential or axial. Gas exit may be axial or axial combined with a pressure-recovery device. Dust exit may be with gas purge or for solids only, with the configuration being axial or peripheral. The skimming chamber, multiple cyclone tubes, and the Uniflow cyclone are variations in the standard design.

Multiple Cyclone

Principle—Since small-diameter cyclones are more efficient than large ones (centrifugal force for a given tangential velocity varies inversely as the radius of the cyclone), banks of small (10 in. or less) cyclones are arranged in parallel with feed gas from a plenum chamber. (Fig. 6.)

Comments—The major advantage is high efficiency. The disadvantage is plugging of the small tubes. The individual small cyclone does not operate as efficiently in multiple installation as it would by itself. This difference arises from unequal gas or dust distribution to inlets and recirculation of gas from dust hopper back through dust outlets. Consequently, multiple cyclones are best obtained from a manufacturer as a complete unit in order to ensure good design.

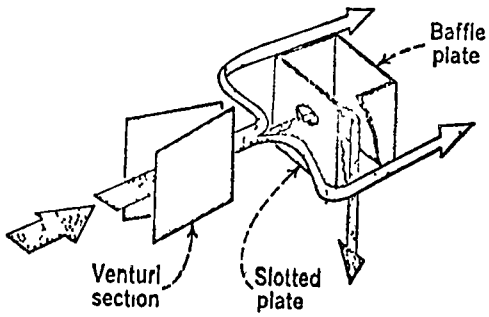
Equipment selection checklist—Table III

Performance and objectives
- Inlet gas volume
- Efficiency required
- Collected contaminant handling or disposal means
- Operating pressure and allowable pressure drop
- Continuous or intermittent operation—frequency of startups
- Surge loads
- Guarantees
- Acceptance tests

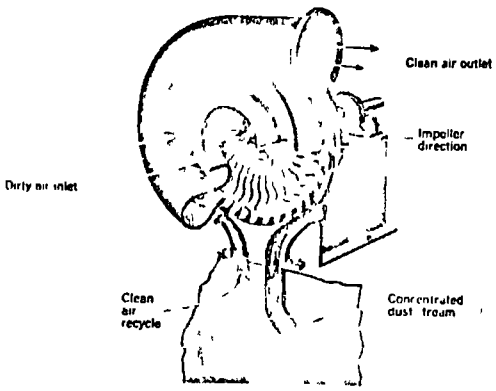
Dust characteristics
- Particle size and distribution
- Dust quantity per hr.
- Sources
- Handling characteristics—erosion, abrasion, frangible, flocculent, adhesive, sticky, linty, bridging
- Recovery value
- Solubility or slurry characteristics including pH
- Bulk density

Gas characteristics
- Composition, molecular weight, reactivity
- Conditions of temperature, pressure, moisture
- Soluble or condensable components
- Required outlet temperature

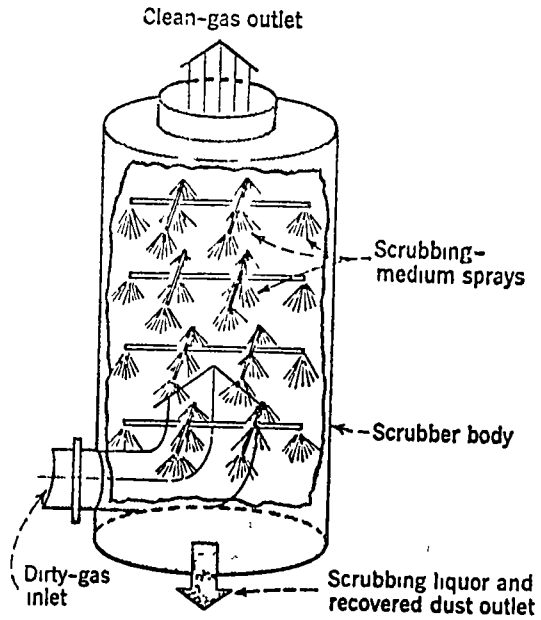
Mechanical features
- Materials of construction
- Nozzle orientation
- Utility characteristics
- Limitations on space and weight
- Proposed location—indoors or outdoors
- Insulation



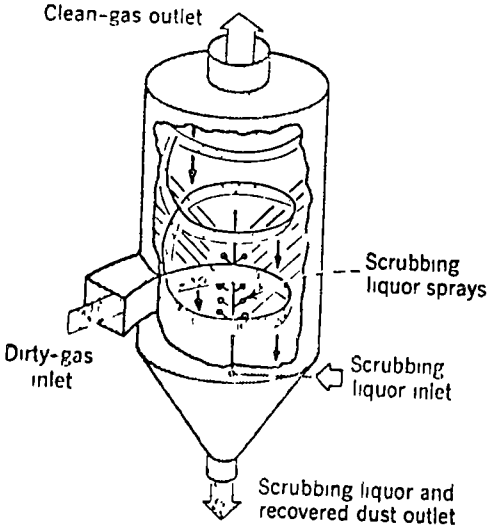
IMPINGEMENT collector (detail of one slot)—Fig. 7

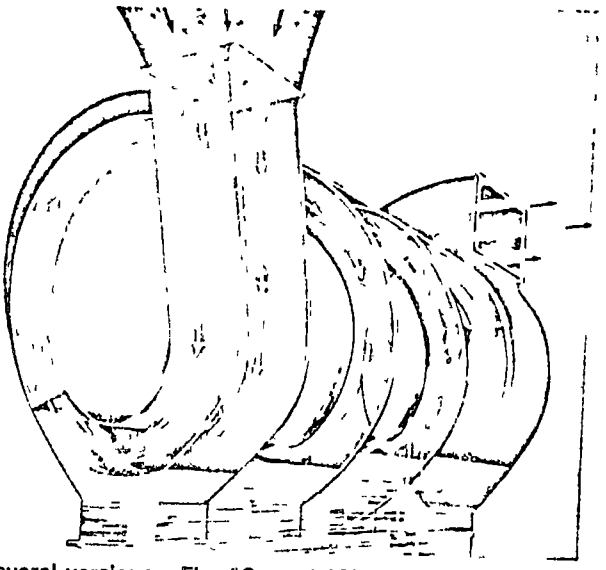


DYNAMIC collector for dust removal—Fig. 8



GRAVITY spray scrubber—Fig. 9



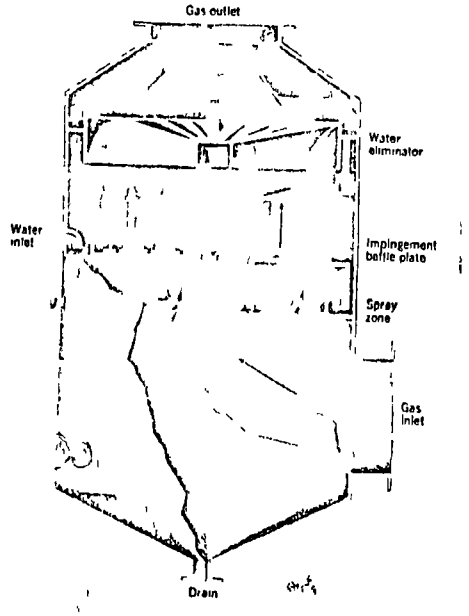


CENTRIFUGAL SCRUBBERS can be had in several versions—Fig 10a and 10b

Impingement Collectors

Principle—Gas velocity is increased in a venturi and particle momentum carries the particles through slots to a flat plate where they drop to a collector Dust particles are collected on a surface while the gas stream is diverted around the plate. (Fig 7)

Comments—Collection of mist is simplified with this collector, since liquid merely runs down the baffle plate These devices may require rappers to free dust that builds on surfaces If the solids are sticky, the surfaces may be continually washed by circulating water, this film, besides cleaning the surface, prevents re-entrainment of particles



IMPINGEMENT scrubber uses baffle—Fig 11

Dynamic Collector

Principle—This is a fan with a specially designed impeller and casing that employs centrifugal force to collect particles at the periphery, where they are drawn off in a concentrated stream (Fig. 8.)

Comments—The unique features of this collector are small space requirement and low pressure drop The packaged unit by American Air Filter combines exhauster, dust separator and storage hopper The dynamic precipitator acts as a true fan although at somewhat lower efficiency, 40 to 50% as against 60 to 65% for a fan designed simply for gas service

WET SCRUBBERS

The wet scrubber recovers product as a slurry or solution that requires further processing either to obtain product or to dispose of as waste

In a wet scrubber

- The gas is both cooled and washed
- Gases may be removed as well as particulates
- Corrosive gases may be neutralized by proper choice of scrubbing medium
- The stack effluent usually will be well cleaned but will contain some unwetted fines, mists, and a steam plume.
- The temperature and moisture content of the inlet gas is essentially unlimited
- Freezing conditions must be considered
- Hazards of explosive dust-air mixtures are reduced
- Equipment occupies only a moderate amount of space.

Efficiencies vary with power input and can extend over a wide range depending on the design Equipment size and initial cost are reasonable, but operating cost is high, especially for high efficiency, which requires large power consumption.

Gravity Spray Scrubber

Principle—Liquid is sprayed into the top of the tower and coarse droplets fall by gravity through a countercurrent flow of the gas being scrubbed Dust particles are collected mainly by inertial impaction and interception (Fig 9)

Comments—Efficiencies and pressure drops are low, but the scrubber is useful for a heavy loading of coarse particulates, or for absorption accompanied by solids removal The wet cap used on top of foundry cupolas is a spray and baffle arrangement in which water both cools the baffle and conveys the collected dust Boiler and process stacks have been scrubbed with sprays installed in the stack, thereby avoiding an additional fan and separate scrubber Entrainment is controlled by using low gas velocities when designing spray towers, but this results in large equipment Sprays are selected to give large droplets that must be heavy enough to fall counter to the gas flow, even though they may be further reduced in size by evaporation

Centrifugal Scrubber

Principle—Liquid is sprayed into the unit and mixed with the rising vortex of gas By impaction and interception the gas and liquid particles combine and are accelerated to the vessel wall by centrifugal force There they are collected The wetted wall also aids collection (Fig 10a, b)

Comments—A variety of types have been developed based on differing of droplet forming and of promoting cyclonic gas action Vaned baffles (Fig 10a) direct gas flow and convert velocity pressure to droplet formation energy Sprays may be installed axially for radially-directed droplets, or circumferentially for tangentially introduced sprays. For higher pressures of 400 psig or so, droplet size is 50 μ or less, instead of, say, 500 μ

Impingement Scrubber

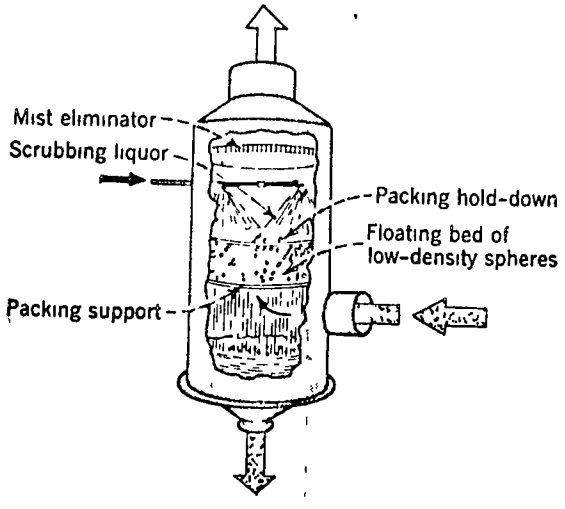
Principle—The gas stream, carrying both dust particles and water droplets from preconditioning sprays, is directed through perforated plates to impinge on baffle plates Gas velocity acts to atomize water on the perforated plate Enlarged particles are collected on vaned mist eliminators and are withdrawn along with the solids collected in the liquid overflow from the impingement plate (Fig 11)

Comments—The scrubber is similar to a sieve-plate column and usually has from one to three plates, although there may be more Extra stages can be added later Each hole in the "sieve" plate has a baffle or "target" above Flow is countercurrent The gas rate in the perforations is high, 75 ft/sec or more, and is used to provide atomization of the liquid on the plate Plugging of holes, which may be ¼ in or less, is not as much of a problem as might be expected, owing to the agitation as well as to the gas preconditioning sprays that wet the underside of the plate Soluble gases can be effectively removed along with the dust

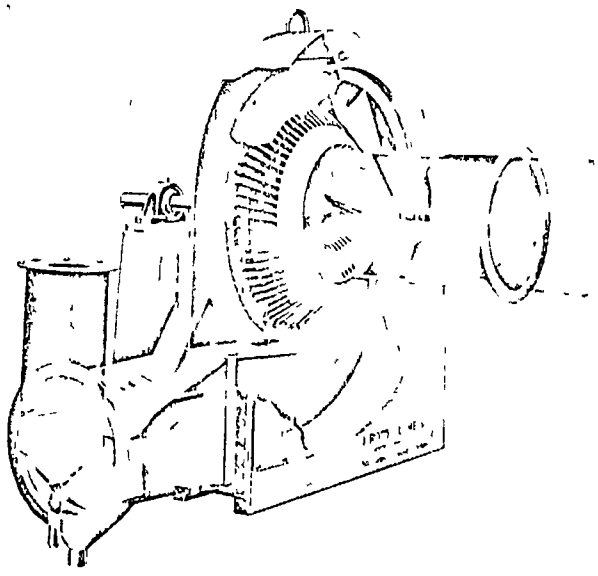
Packed-Bed Scrubber

Principle—Wetted packing provides an impingement surface that prevents reentrainment The liquor provides a means of washing off dust and conveying it in a slurry or solution (Fig 12)

Comments—Packing may be fixed or it may be a floating bed of low-density spheres The advantages are low cost and simplicity, corrosion resistance, and no moving parts Dust collecting may be secondary to direct-contact cooling and gas absorption



PACKED BED scrubber has large surface—Fig 12

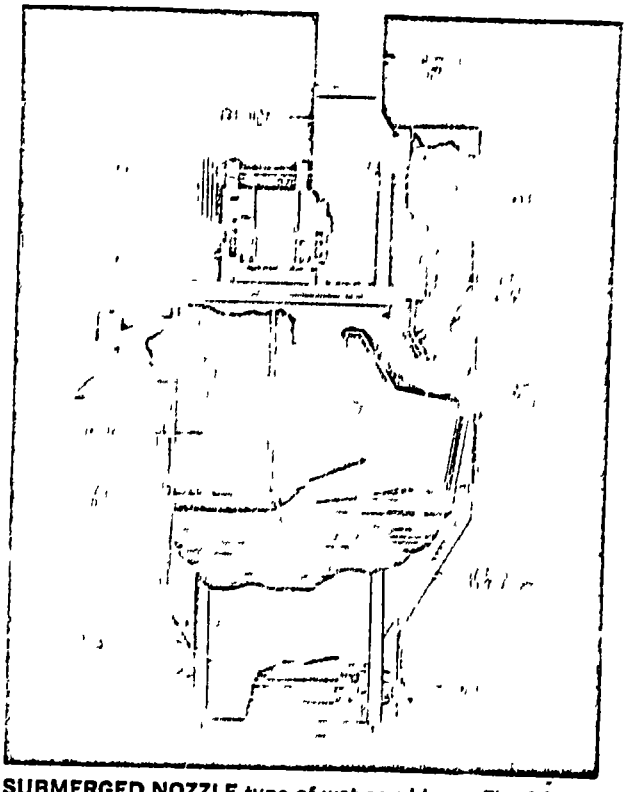


DYNAMIC wet scrubber—Fig 13

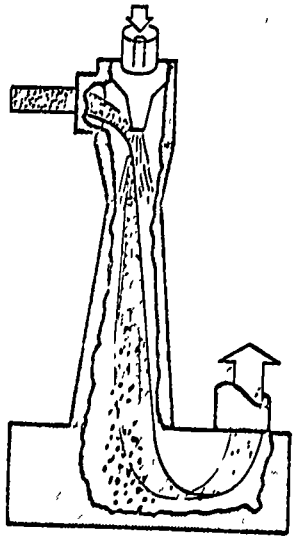
Gases to be removed are below 1% by volume.

The usual countercurrent packed tower has almost no solids-handling capacity, since solids tend to plug the packing and support-plates, which can then be cleaned only by removal. Crossflow scrubbers can handle dust loadings up to 5 grains/cu.ft. by washing the face of the packing with spray nozzles in parallel flow while the body of the packing is irrigated from the top in crossflow.

In a floating bed of plastic spheres, packing movement helps to free the solids.



SUBMERGED NOZZLE type of wet scrubber—Fig. 14



JET scrubber aspirates and collects—Fig. 15

Dynamic Wet Scrubber

Principle—Liquid is sheared mechanically to break the liquid into droplets for collection by inertial impaction between droplets and dust particles (Fig. 13.)

Comments—In the simplest form of dynamic scrubber, water is sprayed into the suction of a fan, and the wetted impeller and housing holds dust particles from recentrainment. The efficiency is high for fine particles and utilities are 3 to 5 gpm./1,000 cfm and 2 to 4 hp/1,000 cfm.

Another unit, the disintegrator, has rotating and stationary bars to break up the water feed stream into fine droplets. This machine seems to be displaced by the venturi today.

Power consumption is very high, 10 to 20 hp./1,000 cfm, efficiency is correspondingly high Rotor speed is 350 to 750 rpm, and buildup must be avoided to prevent rotor unbalance. Consequently, a precleaner, such as a cyclone or centrifugal scrubber, is needed to hold the inlet dust loading on the disintegrator below 0 5 grains/cu ft, and the temperature below 125 F. (Other collectors with mechanically driven elements and a pool of scrubbing liquid are included in the following paragraphs on submerged-nozzle scrubbers.)

Submerged-Nozzle Scrubber

Principle—Gas passing through a nozzle or orifice is scrubbed by the liquid and also atomizes the liquid (assisted in some cases by mechanical means) for further collection of dust particles on the droplets. These droplets are removed in a disengagement chamber, aided by baffles (Fig 14.)

Comments—This type of collector is taken to include scrubbers that atomize liquid entirely by gas kinetic energy, as well as scrubbers in which the gas merely passes through a mechanically formed spray. High dust-loadings can be handled, especially if the units are designed for continuous sludge removal (by conveyor, screw, etc.). Plugging is prevented by designing to avoid close clearances in the area where dry dust meets the spray. The efficiency curve (Fig 20) is for a self-induced spray scrubber without mechanical input.

Jet Scrubber

Principle—Water flow is used in a jet ejector, both to aspirate dusty air and to provide droplets for collecting particulates. The conditioned-dust and the water droplets are separated from the gas in a settling chamber (which may be baffled). (Fig. 15.)

Comments—An induced draft of a few inches of

water is usual because higher values require very high water rates as well as excessive power The jet scrubber can be used where it is not economical to add a fan for a dust collection system and where either mist or easily absorbed gas is to be removed from the gas stream

Venturi Scrubber

Principle—Water is introduced into the throat section and atomized by the high-velocity gas stream The high relative velocity between the accelerating solid particle and the liquid droplet makes for high efficiency by impingement Collection is aided by condensation if the gas is saturated in the reduced-pressure section of the venturi, since the solid particles serve as nuclei for condensing in the pressure-regain section Agglomerated particles built on droplets of 50 μ or more can be collected with high efficiency in a subsequent centrifugal collector (Fig 16)

Comment—High efficiencies require high power input, the venturi scrubber can be designed for large pressure-drops, as much as 80 in water gage, to collect submicron dusts Water can be introduced by spraying or by weir overflow Efficiency is shown in Fig 20, and approaches 100% at 2 μ and 22 in water gage The equipment is simple and can be fabricated in a variety of materials for corrosion resistance

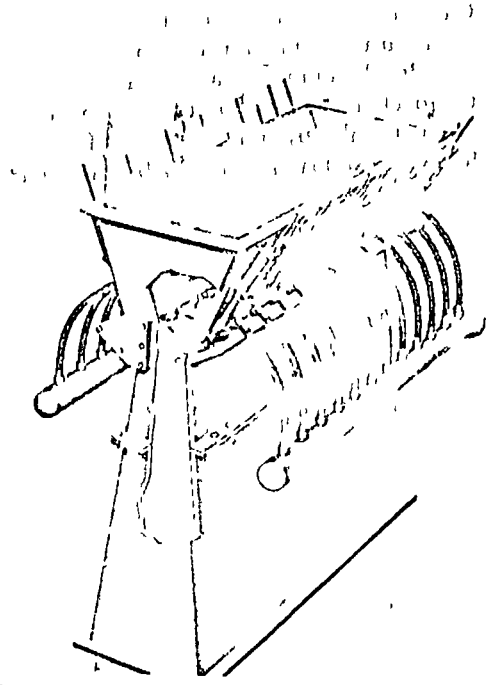
FABRIC FILTERS

Dry collectors have already been compared to wet scrubbers in the previous section on dry inertial collectors Some functional characteristics of fabric filters are similar to those of inertial collectors product is collected in usable condition, cleaned gas is uncooled, and secondary dust problems can be created in handling recovered dust However, the fabric filter can handle much smaller particles at high efficiencies Temperature is limited by the fabrics Moisture content is limited because cold spot condensation can cake solids and also cause corrosion

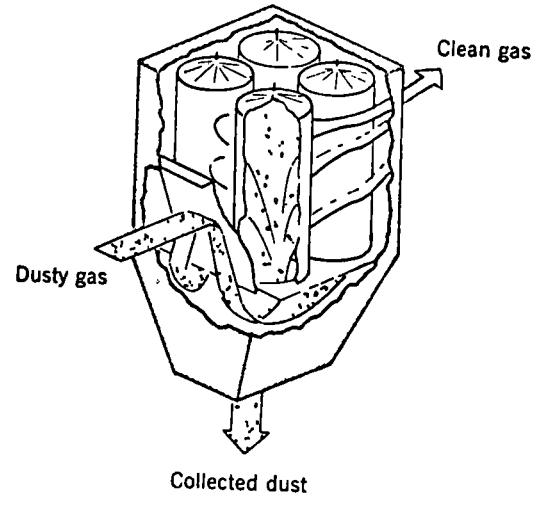
Principle—Filters for industrial gas cleaning are both bag and envelope type, with woven or felted fabric, and made from natural or synthetic fibers. Dirty gas flows through a porous medium and deposits particles in the voids As the voids fill and a cake builds on the fabric surface, the pressure drop increases to a point where the solids must be removed

Comments—Filters are used for high efficiency, 99+%, on small particles in the submicron range Filters will continue to function effectively even when gas properties and process conditions vary Costs are moderate

The principal limitation is temperature, with a maximum of 550 F Cooling a very hot dirty gas may be worthwhile in order to permit using a fabric filter If the gas is below the dewpoint, heating some 50 to 75 F. above the dewpoint will allow a dry unit.



VENTURI SCRUBBER (detail of throat)—Fig 16

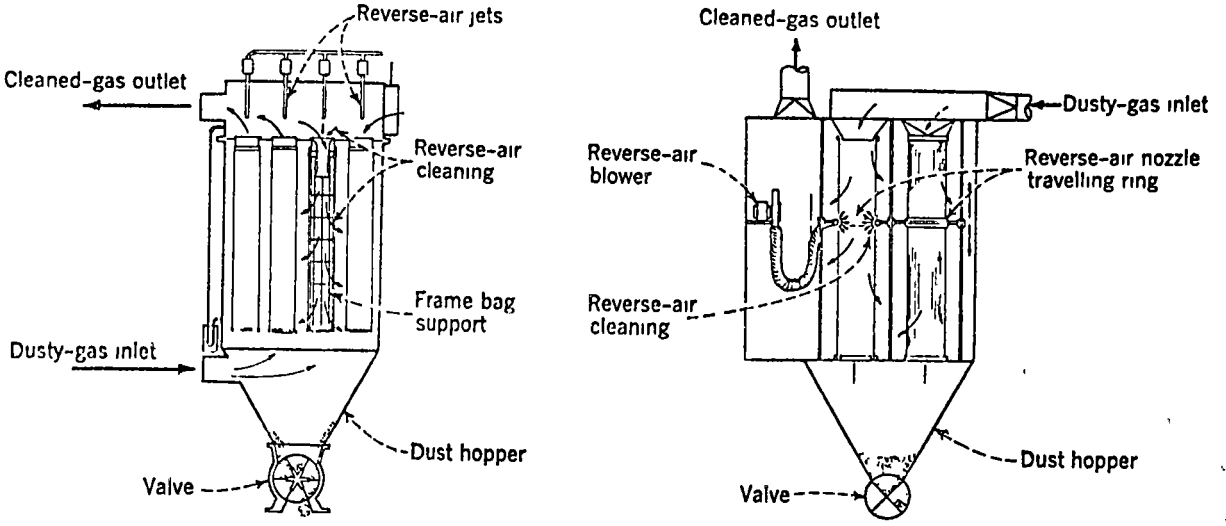


FABRIC filter (collection inside bags)—Fig 17

Space required is large but may be acceptable because the recovered material is dry and ready for either use or disposal (unlike wet-scrubber recoveries).

Intermittently Cleaned Filters

One type of filter is cleaned intermittently by shutting down the process and using shakers or reverse-air-jets to remove the dust cake Another type operates continuously by sequentially cleaning one isolated compartment after another As the compartments comprising the filter are cleaned they are put online again These filters operate at air-volume/cloth-area ratios of 1 5 to 3 cfm /sq ft. of filter area, or in terms of velocity, 1 5 to 3 ft /min Filter media are woven fabrics chosen for thermal, chemical and mechanical endurance.[9] (Fig. 17.)



FABRIC FILTERS with reverse air cleaning (dust collected outside and inside bags)—Fig 18

Continuously Cleaned Filters

Continuous cleaning of filter media without isolating any part of the equipment is accomplished by a travelling blow-ring or by reverse-air-jets These cleaning methods are so thorough and leave so little filter cake that woven fabrics cannot be used without loss of efficiency * Hence felted fabrics are employed [0] Air flowrates of 15 ft/min are usual and result in more compact baghouses This kind of filter permits higher dust-loads, but is more complex, hence has higher first cost and maintenance (Fig 18.)

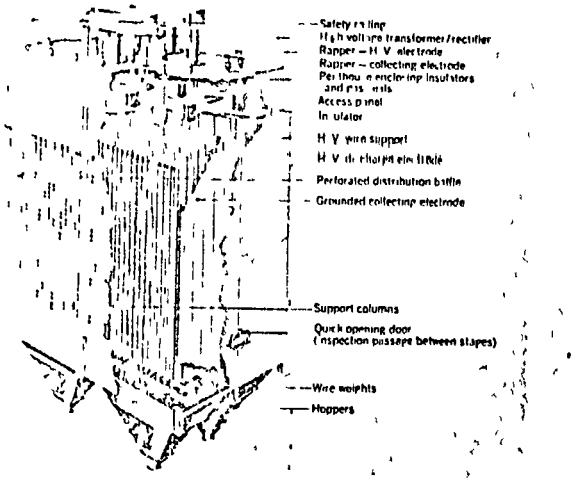
ELECTROSTATIC PRECIPITATORS

The electrostatic precipitator has the advantage of permitting dry collection, and is highly efficient on small particles A fabric filter might be a first choice, however, unless the process stream is hot or corrosive If the particulate is coarse, a wet scrubber is lower in cost. But the pressure drop for the filter or scrubber will be higher than for the precipitator, and the scrubber's operating costs are likewise higher Capital cost of electrostatic precipitators is usually the highest of all collectors, but a complete economic comparison must be made for a true picture

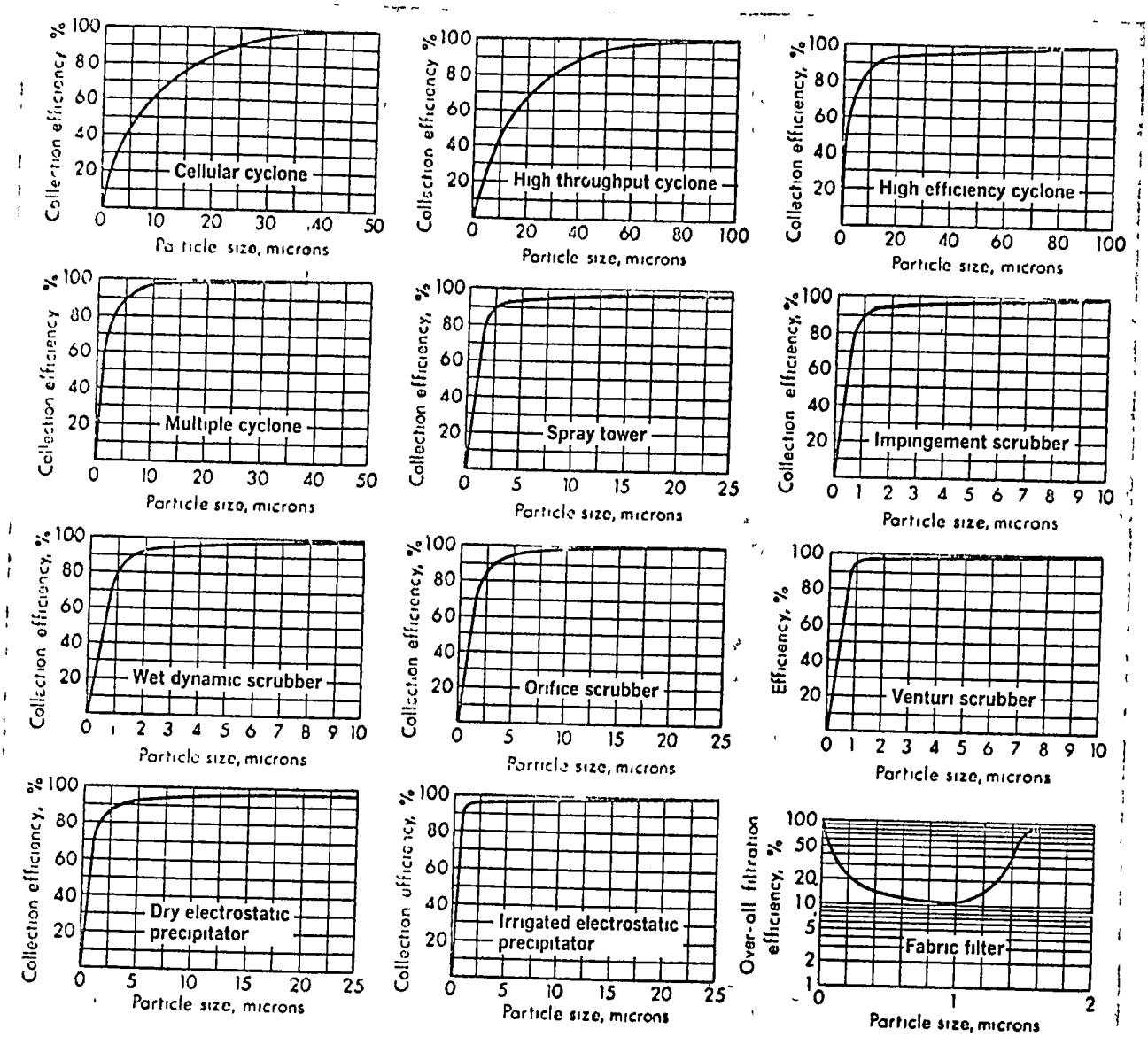
Principle—The gas between a high-voltage electrode and a grounded (or oppositely charged) electrode, is ionized Dust particles are charged by the gas ions and migrate to the grounded collecting electrode, where they adhere Mists run off the collecting surface, often aided by addition of irrigation streams Solids are most commonly removed by rapping with hammers or vibrators, although removal can be by washing or scraping Pipe-type precipitators are used for mists or water flushing, and plate-types are used for dry collection and large gas flows (Fig 19)

Comments—Although there is widespread use of electrostatic precipitators and fundamentals are well-developed, piloting a precipitator application is often worthwhile, since particle properties may vary between installations and theoretical efficiency is never attained Some common applications are the collection of fly ash from pulverized-coal-fired boilers, cement-kiln dust, sulfuric acid mist, catalyst dust in oil refineries, and steel blast-furnace dust Efficiencies are high, as shown in the curves of Fig 20 Operating temperatures range from 0 to 700 F. although units have been designed for temperatures of −70 or +1,000 F. Pressure drop is small due to low velocities, but this makes for a large installation.

* Woven fil[illegible]ers are porous, and do not filter efficiently until a cake of dust is built up



ELECTROSTATIC precipitator—Fig. 19



EFFICIENCY CURVES for various types of dust collecting equipment—Fig 20

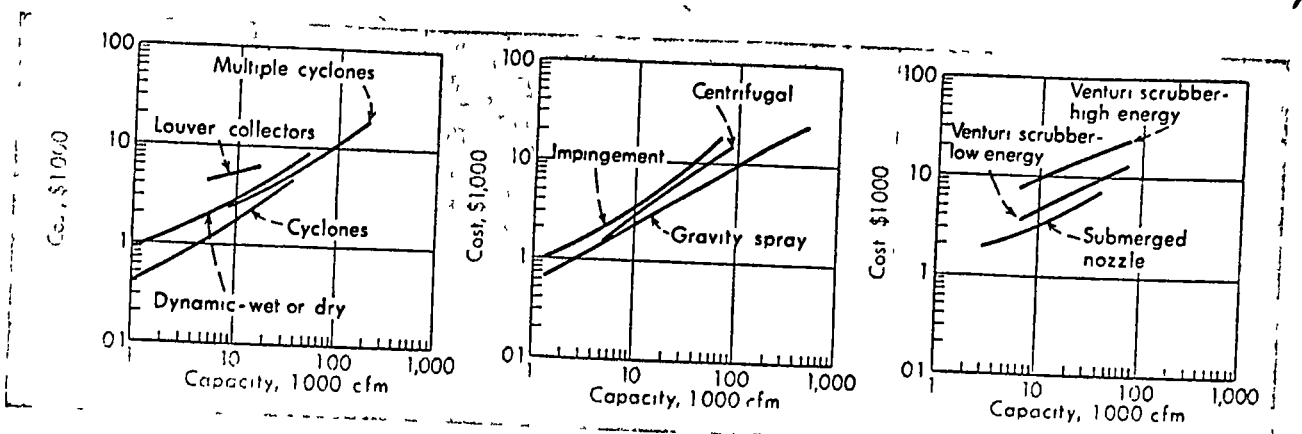
In considering electrostatic precipitation, the most important characteristic of a dust is its electrical conductivity. The dust conductivity must lie between that of a good conductor such as a solid metal and that of a good electrical insulator—and not too near either extreme The reciprocal of conductivity, electrical resistivity, is used to define this property. For most-effective operation of a precipitator the dust resistivity should be between 10^4 and 10^{10} ohm-cm Particles with a very low electrical resistivity readily lose their charge on the collecting electrode, only to be reentrained On the other hand, materials with high electrical resistivity coat and insulate the collecting electrode, thereby reducing potential across the gas stream, this may lead to a spark discharge that reverses ionization and causes reentrainment Conditioning agents such as moisture, acid mist, and ammonia can be added to the gas to reduce resistivity

ESTIMATING COLLECTOR SPECIFICATIONS

To make a preliminary selection of a suitable type of gas-cleaning plant, only four basic items are required dust loading, particle size, gas flow and allowable emission rate Other factors listed in Table II, Data Required for Equipment Selection, will be important in comparing the collectors that are under consideration.

The required factors can be estimated for an existing process except for particle size. However, for a process in the design stage, both dust size and loading may be difficult to estimate, especially if process experience is not available within the organization or from suppliers or the literature A broad list of processes and usual collector applications has been compiled by Kane.[7]

If a tentative choice of collector can be made, pilot plant trials may be the simplest approach, oper-



TYPICAL COSTS of various kinds of dust collectors plotted against capacity (costs

ating one or more types of collectors on an existing-process sidestream or in a new-process pilot plant If pilot apparatus can be chosen and operated, the analysis of particle size distribution of dust can be ignored The dust loading will be checked in the normal course of efficiency measurement, permitting direct evaluation for simple scaleup Many suppliers have pilot-model collectors available for rental, often with some refund on purchase of a full-scale unit Installation and operation of a 1,000 cfm pilot device may cost from $500 to $5,000 or more, depending on the complexity of installation and the auxiliaries that may be required

Going a step further, before making a choice, some simple lab work may prove economical in the long run Laboratory data can be obtained from an existing process by collecting dust samples for particle size determination, either in your plant's lab, or by suppliers or consultants.

A microscopic count (described later) is tedious but requires only equipment usually available However, collecting accumulated dust from the building corners or duct elbows, instead of sampling properly, can be misleading The particle size may appear finer or coarser, agglomeration of particulates may change the size, or hygroscopic solids may change characteristics as water is picked up or other contaminants are included

Lab data on crudely collected samples can be obtained quickly and cheaply but will probably have to be supplemented later by isokinetic sampling (described later), depending on the size of the project and the economic risk that can be tolerated.

It may be feasible to proceed with installation and plan to modify, supplement, or add stages to the collector For example, a venturi with adjustable pressure drop can be installed, a wet collector can be added after a cyclone, or more stages may be added to some types of centrifugal wet scrubber

Determining the desired emission depends on one or more factors air pollution codes, toxicity limits, and economics Legal requirements of air pollution control in the U.S. are very complex, depending on federal, state and local governments Laws are concerned with the type and amount of particulate and gaseous emissions and also the appearance of smoke A dust-control system is subject to future, more limiting legal requirements and should be selected with some thought toward future improvement

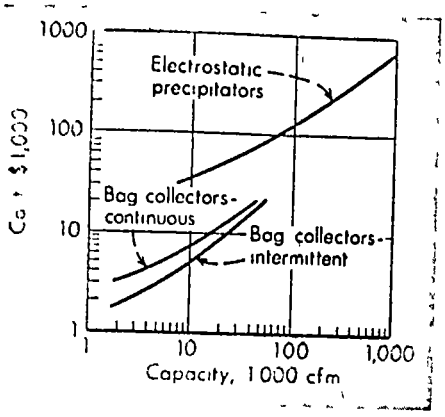
To determine emission requirements of a particular location, government agencies should be contacted The permit system is used by most control agencies in this country and should be investigated early in the program Literature on air pollution is helpful as a source of pollution laws (See "Pollution Laws" in the references at the end of the article) A digest of state laws[53] (Digest of State Air Pollution Laws) and a bibliography[51] are available from the Government Printing Office Obtaining the information is simple, but interpretation and compliance may be a problem, which is not within the scope of this article

Hazard control may be an added initial requirement Data are available for many dusts and vapors, although new materials may require some lab work Dust hazards to consider are explosive concentrations with air, flammability, and toxicity to plant or animal life, including radioactive hazards Vapors in the gas stream must be checked for explosive limits and toxicity A summary of properties is given in the table "Explosion Characteristics of Various Dusts"[20] It will be noted that concentrations involved in gas cleaning are usually below the minimum explosive concentration Recommendations for safeguards are contained in the safety codes of the National Fire Protection Association[23]

A very broad guide to allowable emission may be drawn from the following Emission limits under an early code permitted 0.85 lb. fly ash per 1,000 lb. of gas corrected to 12% carbon dioxide This is equal to 0 48 grains/cu ft Newer codes limit emission to 0 25 grains/cu ft Fine particulate matter of 0 01 to 0 02 grains/cu ft is the limit for a power plant emission that is to be invisible Besides particulate concentration, the particle size and refractive index of the material affects light-scattering ability.

SAMPLING AND ANALYSIS

Sizing a proposed collector or checking the performance of installed equipment may very well re-



are for equipment only)—Fig 21

quite sampling and analysis to determine dust loading at inlet and outlet Or a sample may be needed for particle size determination There is a variety of techniques which can be used, permitting a choice depending on convenience, cost or accuracy A summary is presented in "Aerosol Sampling and Analyzing Instruments"[50] As will be seen, test equipment choice depends on the process characteristics, so the investigator must have some idea of the magnitude of the answers he is setting out to find, for example, what rate and time of sampling will yield a significant weight of solids

The gas flowrate must first be measured For most process gas streams the pitot tube and inclined manometer are suitable For obtaining a rough measure of velocity below 10 ft / sec , a vane anemometer may be used High velocities in small ducts may be measured with an orifice or a venturi meter Methods are discussed in Perry[9] and the Western Precipitation bulletin WP-50[44]

There are many means of measuring gas velocity but the standard pitot tube and differential pressure gauge is relatively simple and reliable The operator must be careful that the section of duct is straight for 6 to 10 duct diameters upstream and 2 to 4 diameters downstream, to ensure uniform flow, also that the dust is easily accessible, and that the pitot

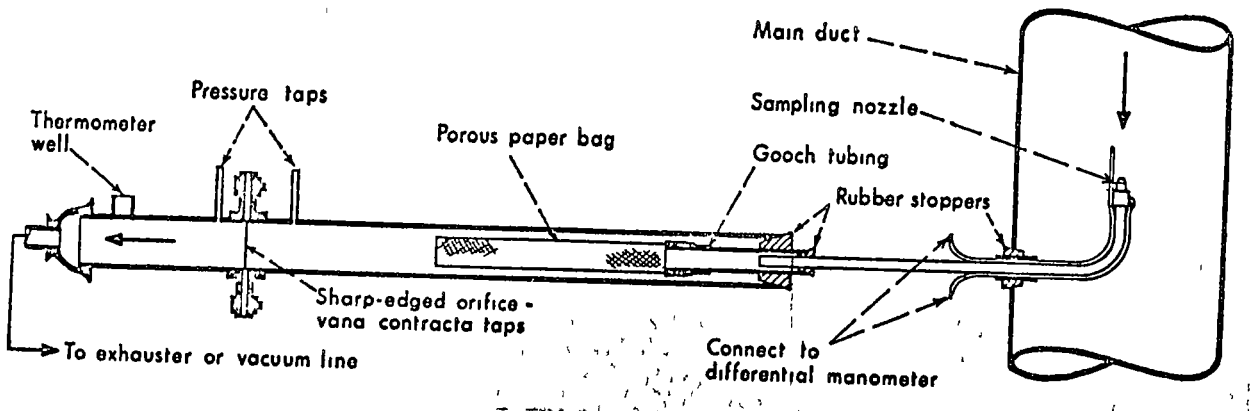
Process and safety checklist—Table IV

- Dirty gas heat—removal or recovery
- Startup preheating equipment
- Cleaned gas handling—vent or recycle
- Waste treatment and disposal facilities
- Storage requirements
- Freezeup protection
- Auxiliaries required
- Controls and measurements required
- **Utilities—type and capacity available**
- Layout
  - Fan location
  - Access—installation, cleaning, maintenance, sampling
- Plant location
- Future expansions or tightened restrictions
- Economics
  - Equipment costs
  - Operating costs
  - Recovered material value
- Approvals—insurance and permits
- Hazard protection—flammable, explosive, toxic materials
- Electrical classification of area
- Pollution control—air and water

tube is pointing directly upstream The combined pitot-static tube consists of two concentric tubes, one for impact pressure and the outer one for static pressure The pressure difference, measured by an inclined manometer, is the velocity pressure The standard type "L" pitot tube is suitable unless dust loading or gas humidity is high enough to cause plugging, in which case, the special type "S" pitot tube is used Wet- and dry-bulb gas temperatures are taken for use in calculating both gas density and humidity

Velocity pressures from manometer readings are measured in equal areas in the duct and used to calculate velocities as in Perry.[9]

The velocities are averaged, and duct flow is ob-



NULL-BALANCE sampling equipment—Fig. 22

tained by multiplying the average velocity and duct cross-sectional area

To determine the dust loading in a duct, the method of isokinetic sampling is used to withdraw and collect all dust in a measured volume of gas, matching the sampler velocity with that in the main duct and ensuring a representative dust sample There are two methods of doing this Duct velocity may be measured and the sampler velocity adjusted to the isokinetic velocity Or a null-balance probe can be used (Fig 22) to match static pressures, thereby matching velocities without measuring duct velocity The former method is described in several references,[32,39,44] and the latter is described by Lapple[40] See also Ref 44 The sampling train (Fig 24) is assembled from a choice of components Thanks to the growing interest in air pollution, components that once had to be made by the user are now commercially available

Equipment is connected as shown in the schematic arrangement, Fig 23, with a sharp-edged nozzle, usually ¼ in or more in diameter of opening, pointing upstream Dusty gas is withdrawn at a rate fixed in such a manner that the velocity at the face of the probe is within 10% of the velocity in the duct near the probe

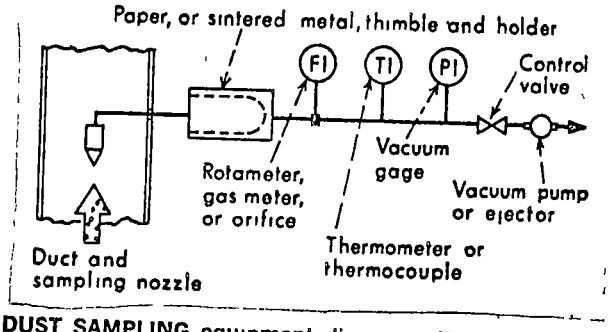
The gas is drawn through the sampling train by a vacuum pump—or an ejector operating on air, steam or water—and capable of maintaining a flow of ½ to 2 cfm as resistance increases in the filter owing to dust buildup

The gas sample stream must be metered by some suitable instrument, such as a rotameter, orifice and manometer, or gas meter The rate of sampling is controlled by a valve for variations in temperature, vacuum or density

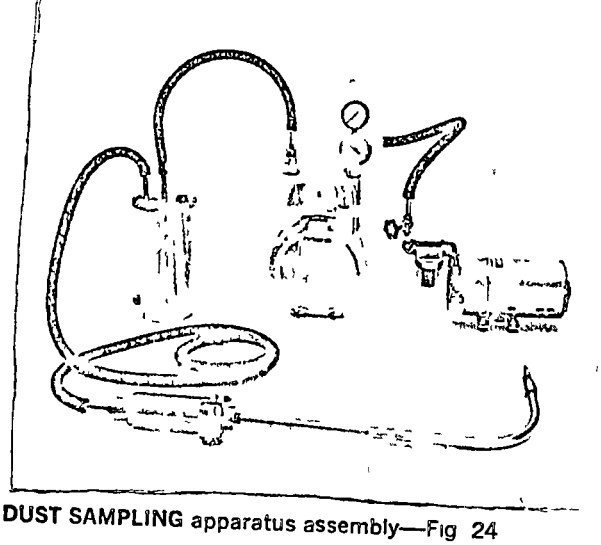
The dusty gas picked up by the sample probe is filtered in a preweighed paper or sintered-metal thimble The filters or separating devices used are usually at least 99% efficient The probe is traversed like the pitot tube and held at the same locations with the sampling flow set to equal duct velocity at that location

A simplified dust sampling may be made on the exit of a wet scrubber if it is felt that all particles are less than a 5μ and sampling need not be isokinetic Also on a wet scrubber outlet the temperature of the gas up to the filter must be kept above the dewpoint by heating with an electric resistance-heater Placing the filter in the probe assembly (where it is heated by stackgas) avoids condensation, loss of sample, or plugging in the tube between probe and remote filter

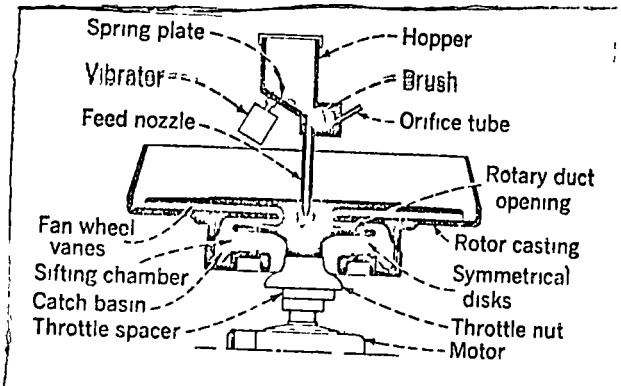
The sample collector is not limited to paper filters



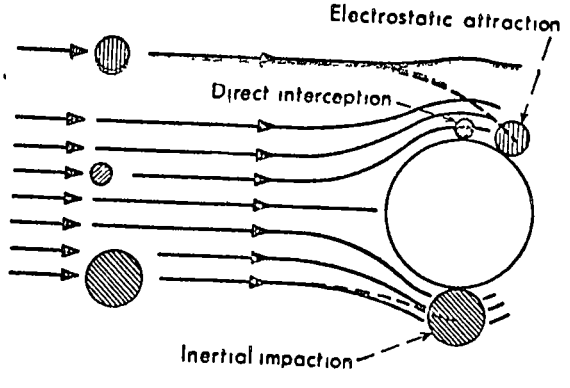
DUST SAMPLING equipment diagram—Fig. 23



DUST SAMPLING apparatus assembly—Fig 24



BAHCO CLASSIFIER, cross sectional diagram—Fig 25



MECHANISMS of particle collection—Fig 26

and in fact, other types may be more suitable A description of a variety of such devices is given in Stern II p 497[13] and Western Precipitation bulletin WP-50[41] The filter medium can be chosen from papers, fabrics, porous alundum, or cellulose ester membranes, thereby permitting selection for special conditions—high temperatures, extremely small particles, low ash content media, or transparency of media with oil or water treatment after sample collection

Small-diameter cyclones can be used to collect samples if the dust is coarse, or if total dust measurement is not important One manufacturer (Dustex) uses the cyclone efficiency for simple scaleup (assuming no efficiency is lost in gas distribution) to the multiple cyclone needed for the commercial-sized collector

Another common sampling device, the impinger, consists of a flat surface with sample stream directed through a jet to impinge on the plate, usually submerged Solid particles down to 1μ are determined after evaporation

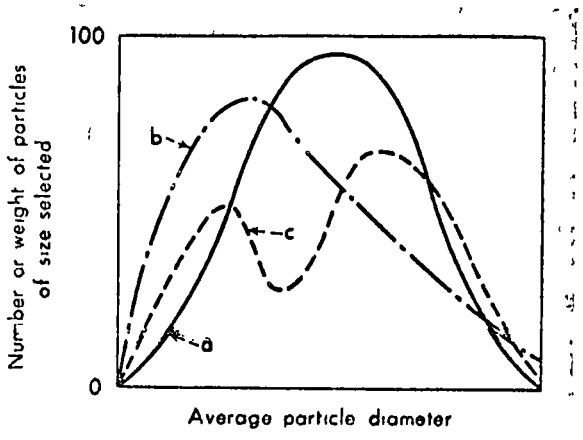
The total gas volume is the product of the rate of sampling and the duration of sampling time The sample weight is obtained, by difference, after drying and weighing Dividing the sample weight (in grains) by the gas volume (in standard, or actual, cubic feet) gives the dust loading of the gas stream.*

Efficiency of a collector is the difference between inlet and outlet loading, divided by the inlet loading The ASME procedure for calculating efficiency permits using the weight of dust caught instead of either inlet or outlet dust

A particle-size analysis should be run on the sample collected Some idea of particle size is a prerequisite to selecting a dust collector. There are many approaches depending on the situation Adequate facilities may already be available within the organization, or it may be worthwhile to obtain analytical equipment for the current study, if future gas-cleaning problems will justify the effort and equipment On the other hand, the process being studied may be a duplication of an existing plant with much background experience to draw upon

If answers are needed with a minimum of cost and time, it may be advantageous to call in outside analytical services that can provide the analysis for less than $100 per sample Many of the dust collection equipment manufacturers—if one can be chosen at this point—can provide the service

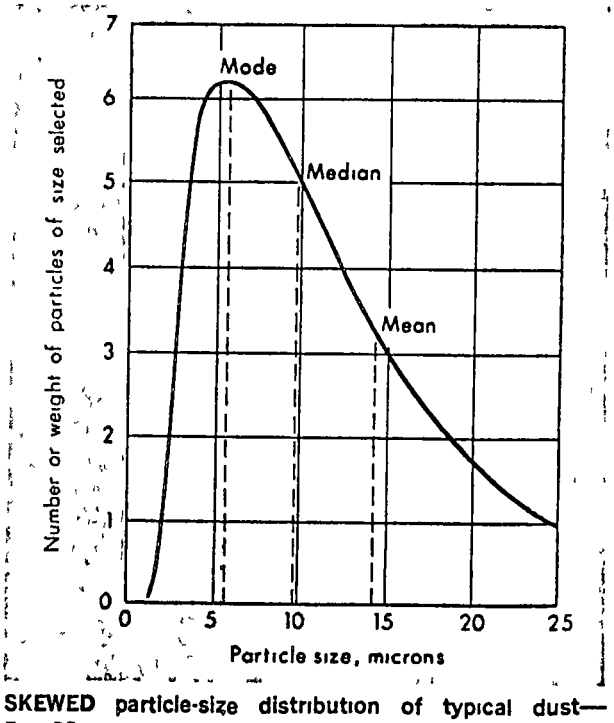
A summary of size analysis techniques and devices appeared in CHEMICAL ENGINEERING recently[41] Methods of particle-size analysis are varied to suit the nature of the particulate or the needs of the analyst or the method of sample collection, a complete picture of test methods and devices is beyond the scope of this article However, it might be well to give some specific examples of the commonly used.



TYPICAL particle size distributions, (a) normal, (b) skewed, (c) double peaked probability—Fig 27

methods that are applied in dust collector work

The Bahco Micro-Particle Classifier is a combination air centrifuge-elutriator, and is an ASME standard for particle-sizing[34] A weighed sample of 10 to 20 g is charged into the hopper, Fig 25, and introduced through a feed mechanism into a spiral of air having suitable tangential and radial velocities A portion of the sample is carried by centrifugal force against the air flow and toward the periphery of the spiral The remainder of the sample —the smaller, lighter particles—is carried with air flow toward the center The air is pumped through the unit, by means of an integral fan impeller, at a rate controlled by adjusting the air inlet orifice The residue is weighed after removal of a light fraction,



SKEWED particle-size distribution of typical dust—Fig. 28

* Sometimes, loading is reported in g /cu m (1 grain/cu ft = 2 3 g /cu m)

Calculation of collector efficiency—Table V

Particle Size Distribution, Microns	Particle Size Midpoint of Range, Microns	Fraction of Total Dust in Range, %		Cyclone Efficiency at Midpoint, %*		Percent Dust Collected	Dust Emitted, %†		Electrostatic Precipitator Efficiency at Midpoint, %		Dust Collected, %
<2½	1¼	12	×	33 5	=	4 0	50 3	×	77 0	=	38 7
2½-5	3¾	8	×	64 5	=	5 2	17 6	×	90 5	=	16 0
5-7½	6¼	6	×	76 7	=	4 6	8 8	×	94 0	=	8 3
7½-10	8¾	4	×	84 2	=	3 4	3.8	×	95 0	=	3 6
10-15	12½	8	×	89 3	=	7 1	5.7	×	95 5	=	5 4
15-20	17½	7	×	92 0	=	6 4	3 8	×	96 0	=	3 7
20-30	25	10	×	94 3	=	9 4	3 8	×	96 5	=	3 7
30-40	35	10	×	96 0	=	9.6	2 5	×	96 8	=	2 4
40-60	50	15	×	97.3	=	14.6	2.5	×	97 7	=	2.4
60-75	67½	10	×	98 5	=	9 9	0.6	×	98 7	=	0 6
75-104	89½	7	×	99.1	=	6.9	0 6	×	99 2	=	0 6
104-150	127	3	×	100 0	=	3.0	—		—		—
						84.1%					85 4%

Data are those of Stairmand (Ref 12)

*Efficiencies as read from an enlarged curve

†Calculating emitted dust from collected

Percent of 1¼ micron dust emitted = $\frac{12 - 4\ 0}{100 - 84\ 1} = 50\ 3\%$

Calculating combined efficiency

Cyclone fraction emitted = 1 000 − 0 841 = 0 159

Precipitator fraction emitted = 1 00 − 0 854 = 0 146

Combined fraction emitted = 0 159 × 0 146 = 0 0232

Combined fraction collected = 1 − 0 0232 = 0 977

Combined percent collected = 97 7%

rd the light-cut weight is determined by difference he process is repeated to obtain nine fractions Each ifice setting must be calibrated on a dust of known ze distribution and the terminal-velocity values assigned The development of standardization techniques are discussed by Crandall [35]

Other useful methods include electronic counting by the Coulter counter in which a suspension is put through an aperture, essentially one particle at a time, with electronic recording of each particle by size

The cascade impactor projects particles through a jet onto a plate where large particles are collected, the fines going on to the next stage

Elutriation is applied in the Roller analyzer on the principle of the settling chamber described under collectors, using an airstream to remove a fines fraction, depending on velocity These methods and others are reviewed in Perry[9] as well as others [13, 43, 45]

A sieve shaker can provide several particle size ranges down to 50μ particles (43μ equals 325 mesh) About 100 g of sample are needed. There are some limitations thin, flat flakes may give artificially large weight fractions of the larger particles, needle-like crystals may conversely appear in the analysis as smaller sizes, some materials finer than 150μ may flocculate, and other materials may be degraded

The sieve analysis should be supplemented by a microscopic examination to check particle shape In the particle sizes between 0 2 and 100μ the optical microscope can be used without sieves The method is laborious but can be simplified by using photomicrographs or by projecting the image of the particles on a screen Theoretical and practical aspects are covered in detail in the literature [45]

An important property needed for selecting an electrostatic precipitator is the electrical resistivity of the dust to be handled The measurement can be omitted if a precipitator is commonly used for the dust or if the equipment designer is otherwise familiar with it

Several methods for particle resistivity measurement are discussed in White,[30] and resistivities of some representative dusts and fumes are given A standard method along with apparatus construction details is given in the ASME Power Test Code 28,[34] and in the API manual, Electrostatic Precipitators [26]

MECHANISMS

Mechanisms governing the collection of particulate matter have been studied singly and combined but do not serve as a means of classifying collectors, since there may be more than one mechanism at work Operation of a collector is considered to proceed in three phases (1) depositing of particles on a collecting surface, (2) retaining solids on the surface, and (3) removal Parameters describing the mechanisms

Over-all cost of gas cleaning—Table VI

Collector Type	Efficiency on Standard Dust, %	Average Pressure Drop, in w.g.	Installed Cost, $	Power Cost, $/yr.	Water Required, Gal/1,000 Cu. Ft.	Water Cost $/Yr.	Maintenance, $/Yr.	Total Annual Cost, $/Yr.	Total Annual Cost ¢/(Yr)(Cfm.)
Dry									
1 Louver collector	58 6	1 7	34,500	1,560	——	——	300	5,310	8 9
2 Medium efficiency cyclone	65.3	3 7	25,000	3,380	——	——	200	6,080	10.1
3. High efficiency cyclone	84.2	4.9	48,500	4,520	——	——	200	9,570	16.0
4 Multiple cyclone	93 8	4 3	52,500	3,960	——	——	200	9,410	15.7
5 Electrostatic Precipitator	99 0	0.9	233,000	2,000	——	——	1,300	26,600	44 4
6 Fabric filter, shaker*	99.7	2 5	165,000	3,740	——	——	10,000	30,240	50 4
7 Fabric filter, envelope*	99 8	2 0	152,000	3,380	——	——	9,500	28,080	47.0
8 Fabric filter, reverse jet	99 9	3 0	231,000	7,920	——	——	19,000	50,020	83.6
Wet									
9 Submerged Nozzle	93 6	6.1	66,700	5,640	0.7	1,010	700	14,020	23.3
10 Spray Chamber	94 5	1.4	139,000	4,760	21.7	31,250	1,000	50,910	84 8
11 Impingement Scrubber	97.9	6 1	82,200	5,800	3 6	5,190	1,000	20,210	33 7
12 Wet Dynamic Scrubber	98 5	——	136,000	45,400	6.0	8,640	700	68,340	141
13 Low energy venturi	99 7	20 0	107,000	18,820	8 4	12,100	1,000	42,620	71 2
14 High energy venturi	99 9	31 5	117,000	29,740	8.4	12,100	1,000	54,540	91.0

Notes
The installed cost includes equipment auxiliaries, such as fans, pumps, and motors (but not including solids disposal equipment), site preparation and installation Installation charges are 100% of all equipment except electrostatic precipators and dynamic scrubbers which are 50%
Prices are adjusted to 1968 with a Marshall and Stevens index of 273 The British pound is taken at $2 84 U S
The cost of power is taken at $0 01 per kwh Efficiencies of fans and motors are assumed 60% Water cost is $0 05 per 1,000 gal and reported usage converted from Imperial (assumed) to U S gallons (Data are from Stairmand, Ref 11)

*Maintenance charges include bag changes, once per year for envelope type and twice for shaler and reverse jet filters

of deposition or collection have been described by Lunde and Lapple,[19] (a table of parameters is reproduced in Per › p 20-65[9]) and are generally described below as a means of understanding operating principles of collectors

Gravity Settling—The weight of particles may be enough to permit settling from a moving gas stream, where the dust is more than 50μ, in a gravity settling chamber or a baffle chamber.

Centrifugal Separation—Particles in a vortex gas flow are separated by centrifugal force and are directed to the outer wall, as in a cyclone or centrifugal scrubber

Direct Interception—A fluid streamline curving around an obstacle such as a filter element or water droplet may carry a particle within contacting distance of the obstacle, and the collision will arrest the particle on the element or droplet See Fig 26, Mechanisms of Particle Collection

Inertial Impaction—The inertia of the particle causes it to continue in its path rather than follow the streamline curving around the obstacle, thus permitting contact of the particle with the obstacle.

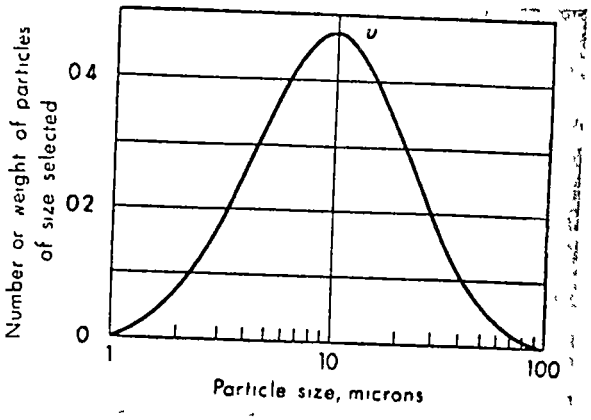
Diffusional Deposition—For particles smaller than 0.1μ at low velocities, molecular impacts of Brownian movement deflect the path of the particle, increasing chances of collision with filter elements or water droplets

Electrostatic Precipitation—A collector body or a particle, or both, may have a static charge that will introduce a force to affect the movement of the particle

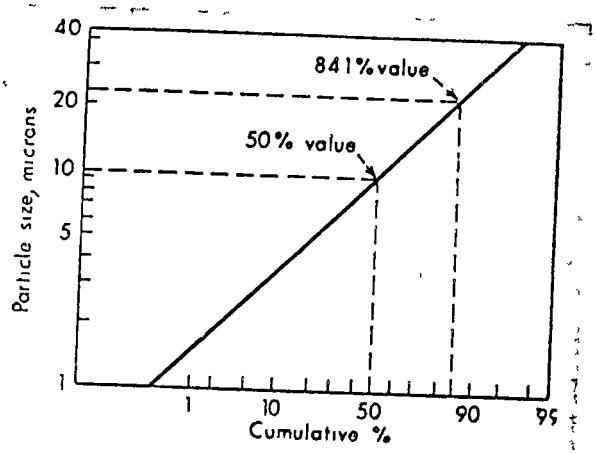
SAMPLE PROBLEM

Over-all collection efficiency can be calculated by using a collector efficiency curve in combination with the particle size distribution curve, provided that the method of particle size measurement is the same for both curves Calculations are shown in Table V for a high-efficiency cyclone followed by an electrostatic precipitator Data are from Stairmand[11] The test dust used compares to a typical fly ash and is given in Table VI, Standard Test Dust Characteristics The efficiency curves used are those shown in Fig 20.

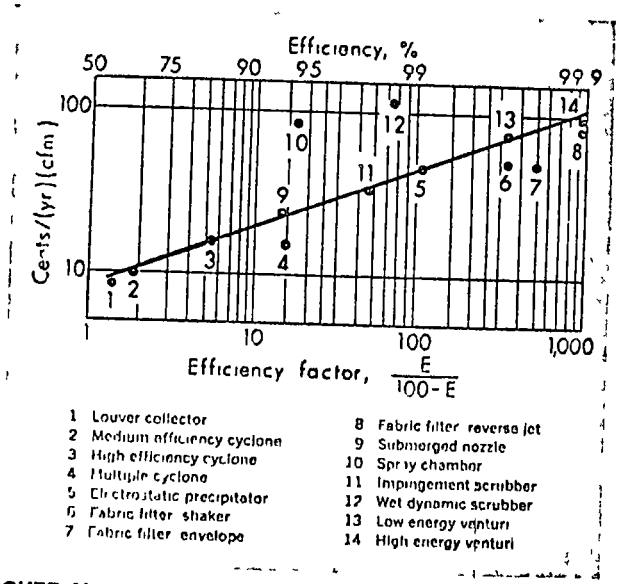
From the collector efficiency curve choose several efficiencies and the corresponding ranges of particle sizes. From the size distribution curve (or table, in this case) obtain the percentage of dust within the



PARTICLE-SIZE distribution of Fig 28, plotted with logarithmic abscissa (particle size)—Fig 29



LOG PROBABILITY curve for particle size distribution of above figure—Fig 29



OVER-ALL COST of gas cleaning (Stairmand[12])—Fig. 30

size increment For example, 12% of the total dust is less than 2½ μ, and the midpoint of the range is 1¼μ The cyclone efficiency is 33 5% at 1¼μ

The cyclone has a collection efficiency of 84 1% and emits 15 9% of the inlet dust The electrostatic precipitator collects 85 4% of the cyclone emission The combined efficiency is 97 7%

EQUIPMENT COSTS

Costs shown on Fig 21 are manufacturers' prices for dust collectors only System costs must be developed for the individual case, adding the cost of freight, foundations, supports, erection, and auxiliary equipment Collector costs may be adjusted for special materials of construction The cost basis year is 1968 (Marshall and Stevens Index = 273)

For any one type of collector, price may vary widely depending on the required duty The costs presented are for "typical" applications suitable for a preliminary comparison Where costs of systems are of the same order of magnitude, it is probably worthwhile to obtain quotations for each dust collector

Over-All Cost of Gas Cleaning

In an economic comparison between different collectors for a particular application, the efficiencies are likely to be different The higher cost for better collection can be compared with the cheaper installation, as was compared in Table V Costs above those shown tend toward an uneconomical equipment choice, while those below tend toward being a good buy

The original data for this figure were presented by Stairmand[12] and are adjusted to current U S costs in Table VI Stairmand developed the operating costs of the various collector systems cleaning 60,000 cfm gas at 68 F with an inlet dust-loading of 5 grains/cu ft of the standard test dust given in Table V, with 30% less than 10 μ particle size

It is interesting to note the high-cost units are the spray chamber (with a high water-rate) and the dynamic scrubber (with a high power-rate) Also, the electrostatic precipitator may have a high first cost but efficiency is high and power costs are reasonable

CHOOSING A COLLECTOR

Let us look at the selection of a collector from meager preliminary information Take as an example a process in which organic chemicals are spray-dried and collected by a cyclone, the dusty gas then going to a spray tower It is desirable to replace the existing inefficient wet collector to meet air pollution abatement requirements and to recover product

Material-balance calculations of product recovery efficiency can be used to determine dust-loading and water evaporated in the dryer Microscopic counts of dust samples collected downstream from

the cyclone give particle size A manometer can be be used to measure pressures and, with the fan curves, the gas flow is determined

State air pollution laws fix the emission based on stack height and distance from the property line.

A summary of data looks like this.

Dust loading to collector	50 to 200 lb /hr.
Particle size—Product A	50% < 30 μ
Product B	50% < 20 μ
Product C	50% < 5 μ
Gas flow at inlet conditions	20,000 cfm
Gas temperature	250 F
Gas humidity	3,000 lb /hr.
Dust emission allowable from collector	20 lb /hr

Converting the dust loading to grains/cu ft

$$\frac{200 \text{ lb}}{\text{hr}} \times 7{,}000 \frac{\text{gr}}{\text{lb}} \times \frac{1}{20{,}000} \frac{\text{min}}{\text{cu ft}} \times \frac{1 \text{ hr}}{60 \text{ min}} = 1.17 \text{ gr /cu ft}$$

The requirement is to emit no more than 20 lb /hr from a maximum of 200 lb /hr, or 10% emission Collection efficiency is then 90% for a dust loading of a little more than 1 grain/cu ft of particulate with a mean particle diameter of 5 μ

From the note on Table I, we find that the loading is "light" and the particle size "fine" From the table in Ref 7, Industrial Collector Applications, Lines 4 and 39 favor high-efficiency centrifugals, wet collectors and fabric filters

Cyclones are unsuitable, which is evident since we are collecting dust that already has passed a cyclone Electrostatic precipitators are not likely since the gas-handling capacity is somewhat small for good operating efficiencies, and also the electrical resistivity of an organic dust will probably be too high Multiple high-efficiency cyclones are small in diameter and subject to plugging with sticky organics Fabric filters are excellent collectors for fine materials, especially when we would like to recover usable product, but we should keep the sticking problem in mind Wet scrubbers will give a clean stack but with a wet plume, the recovered product will be degraded in value, since it will have to be dried again Product value is 2¢/lb dry and 1¢/lb wet

Referring to Table I, Equipment Application, we can choose centrifugal, impingement and venturi scrubbers Other equipment types are excluded because, let us assume, they are unsuited for scrubbing with dust slurries Recovered dust will have to be recycled to build up concentration for economical recovery

We will compare each selection by picking the operating values of pressure losses and liquid rate at midrange Efficiency is read from the curves of Fig 20

The results of comparing the selected collectors are shown in Table VII It must be emphasized that this is a preliminary choice only Added costs such as tanks, bag replacements, larger fans and maintenance costs, have been ignored The happy factor of a tax credit for pollution-control equipment is also omitted For the sake of simplicity, the gas-handling requirement is at actual conditions rather than at standard conditions

An alternative method for quick comparison is the use of Table VI to obtain the over-all cost of gas cleaning as shown on Line 12, Table VII The two costs for each collector are different, especially in the case of the bag collector, but looking at the recalculated "return" leads to the same conclusions The fabric filter is probably a good selection if product will not cake on the bags or if product cross-contamination does not require changing bags A low pressure-drop wet scrubber, such as the centrifugal or impinge-

Example of collector selection—Table VII

	Wet Scrubbers			Continuous Fabric Filter
	Centrifugal	Impingement	Venturi	
1. Efficiency	94	97	99.6	>99.9
2. Pressure loss—liquid, psi	60	60	15	———
3. Liquid rate, gpm.	100	60	100	———
4. Pressure loss—gas, in w g	4	5	20	4
5. Power required—gas, hp	74	79	158	74
6. Power required—liquid, hp	7	4	2	———
7 Power cost, $/yr.	4,800	5,000	9,600	4,400
8. Equipment cost, $/yr	1,000	1,200	2,000	2,200
9. Total cost, $/yr	5,800	6,200	11,600	6,600
10 Recovered product value, $/yr	15,000	15,500	15,900	32,000
11 "Return" (line 10 —line 9), $/yr.	9,200	9,300	4,300	25,400
12 Over all cost from Table VI by interpolation $/yr	3,500	5,000	9,300	15,200
13 Return (line 10— line 12), $/yr.	11,500	10,500	6,600	16,800

Notes

System pressure without collector = 10 in w g

$$\text{Fan hp} = \frac{\text{cfm} \times \text{p}}{6{,}356 \times 60\% \text{ Eff}} = 5.2 \times \text{p}$$

$$\text{Pump hp} = \frac{\text{gpm} \times \text{sg} \times (2.31 \text{ psi})}{3{,}960 \times 50\% \text{ Eff}} = 0.0012 \times \text{gpm.} \times \text{psi.}$$

Electric cost =

$$\text{hp} \times 8{,}000 \frac{\text{hr}}{\text{yr}} \times 0.746 \frac{\text{kwh}}{\text{hp hr}} \times 0.01 \frac{\$}{\text{kwh}} = 60 \times \text{hp}$$

Installed cost = 200% × equipment cost from Fig 2 × 10% depreciation/yr

NOTAS DEL PROFESOR PAUL R. HARRISON

Emissons fron Internal Combustion Engines

A. Evaporation

1. Aromatic Hydrocarbons

2. Non aromatic Hydrocarbons

B. Combustion

1. CO_2

2. H_2O

3. CO

4. NO- NO_2 (NO_X)

5. Hydrocarbons:
   Reactive
   Nonreactive

6. Particulate:
   Filterable
   Nonfilterable

C. Other

1. Crankcase Vapors(Blowby and Oil break down)

2. Lead

3. Other Trace Metels

4. Sulferdioxide and Sulfuric acid from Oils

5. Sulfer dioxide from gasoline

DISCUSSION, Notes:

A. Evaporation:

Gasoline vapors are 22% Reactive. This may vary with source and/or Country.

Reactivity of various Hydrocarbons

Olefins	100%
Parafins	10%
Aromatics	30%

Sample Calculation:

Assume 730 gallons of fuel / year/ car (Los Angeles)

1% Evaporation from tank and from carborator

1% spillage at service station loading, etc.

Thus approximately 15 gallons / year / car is evaporated ($\simeq$50 liters) At 22% reactivity, approximately 10 liters, or 50 kg/car/year (car-Automobile). In Mexico we could approximate that 4×10^7kg / year is emmited and reacted by evaporation only. Note: Almost all the hydrocarbons emmitted are reacted upon at some time , but not as fas t and not by the same mechanisms.

b. Combustion:

1. CO_2
2. H_2O

These are natual results of combustion and are not usually considered as pollutants. However the amount of water emitted is significat.

Assume 95% completion of combustion and 750 gallons of gas per year per automobile.

(% of H by weight) x 750 x 8lbs/gal x 8 =

lbs of H_2O /car-year $\simeq 5 \times 10^4 \times \%H =$

In Mexico: $\frac{8 \times 10^5}{3.64 \times 10^2} \times \frac{5 \times 10^4}{2.2} \times$ % H by weight =

($5x\ 10^{6}$ x %H) kg per day H_2O.

A similar gross calculation can be made for CO_2.

Thus several tons of water is put into the air by automobile Combustion alone.

TABLE:

Emission Levels (grams per mile) for 1970 American Production Automobiles:

Pollutant	Amount
Hydrocarbon (HC)	2.2
CO	23.
NO_x	6.0
Particulates:	
Filterable	0.3
Total	1.4

Hydrocarbons:

A study by the DuPont corporation stated that exhaust hydrocarbons are directly proportional to fuel aromatics except for Toluene; thus the exhaust gases are 36% reactive.

Table:

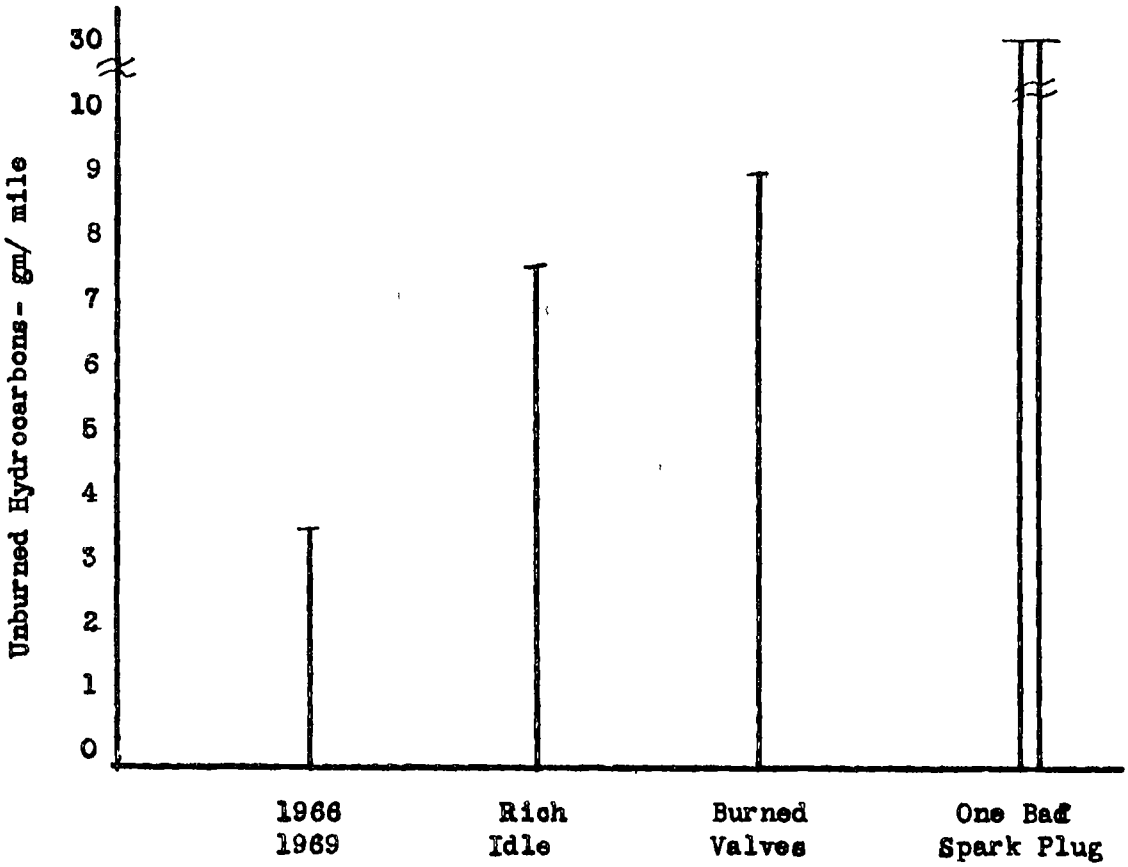
Hydrocarbons can be broken down further:

Formaldehyde	4.9 ppm of exhaust
Acetaldehyde	1.2
Acrolein	0.6
2-Butanone	0.25
m , O Tolaldhyde	0.30
Others	1.0
Total	8.2

This study was for a 1970 Ford Mustang at 30 mph.

Thus there are many forms of Hydrocarbons of different reactivities.

The effect of bad maintenance can best be described by the following table:



It is very evident that badly maintained engins increase the pollution Emissions significantly!!!

Oxides of Nitrogen:

Similar calculations can be made using the information in the table of emission levels.

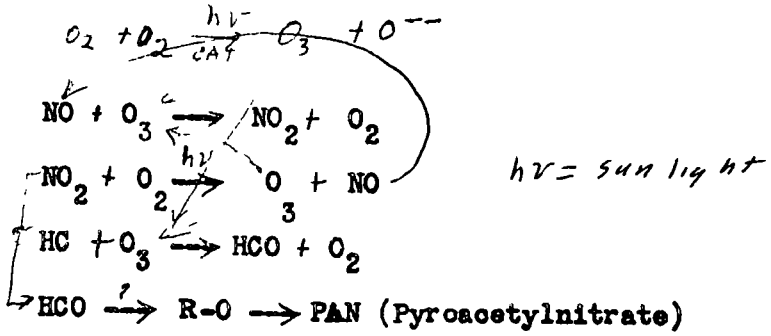
ONE MUST REMEMBER THAT THESE LEVELS GIVEN IN THE TABLE ARE FOR RECENT AND NEW AUTOMOBILES. Emissions for older and less maintained cars will be higher by several percent, as seen from the above table.

Since it takes two tons of NO_x to react with One ton of Reactive HC.

The Hydrocarbons are controlling the reactions by a factor of 2.

Photo chemical reactions can be grossly simplified by the following

equations:



etc.

"Smog"

There are many more equations but the principle is that sunlight creates and interrelated reaction resulting in the formation of undesirable and noxious gasses and particulates. See references for a larger but more complete model of these reactions.

Lead: and particulates:

There is 2-3 gm of lead per gallon of gasoline, on the average.

Or, 2 Kg / auto/~~mix~~ year--assuming 50% of the lead becomes airborne, (It is thought to be larger).

Thus, $\simeq$ 1kg/auto/year = 8×10^5 Kg / year in Mexico

Anouther comparison can be made.

Assume that the average suspended particulate concentration in Mexico is 130 ug/m^3 and that the averave lead concentration is 8 ug/m^3, lead accounts for 3% of all the particultae in th e air in the city!! Most of it comming from automobiles!

Comparison of differant types of engines and their emmissions:

The following table is a summation of the probable emission from various types of suggested or available auto engines.

EMISSIONS FROM ALTERNATE POWER SOURCES (TONS/DAY IN LOS ANGELES)

Power System	Exhaust HC	Exhaust CO	Exhaust NO_x	Evap. HC	Equivalent Reaction T/D HC exhaust	Equivalent Reaction T/D HC evap.	Equivalent Reaction T/D NO_x	Equivalent Reaction T/D Normalized to ICE HC exhaust	Normalized to ICE HC evap.	Normalized to ICE NO_x
ICE	252	2640	688	137	91	30	344	1	1	1
Diesel	400	575	688	14	144	2.5	344	1.58	.083	1
Gas Turbine	58	575	150	23	21	3.6	73	.23	.12	.211
Rankine										
Steam	12	115	58	19	4	3.0	29	.044	.1	.084
Organic	15	140	70	23	5	3.6	35	.055	.12	.103
Organic future	10	100	50	16	4	2.6	25	.044	.083	.073
Stirling	10	100	50	15	4	2.4	25	.044	.080	.073
Battery-Electric										
Present	neg	neg	2,900	neg	neg	neg	100	0	0	.290
Future	neg	neg	90	neg	neg	neg	75	0	0	.022
Hybrid	46	460	46	17	17	1.	23	.187	.033	.067

Other Pollutants:

There are other trace elements resulting from the opper ation of auto - mobiles , but they are of little consequence directly. It should be pointed out that the lead particles are usually emmitted as lead-halide compounds such as lead, oloro-bromide as very small particles. These particles average less that 0.1 micron in the air. Theys are thought to be hygroscopic and attratt water vapor. Thus possible combination with water to form "Haze" and fog.

Crankcase "blowby" is significant and is derived by mechanical turbulance in the engine, heat and combustion gasses "blowing by the rings in the cilinder chamber into the crankcase and oil resevoir. Much Hydrocarbons are gennerated in this way.

Since there is sulfer in the oil, sulfuric acid slowly forms in the crankcase. Most is neutralized but some can always be present. Some autos have Mangenese oil plugs to absourbe the acids .

Some gasolines have a small amount of sulfer in them, but it is usually less that 1% and is not considered significant compared with the other pollutants emmitted.

VISIBILITY AND AIR POLLUTION

Introduction

The increasing emphasis on air pollution control has caused a marked and continuing reduction in the number of large particles which are being injected into the atmosphere. As a result, the total mass of air pollutants produced in many areas is decreasing. However, the materials of interest in atmospheric visibility reactions, (particles in the size range from 0.1μ to 5μ) are not being effectively removed. For this and other reasons, including photochemical reactions and natural phenomena, many major urban areas are plagued by visibility problems.

Basic Considerations

The visual range (often referred to as visibility) is basically determined by the lighting conditions, the characteristics of the object viewed, the amount of light scattered by atmospheric gas molecules, the amount of light scattered by atmospheric aerosols, the amount of light absorbed by atmospheric gases, and the amount of light absorbed by atmospheric aerosols.

If a light beam of intensity 7 passing through an incremental

distance dX is reduced by scattering and absorption, the amount of reduction, dI will be proportional to the original intensity I (Beer-Lambert Law). Therefore:

$$dI = -\sigma I dX \tag{1}$$

where σ is the extinction coefficient. Over the entire path length from the object to the observer this equation becomes:

$$I = I_o e^{-\sigma X} \tag{2}$$

The reduction in apparent contrast, C, of an object can also be determined from an expression of the same form. Thus:

$$C = C_o e^{-\sigma X} \tag{3}$$

For an average human eye, the contrast detection threshold is probably near 0.05 $(\frac{C}{Co})$ for daytime visual determinations. Inserting this value in (3) gives:

$$e^{-\sigma X} = 0.05$$

$$\sigma X = 2.995$$

$$X = \frac{2.995}{\sigma} \tag{4}$$

Historically the contrast detection threshold has been taken as 0.02 resulting in $X = \frac{3.912}{\sigma}$, a more conservative estimation of visibility reduction.

In order for these estimations to be valid, it must be assumed that the extinction coefficient is constant along the path length. In most cases, the assumption of a spaciality constant σ is not absolutely correct, but since visual range is based on complex phenomena including variations in human eyes, meterological variations, lighting, etc., these equations can be used as measures of "average

visual range" without causing serious difficulties. Often times, X in Equation (5) is termed the meterological range, which is defined as the distance an ideal black object against the horizon sky in daytime can be distinguished by an eye with a threshold contrast of 0.02 (wavelength of light = 550 mm).

The magnitude of the extinction coefficient, σ, is difficult to determine. The four components which affect the coefficient are: Rayleigh scattering by air molecules, and particles much smaller than the wavelength of light, Mie scattering caused by particles of a size comparable to the wavelength of visible light, absorption by aerosols (resulting in smoke or haze of obvious color), and absorption by gases such as NO_2.

Rayleigh scattering is normally much smaller than Mie scattering (with Rayleigh scattering only, the visual range would exceed 200 km) and is often not considered in visibility estimations.

The absorption of light by aerosols is often, of necessity, assumed to be negligible. Instruments are not yet available to measure this phenomena and calculations of absorption cross sections, based on chemical composition and size distribution data, bog down in a mass of assumptions. Most studies on this subject, indicate that aerosol absorption is indeed small, but more study is needed to assure this point. In special cases (e.g. plumes with high iron particle content) absorption may be of considerable importance.

The absorption of light by gases is fairly well understood. The only major absorbing gas normally present in significant concentration the atmosphere in NO_2. This gas is usually present in conjuction with heavy particulate pollution (smog) so it is of little total

consequence in visual range determinations. Recent preliminary field experiments indicate that gas absorption only accounts for from 10 to 14% of the total light attenuation.

This leaves Mie scattering as the major cause of light attenuation in the atmosphere. The characteristics of the aerosol which are of importance are:

1. Size distribution
2. Refractive index
3. Particle shape and physical structure
4. Variations in these parameters in time and space

A simplified expression to determine the magnitude of σ is:

$$\sigma = \sum_{i=1}^{n} N_i K_i \pi r^2 \qquad (6)$$

where:

N_i = number of particles in the *ith* class interval

K_i = scattering area of particle of radius r_i =

$$\frac{\text{flux scattered by a particle}}{\text{flux geometrically incident of particle}}$$

The value of K is dependent on the wavelength of incident light, the refractive index of the material, and the particle size. A plot of K values for various types of particles is shown in Figure 1 and a plot of approximate K values as a function of the dimensionless parameter $4\pi r (m-1)/\lambda$ is given in Figure 2. Here m is the refractive index and λ is the wavelength of light. It is apparent that the assumption $K \cong 2$ for most nonabsorbing aerosol particles can be

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introduced without serious error.

Applications in Atmospheric Visibility Calculations

If the assumption is made that particulate material in the atmosphere is of uniform size and the scattering alone accounts for the extinction then the particle mass can be directly related to visibility. Equation (5) becomes:

$$\sigma = N\ K\ \pi r^2 \tag{7}$$

and substituting particle mass, M, for N

$$M = N\ 4/3\ \pi r^3 \rho$$

Equation (4) becomes

$$X = \frac{4.0\ \rho r}{KM} \tag{8}$$

If M is taken as pollutant mass per cubic meter of air and values of K are obtained from the literature for homogeneous aerosols of various materials, Equation (8):

$$X \cdot M = \frac{4.0\ \rho r}{K} \tag{9}$$

Thus for a given aerosol the product of visible range, X, and pollutant concentration is a constant. Stated another way, the value of the expression $\frac{4.0\ \rho r}{K}$ is the mass of material that is contained in a volume of air one square meter in cross section, extending from the observer to the limit of visibility.

For an oil droplet aerosol of 0.6 μ diameter, $\rho = 0.9$ and $k = 4.1$

$$X \cdot M = \frac{4.0\ (0.9)\ 0.3 \times 10^{-4}}{4.1} \times 10^{4}$$

$$= 0.264\ g/m^2$$

Thus the visibility is determined by the length of a column on square meter in cross sections which contain 0.264g of 0.6μ oil droplets. If the atmospheric concentration of such droplets was $26.4\mu\ g/m^3$ ($26.4 \times 10^{-6}\ g/m^3$) then X, the visible range, would be 10^4 m = 10Km. Similarly for a water droplet aerosol of 1.0 diameter droplets, $k = 3.9$ and the visibility limit would be determined by $0.51\ g/m^2$.

These calculations suggest a rule of thumb that is often useful: $0.5\ g/m^2$ OF MATERIAL OF THE OPTIMUM PARTICLE SIZE WILL DETERMINE THE LIMIT OF VISIBILITY.

Recent studies using integrating light scattering instruments have indicated that in an urban atmosphere, under relatively dry conditions (relative humidity 70%) the relationship:

$$\frac{M(g/m^3)}{\sigma\ (M-1)} = 0.45\ ^{+0.45}_{-0.22}\ g/m^2$$

exists, where the sub- and superscripts indicate the 90% confidence limits. Thus from Equation (4):

$$x = \frac{2.295}{\sigma}$$

$$X \cdot M = 2.295 \cdot \frac{M}{\sigma}$$

$$= 2.295 \cdot 0.45 \overset{+0.45}{-0.22}$$

$$= 1.03 \overset{+0.45}{-0.22} \text{ g/m}^2$$

which may be a refinement of the rule of thumb given earlier. This equation can be considered to apply to the "normal" heterogenous aerosols found in urban areas, and is not limited to the homogeneous cases listed earlier.

Visibility in Smoke Plumes

In the atmosphere, the aerosols present are relatively uniform in size distribution and concentration, due to the processes of coagulation, sedimentation, scavenging, etc. Therefore, for a given location, visibility estimations can be made based on the averaging assumption mentioned earlier. However, in a stack plume the aerosol size distribution, particle concentration and composition, moisture content, etc, can vary markedly. These factors make visibility calculation in the plume difficult.

Often, the same sampling assumptions that were made for general visibility calculations are made for stack plumes. This leads to some interesting and perhaps enlightening results. For example, if Equations (2) and (7) are combined and rewritten in terms of mass concentration rather than particle number concentration, we obtain the expression:

$$\frac{I}{I_o} = T = e^{-3/4\frac{MKX}{\rho r}} \qquad (10)$$

where:

T = transmittance of the plume

M = mass concentration of the particles

$= 4/3\ \pi r^3 \rho N$

ρ = particle density

X = path length through the plume

Even if K is assumed to be a constant, 2.0, and the mass concentration is held constant, the transmittance will change with a change in particle size. A family of curves showing the relationship between plume transmittance and mass concentrations in a plume three meters in diameter with black or white particles of different sizes is shown in Figure 3. In preparing this figure, the following assumptions were made:

$\rho = 1.0$

refractive index (white) = 1.5

refractive index (black) = 2(1-0.5i) (imaginary number)

r(microns)	0.05	0.1	0.2	0.4	0.8	1.6	3.2
K(white)	0.03	0.14	0.88	1.87	2.0	2.0	2.0
K(black)	0.88	1.87	2.0	2.0	2.0	2.0	2.0

Above 0.4 radius particles black and white smokes give the

same curves for transmittance, but below this size the light extinctions by black particles is greater than white.

Approximately 70 years ago a French Engineer, Maximillian Ringelmann devised a procedure for assessing transmittance through black smoke. Using his method, the lanenance of the plume is compared to the lumenance of four white charts (numbered 1, 2, 3, and 4) on which black grids observing respectively 20, 40, 60, and 80 percent of the chart surfaces. The observer places the charts far enough from the observation point to insure that the grids will appear as uniform shades of grey equivalent to 20, 40, 60, and 80 percent transmittance. The stack plume is then compared to the charts, using the same background, and reported as being comparable to a Ringelmann Number of 1, 2, 3, 4, or 5 (totally black). Mathematically, this can be expressed as:

$$N_R = 5 \left[1-(I/Io)_S\right] \tag{11}$$

$$= 5 \left(1 - e^{-3/4 \frac{MKX}{\rho r}}\right) \tag{12}$$

where:

N_R = Ringelmann Number

$(I/Io)_S$ = transmittance through stack plume

For many years, this Ringelmann scale has been used as a quick and inexpensive method to control stack effluents. However, many problems arise. Since lighting and background conditions are

important in determining the Ringelmann value that will result from the comparison and since plume thickness (i.e. stack diameter) plays a roll in the blackness of the effluent, the results of a Ringelmann test may not always be completely correct.

Perhaps a better way to control stack effluents would be to set a standard for plume transmittance that would be based on a minimum amount of visibility reduction downwind. Such a regulation must take into account stack size, mass emission rate, particle size distribution, meterological conditions, etc.

Since the readings of an opacity instrument (a photocell and light source mounted inside a stack) are governed by the same equations as those which apply to atmospheric visibility, then opacity instrument could be used as the control mechanism.

The extinction coefficient in the stack (observed by the photo cell) will be:

$$\sigma_s = \pi \Sigma N_i K_i r_i^2 \tag{13}$$

and

$$N_i = \frac{M_i}{4/3\ \pi r_i^3 \rho_i}$$

therefore

$$S = \pi\ K_i r_i^2\ \left(\frac{M_i}{4/3\ \pi r3\ \rho_i}\right) = 3/4\ \frac{M_i K_i}{r_i \rho_i} \tag{14}$$

Equation (14) may also be used to determine the extinction coefficient that will exist in the atmosphere as a result of the pollutant plume, if the particle size distribution assumes reason-

ably constant. Only the mass concentration in each interval will change. Thus:

$$\frac{\sigma_{stack} = 3/4 \sum \frac{M_{i\ stack}\ K_i}{r_i \rho_i}}{\sigma_{atmosphere} = 3/4 \sum \frac{M_{i\ atm}\ K_i}{r_i\ \rho_{i\ atm}}}$$

Hence:

$$\frac{\sigma_S}{\sigma_{atm}} = \frac{M_{i\ stack}}{M_{i\ atm}} = \frac{M_{stack}}{M_{atm}} \qquad (15)$$

σ atm will vary along a plume because dispersion and diffusion will act to reduce the mass concentration, M, as the plume moves away from the source. A dispersion equation such as the Sutton equation can be used to estimate M at any point and thus produce an expression for M (X). Therefore, Equation (15) can be rewritten:

$$\frac{\sigma_s}{\sigma_a(X)} = \frac{M_{stack}}{M_{atm}\ (X)} \qquad (16)$$

σ is considered constant since the opacity instrument sites across the stack. At the stack the instrument reacting $T = (I/Io)_s$ will be:

$$T_s = e^{-\sigma_s D}$$

$$\ln \frac{1}{T_s} = A_s = \sigma_s D \qquad (17)$$

where A_s is called the absorbance and D is the stack diameter at the point where the opacity meter is maintained. The mass concentration in the stack effluent (M_s) is related to the stack diameter, the gas velocity, v, and the mass emission rate, Q.

$$M_s = \frac{Q}{\frac{\pi D^2}{4} v} \tag{18}$$

combining 16, 17, and 18, the expression

$$\sigma(X) = \frac{A_s M(X) \pi D v}{4 Q} \tag{19}$$

If an opacity meter were set up in the stack plume it would react just as the meter in the stack, giving

$$T_{atm}(X) = e^{-\sigma a(X)X}$$

Over a short distance, dX, $\sigma_a(X)$ can be considered constant and $dT_a = e^{-\sigma a(X)\, dX}$ or

$$dA_A = \sigma_a(X)\, dX \tag{20}$$

Inserting this information into Equation (19) yields

$$dA_A = \frac{A_s \pi D v}{4Q} M(X)\, dX \tag{21}$$

Based on this equation it is now possible to calculate the visibility reduction which will occur in the plume. Starting at some distance X_1 from the stack (the property line for example) and sighting downwind the visible range (r) can be determined by integrating

Equation (21).

$$\int_{X_1}^{X_1 + R} dA_A = \frac{A_s \pi D v}{4Q} \int_{X_1}^{X + R} M(X)\, dX \qquad (22$$

From Equation (4) and the definitions of visibility, the left hand side of this equation will equal 2.995 if R is the visual range for an ideal black object. The right hand side requires a relationship between M(X) and X. The Sutton's equations is one of the simpler formulas that will provide this information. For a point source this equation states:

$$M(X) = \frac{Q}{\pi \bar{u}\, C_Z^{\,2}\, (X)^{2-n}} \qquad (23)$$

where

$\bar{u}$ = average wind speed

C_Z = a dispersion parameter

n = an atmospheric stability

M(X) is the atmospheric concentration along the plume centerline. Since the visibility determination is begun at some point, X, downwind, perhaps the equation would best be written as:

$$M(X) = \frac{Q}{\pi \bar{u}\, C_Z^{\,2}\, (X_1 + X)^{\,2-n}} \qquad (24)$$

Now, Equation (22) may be written as:

$$2.995 = \frac{A_s Dv}{4\bar{u}C_Z^2} \int_{X_1}^{X_1 + R} X^{n-2} dX \qquad (25)$$

Notice that the mass emission rate, Q, no longer appears in the equation. Therefore, visibility requirements can be used in lieu of mass emission regulations.

Integrating (25):

$$\frac{X^{n-1}}{n-1} \Bigg|_{X_1}^{X + R} = \frac{(2.995)\ (4)\ (\bar{u})\ (C_Z^2)}{A_s\ Dv}$$

which reduces to :

$$As = \frac{11.980\ \bar{u}\ C_Z^2}{Dv} \left(\frac{1-n}{X_1^{n-1} - (X_1 + R)^{n-1}}\right) \qquad (26)$$

Equation (26) gives the value of absorbance, A_s, which must be read at a stack of diameter, D, and an exit velocity, v, to maintain a visibility of distance R in the plume, starting at a distance X_1 downwind from the stack.

Since A_s is related to the Ringelmann Number by :

$$NR = 5\ (1-I/Io) = 5(1-e^{As})$$

Equation (26) can be written:

$$N_R = 5\ 1\text{-}\exp\left\{\left[\frac{11.98\ \bar{u}\ C_Z{}^2}{Dv}\left(\frac{1-n}{X^{n-1} - (X_1 + R)^{n-1}}\right)\right]\right\} \quad (2,$$

These equations could be used to regulate stack emissions by settling a visibility criterion based on average meterological conditions .Texas regulations for mass emission are based on the average values of:

$\bar{u}$ = 3.8 meters per second

n = 0.25

Z^2= 0.01)

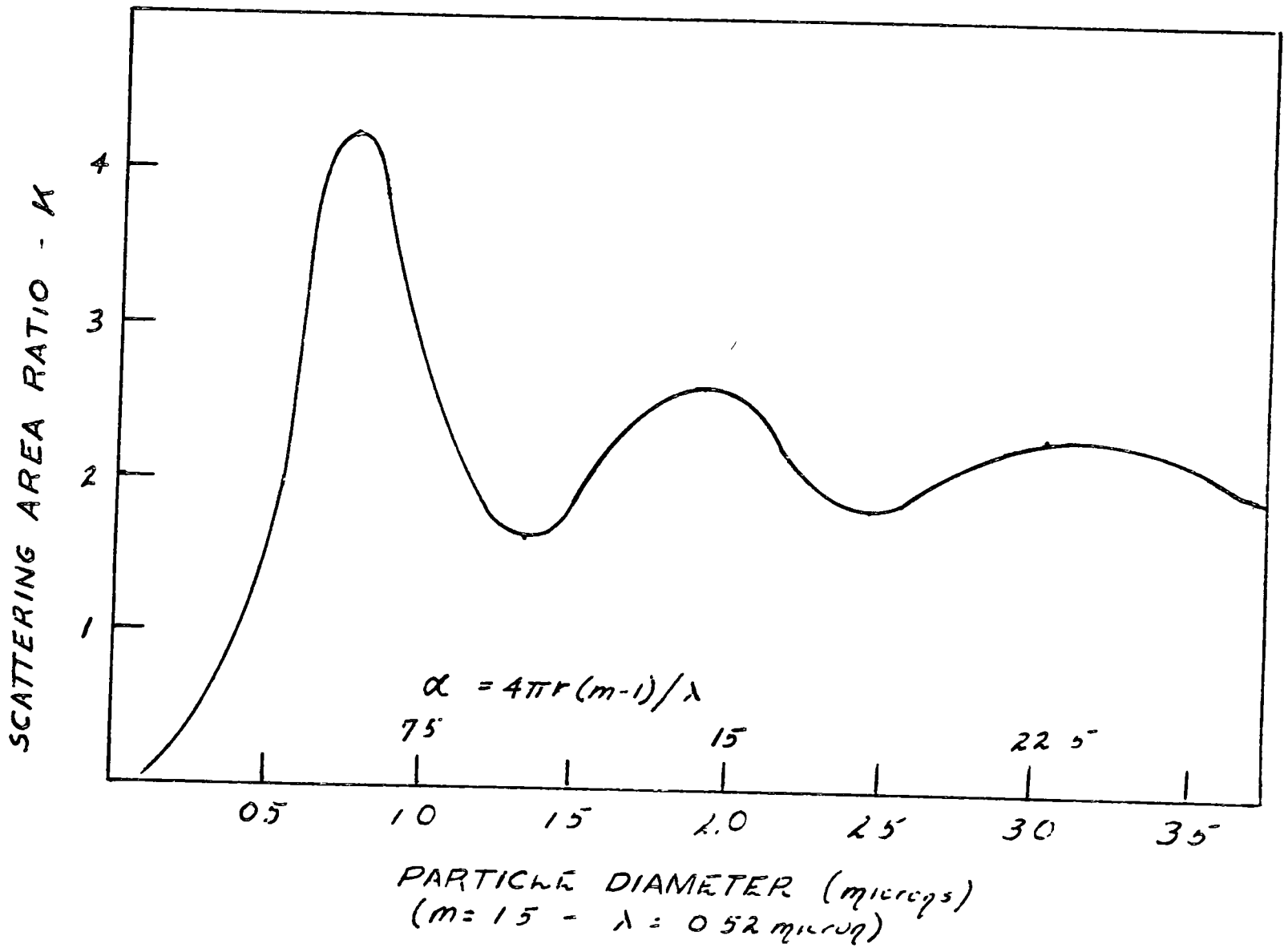
With R set, the stack owner could use Equation (26) to solve for the photocell reading required for his particular case.

Example: If visibility is required to be no less than three miles in a plume, starting at the plant property line, 100 meter reading (A_s) will be required if the stack diameter is two miles and the stack velocity is 10 m/sec.

Solving (26):

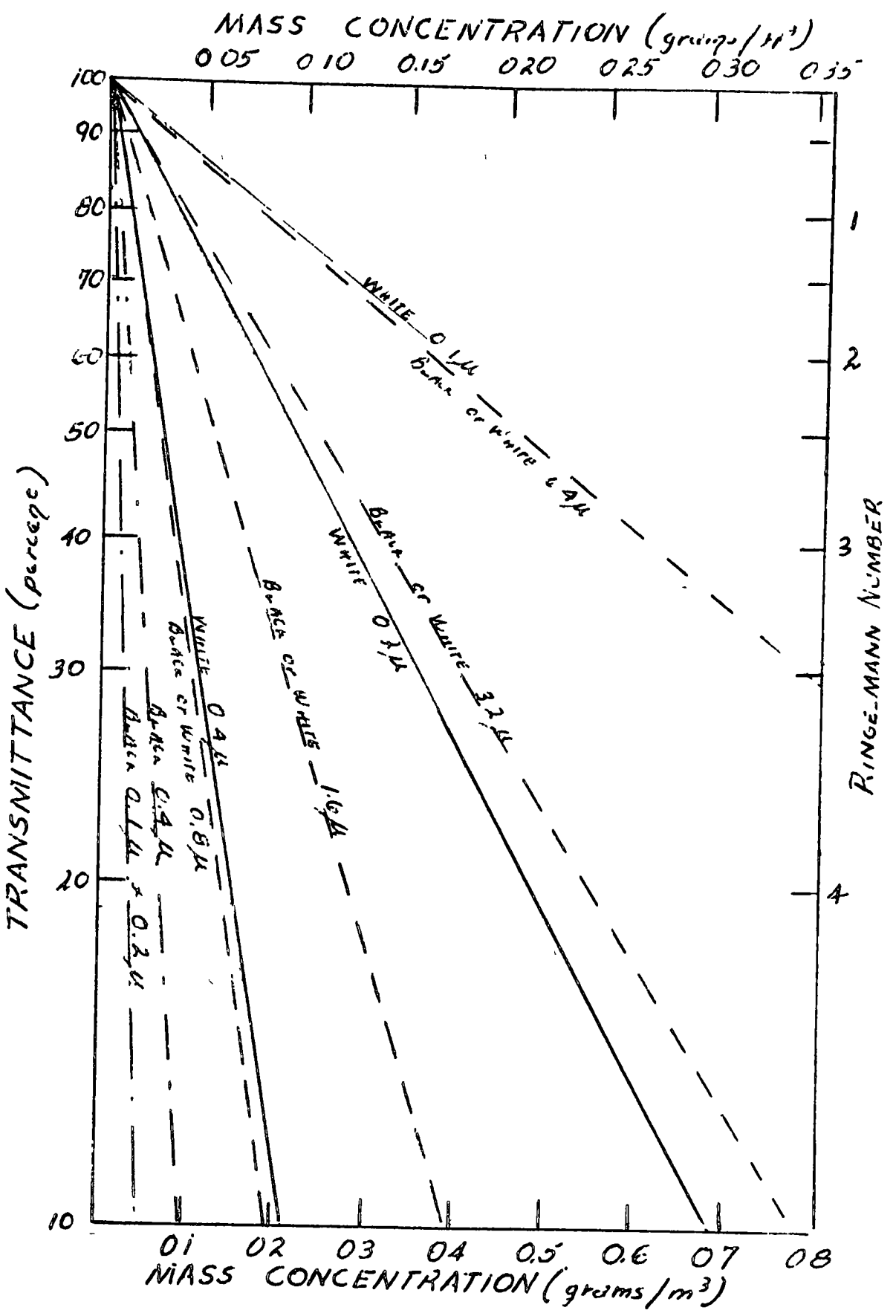
$$A_s = \frac{(11.98)\ (3.8)\ (.01)}{(2)\ (10)}\left(\frac{1 - 0.25}{(100)^{-0.75} - (4927)^{-0\ 75}}\right)$$

A_s = 0.57 (T = 56.6%)



Scattering Area Ratio for Various Size Monodispersal Aersols

(Mie Theory)



Transmittance vs. Mass Concentration in a 3 meter Diameter Plume

(ρp = 1g/cc)

RETURN TO GEORGE KIMURA

KIMURA

Determining Dust Concentration in a Gas Stream

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POWER TEST CODES

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
United Engineering Center
345 East 47th Street New York, N.Y. 10017

Determining Dust Concentration in a Gas Stream

POWER TEST CODES

KIMURA

Foreword

THE first of the ASME Power Test Codes related to the abatement of atmospheric pollution dealt with the test of dust separating apparatus It was published in 1941 The experience with this code identified a difficult measuring problem which led to the formation of the second in the series, a procedure for measuring the dust concentration in a gas stream

As recognized by those who have had experience with the measurement of dust in gas streams, there are many practical difficulties In the formation of a code for these measurements, the committee has adhered to procedures which are believed to be technically sound Unfortunately, however, they are not simple nor easy to apply The ASME Power Test Codes Committee will welcome suggestions to simplify the procedure without compromising the accuracy of the test results

This revised code was approved by the Power Test Codes Committee on April 3, 1957 It was approved and adopted by the Council as a standard practice of the Society by action of the Board on Codes and Standards on April 29, 1957.

May, 1957

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Test Code for

Determining the Dust Concentration in a Gas Stream

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SECTION 0, INTRODUCTION

1 This code is designed to cover tests on any gas stream confined in a duct and carrying particles 10 micron or larger Capable men should always supervise the conduct of tests

2 Unless otherwise specified, all references to other codes refer to ASME Power Test Codes

3 Before formulating a test to determine the dust concentration in a gas stream, the Code on General Instructions should be studied and followed in detail In particular, before any test is undertaken, its object shall be agreed upon

4 The Code on Definitions and Values defines certain technical terms and numerical constants which are used throughout this code with the meanings and values therein established

5 The sections on Instruments and Apparatus describe many types of instruments and methods which are likely to be required, and discuss their application, calibration, sensitivity, accuracy, etc. Supplements on Instruments and Apparatus referred to in this code are designated by the abbreviation, I & A.

SECTION 1, OBJECT AND SCOPE

6 The object of the test shall be to determine the dust concentration in any gas stream confined in a duct In addition, procedures are given for making a size analysis of the dust sample

7 If the scope of the test includes dust collectors or any other apparatus, it will be necessary to consult such other ASME codes as apply.

8 The determination of special data outside the scope of this code shall be made only with the written agreement of both parties to the test regarding methods of measurement and computation, all of which shall be completely described in the test report.

9 The determination of the dust count, extensively used as a measure of atmospheric dust pollution, is outside the scope of this code.

10 Should the specific directions given in this code for any particular measurement differ from those given in other ASME Power Test Codes for similar measurements, the instructions of this code shall prevail, unless otherwise agreed to by the parties to the test.

SECTION 2, DESCRIPTION AND DEFINITION OF TERMS

PAR NO	TERM	SYMBOL	DESCRIPTION	UNIT
11	Gas flow through duct [1]	W_g	Quantity of gas passing through the duct for the period of the run	lb
		Q_g	Same as above	cu ft at actual temp and pressure
		Q_s [2]	Same as above	cu ft at std density
12	Standard density of gas [1,2]	d_s	Density of the conveying gas at 68 F and 29 92 in Hg abs	lb per cu ft
13	Density of gas in duct [1]	d_d	Density of the gas at the temperature and pressure existing in the duct at the sampling location	lb per cu ft
14	Density of gas at orifice [1]	d_o	Density of the gas at the temperature and pressure existing on the discharge side of the metering orifice	lb per cu ft
15	Gas drawn through sampler [1]	w_g	Quantity of gas passing through the sampler for the period of the run	lb
16	Dust removed from sampled gas	w_r	Quantity of dust removed from the sampled gas for the period of the run (see Par 35 for definition of dust)	lb
17	Temperature of gas in duct	t_d	Temperature of the gas in the duct at the sampling point	F
18	Temperature of gas at orifice	t_o	Temperature of the gas at the exit of the metering orifice	F
19	Pressure of gas in duct	P_{sd}	Static pressure in the duct at the sampling point	in Hg abs at 32 F
20	Pressure of gas at orifice	P_{so}	Static pressure of the gas at the exit of the metering orifice	in Hg abs at 32 F
21	Orifice coefficient of discharge	C_o	Coefficient of discharge for the metering orifice, i e , the ratio of the actual flow to the flow computed for an ideal orifice	a ratio
22	Duration of the run	T	Elapsed time from the beginning to the end of the run	hr
23	Operating time for sampler	T_o	Length of time the sampler is in operation This will be less than the duration of the run by the amount of outage, if outage occurs	hr
24	Dust concentration	m	Dust concentration at the sampling section	lb dust per 1000 lb gas
25	Average velocity of gas in duct	V_d	Average velocity of the gas in the duct at the sampling location	fpm
26	Gas velocity at inlet of sampler	V_n	Velocity of the gas at the inlet nozzle or opening of the sampler	fpm
27	Area of sampler inlet nozzle	A_n	Area of the inlet nozzle, i e , entrance end of the sampling tube	sq ft
28	Area of metering orifice	A_o	Area of the orifice used for metering the gas flow through the sampler	sq ft
29	Area of duct	A_d	Cross-sectional area of the duct at the sampling location	sq ft

[1] Includes any water vapor present
[2] These values will be hypothetical in those cases where correction to standard density results in condensation of vapor

Par No.	Term	Symbol	Description	Unit
30	Pressure differential of manometer across metering orifice	H_o	Deflection of the manometer connected across the metering orifice	in water at 68 F
31	Velocity pressure in duct at sampling point	P_{vd}	Velocity pressure of the gas in the duct at the point where the sampler is spotted	in. water at 68 F
32	Size analysis	S	Percentage by weight of the various sizes of particles, as indicated by the subscripts, e g , $S_{-60+100}$ means the percentage that passes through 60 mesh but is held on 100 mesh sieve	per cent
33	Acceleration of gravity	g	Acceleration of gravity The standard value of 32 2 is usually sufficiently accurate	ft per sec per sec
34	Number of sampling points	N	Number of points in the duct where samples are drawn Also applies to Pitot-tube readings	

35 **Dust, Smoke and Soot.** For the purpose of this code, "dust" is defined as particles of gas-borne solid matter larger than one micron mean diameter Large gas-borne particles (over 100 mu) which are a product of combustion of solid fuel are usually referred to as "cinders," but they come under the general heading of dust Smoke, as distinguished from dust, is the result of incomplete or arrested combustion of the volatile constituents of fuels, and consists of particle sizes smaller than 1 0 micron Soot is composed of agglomerated smoke particles In determining the dust concentration, all material caught should be included.

36 **Test and Run.** "Test" as applied in this code means the entire investigation A "run" is a subdivision of a test consisting of a complete set of observations and recorded data taken at regular intervals for a period of time

Section 3, Guiding Principles

37 In field practice, the method of determining the dust concentration of gases must be adapted to the conditions of construction and operation encountered in each particular case If, as in laboratory work, ducts could be arranged so as to obtain a comparatively uniform flow of the dust-laden gas over the entire cross-sectional area, if the temperature and humidity of the gas could be held within fixed limits, and if the dust concentration and other characteristics could be arranged to best suit the requirements of the test —then the problem would be comparatively simple Unfortunately, ideal conditions are seldom found in field testing Therefore, it behooves the parties to the test to investigate the field conditions thoroughly before making arrangements for conducting a test

38 The following is a list of pertinent items upon which agreement shall be reached by the parties to the test They are listed here merely for check purposes

(*a*) The object, or objects, of the test (see Par 6)
(*b*) Time of making the test
(*c*) The number, type and location of dust samplers and other instruments to be employed where alternatives are permitted (see Section 4)
(*d*) Method of maintaining constancy of test conditions
(*e*) Gas flow rates at which runs are to be made
(*f*) Method of determining gas flow
(*g*) Number and duration of runs (see Par 48)
(*h*) Duration of operation at each test flow before sampling is commenced (see Par 47)
(*i*) Selection of a laboratory for making equipment calibrations, weighings and other required measurements if facilities are not available at the test location
(*j*) Tolerances or margins, if any, to be applied (see Par. 39)

39 **Tolerances.** This code does not include consideration of over-all tolerances or margins The test results shall be reported as computed from the test observations, only calibrations having been applied Certain of the measurements, however, may be subject to appreciable error. The expected limits are stated, where possible, in

Section 4 These and other allowances for errors of measurement are permissible, provided they are agreed upon in advance by the parties to the test, and provided they are clearly stated in the test report Their combined plus or minus value, i e , the tolerance, shall be taken as the square root of the sum of the squares of the percentage effects of the various limits of error on the results of the test Whenever allowances for possible errors of measurement are taken into consideration, the reported test results shall be qualified by the statement that the results may be regarded as correct within a given plus or minus percentage, this value having been determined in accordance with the foregoing method for computing tolerance

40 The parties to the test may designate a person to direct the test and serve as an arbitrator in the event of any dispute as to the accuracy of any observations conditions, or methods of operation

41 Accredited representatives of all parties concerned should be present to verify that the test is conducted in accordance with this code and the agreements made prior to the test, whether the test is directed by an outside person or by a representative of either party

42 **Preparation for Test.** The major points in connection with the test (see Pars 37 and 38) having been agreed upon, it is then necessary to prepare the detailed procedure for the test Care should be used in selecting the best possible sampling cross section of the duct A straight run of duct preceding the point of measurement is of course preferable, when not available, avoid locations near sudden changes in area or direction of the duct, especially 90-deg bends The inlet duct of a fan may be preferable to the outlet duct, for the reason that a fan in operation acts as a separator to a considerable extent That is, the passage of dust-laden gas into and through a fanwheel tends to concentrate dust at the periphery of the casing scroll and at a point adjacent to the back plate or center plate of the wheel, thus causing a condition of stratification, as well as turbulence, to carry into the outlet duct

Vertical ducts are generally preferred as a location for measurements as a further preventive of stratification Room for the test setup and for free movement during the test should not be overlooked when selecting the locations If measurements must be taken in a horizontal duct, the floor of the duct must be kept clean throughout the test

43 Vanes or other apparatus used for straightening gas flow in ducts sometimes have the opposite effect on the dust particles, since they may enhance or intensify the degree of stratification The only satisfactory means for combating wide differences in velocity or stratification over the sampling cross section is to use more sampling points

44 It is not likely that the accuracy of a test will be impaired as the result of sampling the gases at an excessive number of points in the duct On the other hand, error will probably be introduced if the points are too few

The number of Pitot readings required to establish correct volumes and variations in velocity in a duct is dependent upon conditions peculiar to each case This requires a preliminary survey to establish general conditions In few cases will the flow be uniform and it is more usual to find velocities in different parts of the duct varying by as much as 4 to 1 Greater variations are not unusual Also the size and shape of the duct, close proximity to a bend or damper, and the gas volume to be handled, have direct bearing on the number of points required

Where the flow is fairly uniform, i e , where the range of velocities does not exceed 2 to 1, from twelve to twenty points can be used for large ducts (exceeding 25 sq ft area) and from eight to twelve points for small ducts

Where high velocity differentials or extreme turbulence of stream flow are encountered, it will be necessary to double and sometimes to treble the number of points required in order to establish true conditions

Rectangular or square ducts, Fig 1*A*, shall be divided into cross-sectional measuring areas or zones of approximately equal size and shape In number, these zones shall correspond to the number of sampling points thought to be necessary according to the physical conditions of the duct system, survey of velocities, and direction of flow of the gas stream A "point" for sampling the gas will be located at the center of each zone area

The method of subdividing round ducts is shown by Fig 1*B* The number of zones and consequent number of sampling points will depend upon the physical condition of the duct system at the approach to the measuring cross section as well as upon the variation in velocity and direction of gas flow

45 **Preliminary Runs.** One or more preliminary runs shall be conducted for the purpose of

(*a*) Checking instruments
(*b*) Training personnel
(c) Making minor adjustments, the need for which was not evident during preparation for the test

46 Any preliminary run, when completed, may be declared, by mutual agreement, to be an official run.

47 **Constancy of Test Conditions.** Prior to

the start of each run, the operating conditions, especially gas-flow rate, shall be maintained constant, and at the same values as for the run, for at least one hour Ducts shall be inspected for dust deposits to determine the effect of the deposit on duct cross-sectional area Much of this preliminary period is necessary for making the Pitot traverses. However, the Pitot traverses should not be started sooner than one-half hour after the rate of flow has been adjusted. The main purpose, however, of requiring a preliminary period is to allow conditions to become steady. Dust tends to accumulate in various places in ducts and the amount of dust at these points changes with change in rate of flow Steady conditions shall be reached at each rate of flow before the official run is started even if it is found that several hours are required

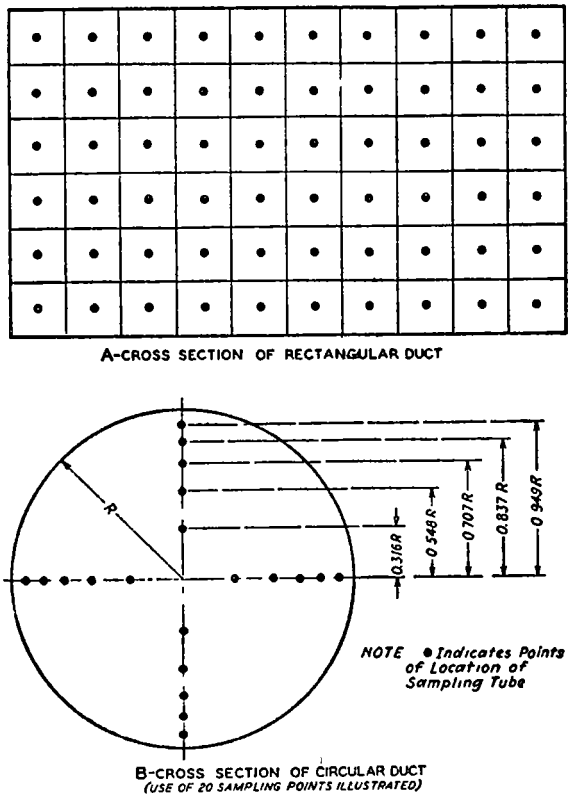

FIG. 1 METHOD OF SUBDIVIDING DUCT INTO MEASURING AREAS OR ZONES

Formula for determining location of points in circular duct

$$r_p = \sqrt{\frac{2R^2(2p-1)}{n}}$$

where r_p = distance from center of duct to point p
R = radius of duct
p = sampling point number To be numbered from center of duct outward All four points on same circumference have same number
n = total number of points

NOTE: r_p will be in same units as R

Example: Duct radius = R, 20 points total
Distance to point 3 = r_3

$$r_3 = \sqrt{\frac{2R^2(2\ 3-1)}{n}} = \sqrt{\frac{2R^2 5}{20}} = \sqrt{\frac{5R^2}{}}$$

$$r_3 = 0\ 707R$$

Although constant operating conditions are necessary to obtain the most reliable results, it is recognized that the operating condition sometimes cannot be maintained constant because of plant requirements In such situations, tests must be conducted with sampling apparatus that employ the null method (see Par 50) of adjusting the rate of sampling In such cases each test run should be at least 50 per cent longer than required for steady load tests The accuracy of the over-all dust concentration obtained with such a test will probably be less than with steady load conditions

48 Number and Duration of Runs. The number of runs is usually determined by the number of basic flow rates at which the gas passes through the duct and by other operating conditions At least two runs should be made at each basic rate, although this is not mandatory The duration of the runs shall be governed by operating conditions, number of sampling points, and the number of samplers operated If possible, the samplers should be operated a minimum of 10 min at each point and there shall be at least two complete circuits of the points If operation is cyclic, each run shall cover at least one cycle of operation

49 Should serious inconsistencies in the observed data be detected during the conduct or computation of any run, that run shall be rejected, and it shall be repeated if necessary to attain the objects of the test In this connection it should be pointed out that rough calculations of the performance should be carried along with the runs, lagging not more than one day behind.

50 Frequency of Readings The frequency at which complete Pitot tube traverses are to be made is covered in Par 69 The inclined manometer connected to the differential-pressure-producing device or the meter used for indicating the correct rate of sampling shall be continuously maintained at the proper setting If the null method is used, in which the sampling velocity is regulated to the existing duct velocity by maintaining a zero differential between static pressure within the sampling nozzle mouth and outside the sampling nozzle mouth at an adjacent point in the duct, no record need be made of the velocity pressure, but for methods requiring a predetermined setting, a record shall be kept of the setting computed for each sampling point. Average gas pressure and temperature at the metering device for each sampling point shall be recorded each

period Other indicating instruments shall be read every 15 min Integrating instruments used for measuring the quantity of gas sampled shall be read at the beginning and end of each run Sometimes it is desirable to read integrating instruments at the end of each hour of operation

51 Procedure for Operating Samplers.

(*a*) From the Pitot traverse readings made during the preliminary period, compute the proper orifice manometer settings or the meter rates for each point (see Par 80)

(*b*) At exactly the start of the run, insert the sampler through the hole provided in the flue and spot the nozzle at the first point as quickly as possible with the nozzle turned downstream Open the control valve in the sampling line to the setting computed for first point and face the nozzle directly into the gas stream

In order to maintain the correct ratio of dust to gas quantities, it is necessary that the sampler face directly into the gas stream and that the sampling velocity be the same as the duct velocity at each sampling point

(*c*) Then adjust the sampling rate to the proper value and maintain the same setting until the sampler is moved

(*d*) Observe and record the average gas temperature and pressure at the metering device

(*e*) Based on these values, compute the adjusted value to be maintained for the next point

(*f*) At the proper time, move the sampler quickly to the next position and correct the flow rate Continue until at least two complete rounds of the sampling points have been made If operation is cyclic, at least one complete cycle must be sampled

(*g*) Should trouble develop, e g, the resistance of the filter build up too high, breakdown of the means of aspiration, etc, shut off the sampler immediately, withdraw the sampling nozzle from the flue, note the time and correct the conditions which are at fault Then start sampling again at the same position, noting the outage time on the data sheet for future reference

(*h*) At the end of the run, remove the sampler without changing the flow rate through it Hold the tube in a vertical position, nozzle up, and tap on the tube to cause any dust sticking to the inside of the tube to enter the filter Increasing the flow rate often aids A stiff round bristle brush of the proper size, used as a swab, will assist in more completely cleaning the tube

(*i*) This cleaning completed, shut off the exhauster, remove the filter and send it to the laboratory for weighing

The foregoing procedure for operating one sampler shall be followed for all samplers used The movement of all samplers should be synchronized

Section 4, Instruments and Methods of Measurement

52 Necessary Instruments The required instruments are described in this section Before proceeding to select or construct instruments, those chapters of I & A dealing with these instruments should be consulted for detailed information Many of the required corrections and conversion factors which have been standardized will be found in these chapters of I & A

53 The instruments and test apparatus required are as follows

(*a*) Pitot tubes for gas-velocity measurements in the duct

(*b*) Dust samplers, nozzles and dust collectors for determining the dust concentration

(*c*) Metering devices, which are usually orifices or gas meters for determining the gas sampling rate

(*d*) One or more exhausting devices for withdrawing the gas

(*e*) Thermometers or thermocouples with their temperature indicator for measuring the gas temperatures in the duct and at the orifices or gas meters

(*f*) Inclined manometers for use with Pitot tubes in reading the velocity pressures

(*g*) Inclined or vertical manometers for indicating the pressure drop across the metering orifices

(*h*) Inclined manometers for use with sampling nozzles if the null method is used

(*i*) Manometers for measuring the static pressure at discharge of the metering orifice

(*j*) Manometers for measuring the static pressure in the duct

(*k*) A laboratory-type balance for weighing the dust samples

(*l*) A drying oven for removing moisture from the dust samples and the filters before weighing, and a desiccator to hold the samples while cooling after drying and before weighing

(*m*) A set of standard sieves (8-in diam) of the following sizes 60, 100, 200 and 325 mesh (see Par 76)

(*n*) The foregoing methods should be supplemented by microscopic examination, espe-

cially for particle sizes smaller than 325 mesh, 44 mu

(*o*) A small riffle sampler with $\frac{3}{8}$- or $\frac{1}{2}$-in divisions for reducing the dust samples (desirable but not necessary)

54 **Dust Samplers.** The function of the sampling device is essentially that of withdrawing a portion of the dust-laden gas at such a rate and in such a manner that it represents a true sample at the point of extraction Having withdrawn the sample, it is then necessary to separate and retain the dust for weighing and to measure the quantity of gas withdrawn The sampling device shall comprise the following parts

(*a*) A tube or nozzle for insertion into the gas stream and through which the sample is withdrawn

(*b*) A filtering or separating device for removing the dust from the sampled gas For the purpose of this code, 99 0 per cent by weight efficiency is considered satisfactory

(*c*) Means for checking the equality of the velocity of the gas entering the nozzle and the velocity of the gas in the flue at the point of withdrawing the sample

(*d*) Means for measuring the quantity of gas sampled

(*e*) An exhausting device for drawing the gas through the sampling nozzle, filter and metering device together with the necessary connecting tubing

55 A number of different types of dust samplers which fulfill the foregoing requirements have been developed and successfully used These are described in the literature, reference to which can be found in the bibliography The sketches of Fig 2 show several representative types Testing experience has not been uniform enough to permit standardizing sampler design This code, therefore, merely gives limiting requirements which past experience has shown desirable to avoid major sources of error.

56 The inlet diameter of the sampling nozzle is dependent upon the volumetric capacity of the separating device through which the sampled gas must pass The diameter shall be at least $\frac{1}{4}$ in and shall be of sufficient size to secure, within reasonable time, true and adequate samples from which accurate results can be obtained as to weight, size and chemical composition It is important to use a thin edge nozzle While a sharp edge nozzle is preferable, it is quite fragile A well rounded edge nozzle is more rugged and is acceptable The tapering, if any, shall be on the outside, not on the inside

57 The sampling tube from the nozzle to the filtering device shall be smooth with no interruptions Its length shall be held to a minimum Adequate means for reclaiming dust deposited in the tube shall be provided. It is preferable to have the filtering device attached to the end of the sampling tube. It is important that the temperature of the gas be above the dew point until after it has passed the filter This may necessitate insulating and heating that portion of the sampling tube outside of the duct as well as the separator Some designs of samplers have the filter located in the nozzle head so that the entire assembly can be inserted into the duct This has some advantages when small sized nozzles can be used

58 The filtering device should be located in front of the measuring and exhausting devices. By agreement of the parties to the test, equipment which is built otherwise may be used, provided it is fully described in the test report For separating the dust from the gas, a filtering material is preferred However, other types of separating devices may be used if their efficiency of separation can be demonstrated to be above 99 0 per cent under test conditions

59 The filter may be made of any material which has a filtering efficiency of 99 0 per cent by weight for dust of the approximate size analysis to be encountered during the test, and which will withstand the temperature, humidity and stress to which it will be subjected during the test In the table below are listed some acceptable materials

Material	Suggested Max Operating Temp, F
Cotton	190
Wool	235
Filter paper	150
Glass wool	650
Nylon	275
Orlon	350

Glass cloth and glass wool have many advantages which are lacking in other materials, but it is difficult to remove the dust without having it contaminated with glass fibers Nylon should not be used for gases containing abnormally high percentages of SO_2

60 The filtering material is usually made in thimble, flat-disk, or bag form so the dust can be retained in or on the filter for drying and weighing Paper or alundum thimbles are manufactured in relatively small sizes with a filtering capacity of 0 5 to 1 5 cfm which limits their use to samplers having nozzles of small diameter Cloth bags can be made of any size, their only limitations besides strength being that they shall be

of fine enough weave to give the required filtering efficiency, large enough to keep the resistance to gas flow within the limits of the exhausting device, and small enough to permit accurately determining their increase in weight as a result of the dust caught It is difficult to control the moisture content of filtering bags, hence the necessity of making the ratio of the weight of the bag to the weight of the dust caught as small as possible As an empirical rule, the bag weight should not exceed 20 per cent of the weight of the dust, preferably, it should be much less Provided the bags do not fail and their resistance does not exceed the capacity of the exhausting device, each run should be of such duration that a relatively large quantity of dust will be caught Not only is the size of the dust sample important from the standpoint of weighing, but it is important to have an adaquate quantity for any analyses required

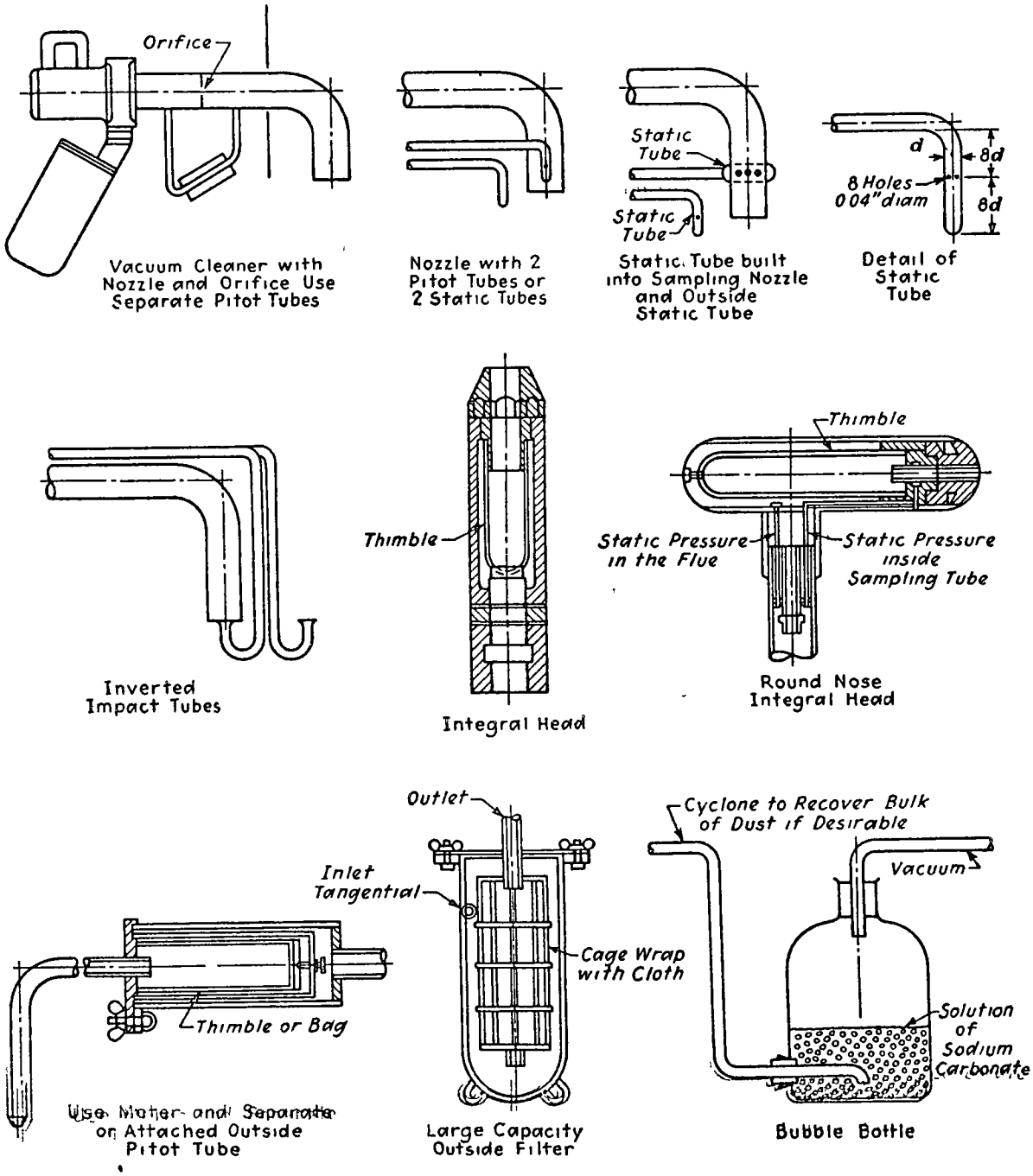

FIG 2 SAMPLING DEVICES

61 At high loads, sufficient dust is usually caught during a run of standard duration At light loads, however, a longer run may be needed to obtain an adequate dust sample One method of minimizing the sampling time is to have varying sized nozzles and always to use the largest sized nozzle which conditions permit Thus, at high gas flow rates, which usually mean high dust loading, a small nozzle can be used At low gas flow rates and low dust loading, the small nozzle can be replaced with one of larger diameter, thereby compensating in some measure for the change Nozzle changes may be made only between runs

62 If the filter is located upstream from the metering and exhausting devices, it is necessary to have the filter encased in an airtight container It is advantageous to have the filter visible, and for that reason glass jars with the inlet and outlet tubes passing through the cap have been used extensively.

63 The rate of sampling is usually controlled by a valve in the sampling line In addition, there is a measuring device for determining gas flow rate This measuring device also serves as a guide in maintaining the gas flow rate at the proper value It may be located at any convenient place in the circuit providing the following precautions are observed

(*a*) A gas-tight connection is maintained between the nozzle and the measuring device

(*b*) The measuring device is preceded by a sufficient straight run of pipe to minimize turbulence in the gas stream (see I & A, Part 5, Chap 4)

(*c*) Any condensation prior to metering is measured and compensated for

Some sampling methods employ a gas meter to measure the quantity of gas sampled, and with suitable equipment this is a satisfactory method Standard gas meters usually have, in addition to the integrating dials, a test dial with a capacity of from one-half to one cubic foot which makes them practical as a guide in determining the instantaneous flow rate which is necessary for proper control The double Pitot tube, the built-in static tube, and the inverted impact tube, all of which use the null method, are illustrated in Fig 2

64 The type of exhauster is immaterial so long as it has adequate capacity Rotary blowers, such as are used for vacuum cleaners, steam, air and water ejectors, have been used for this purpose The selection of the exhauster for any particular test should be governed by the most convenient source of energy available at the sampling locations, and also by the uniformity and dependability of the source of energy. One exhauster, with sufficient capacity for all samplers, or a separate exhauster for each sampler, may be used

65 **Number of Samplers and Their Location.** The duration of the runs is dependent upon the number of sampling points, which in turn is dependent upon the uniformity of gas velocity and dust concentration over the sampling cross section of the flue The ideal arrangement is to have a sampler located at each sampling point, a rather impractical procedure However, by using at least two samplers, the comparison of their operation often aids in detecting trouble which might otherwise pass unnoticed

66 As stated in Par 44, the withdrawal of samples of dust-laden gas from an adequate number of points in the duct cannot be overemphasized in its relation to the accuracy of the test results The duct, whether rectangular or round, shall be divided into measurement zones of equal area A "point" of measurement shall be at the center of area of each measurement zone For a point-to-point traverse, a sampler shall be operated an equal length of time at the center of each subdivision in which there is positive gas flow free from eddy currents and back flow over a substantial portion of the subdivision The number of measurement zones shall be determined according to the statement of Par 44

67 **Pitot Tubes.** The Pitot tubes used for measuring the gas velocities in the flues shall be of good quality and shall have been checked for accuracy in a laboratory equipped for that purpose Other types of velocity-measuring tubes may be used by agreement of the parties to the test provided they have been calibrated Care must be taken to assure tight connections between the Pitot tube and inclined gage

68 The Pitot tube measurements may be required for determining the sampling velocity at each point where the sampling nozzles are to be spotted, and as an alternate method for determining the total quantity of gas passing the test section See Pars 42, 44 and 66 for the method to be employed in determining the points where these measurements are to be made The initial set of velocity-pressure (p_{vd}) readings shall be taken after the unit has been brought to the test load and gas flow and temperature conditions have become steady, but before the start of the test run These velocity-pressure readings, together with gas temperature readings taken at the same points, shall be used in determining the proper sampling rate to be maintained. See Par 80 for method of computing the orifice differential pressure (H_o) from the velocity pressure and temperature of the gas in the flue. The zero point of the Pitot tube manometer combination should be checked frequently.

69 If the gas flow rate at the various sampling points in the duct remains reasonably constant, the initial set of velocity-pressure and temperature readings will suffice If the gas flow rate changes considerably, a complete set of readings shall be taken at least every hour More frequent readings shall be taken if found necessary to assure the desired degree of accuracy For each new set of velocity-pressure and temperature readings, the flow through the sampling tube shall be adjusted accordingly A spare Pitot tube should be available in case of damage to or trouble with those in use

70 **Metering Devices** All devices installed in the sampling lines, whether merely as a guide in regulating the sampling rate or for measuring the quantity of gas sampled, shall be calibrated with a high grade gas meter or gasometer It is not sufficiently accurate to use average values for the coefficient of discharge when the orifices are small Thin-plate orifices are usual, although thick orifices with well-rounded inlets may be employed if desired The size of the orifice depends on the rate of sampling In general, the orifice should be small enough to give a deflection which can be read accurately on the type of manometer used and yet not so small that the added pressure drop will adversely affect the operation of the exhausting device If desired, the orifices can be sized to be used with the same inclined manometers as the Pitot tubes For instructions regarding the design, installation, and use of these orifices, refer to I & A, Part 5, Chap 4, "Flow Measurement by Means of Standardized Nozzles and Orifice Plates" As stated in Par 63, the metering device can be located at any convenient place provided the precautions mentioned therein are taken When gas meters are used they shall be calibrated at the beginning and end of the test

71 **Manometers.** The manometers used with the Pitot tubes shall be of the inclined type graduated to 0 01 in The same type can be used for the orifice differential pressure reading if the orifices are proportioned to suit Inclined gages, whether filled with water or some other liquid, shall not require special calibration if a gage of standard manufacture is used For description and use of manometers and Pitot tubes, refer to Test Codes for Centrifugal Mixed and Axial Flow Compressors and Exhausters (PTC 10), and Fans (PTC 11) When using manometers containing a liquid other than water, care shall be exercised that the density of the liquid during the test is the same as during calibration Correction for the density of such liquids for temperature is often appreciable if the atmospheric temperature differs greatly from 68 F When necessary, the temperature correction for density shall be applied

72 If the metering orifices are designed to give a large deflection, water-filled vertical manometers may be used to measure their differential pressure Similar manometers can be used to measure the pressure drop across the dust separator and the static pressure in the flue The static pressure at the discharge of the metering orifices shall be measured with manometers The divisions of any vertical manometer scale shall be checked against a machinist's scale Sometimes scales graduated to read pressure in inches of water are used with other liquids If a barometer is available, it should be read, otherwise a value of 30 in Hg at 32 F at sea level corrected to the elevation of the test point shall be used

73 **Thermometers and Thermocouples.** The use of either thermometers or thermocouples is permitted for any temperature measurements made under this code Thermometers are well suited for measuring the temperature of the sampled gas at each orifice The gas temperature, especially in large ducts, is best obtained with a thermocouple having the leads directly back of the couple encased in a metal tube in conjunction with a compensated-type temperature indicator The tube through which the leads pass makes it easy to spot the couple at the same points as for the Pitot-tube and dust-sampler traverses

74 **Time Measurements.** Any clock or watch which keeps reasonably good time is sufficiently accurate for these tests Not only shall a record be kept of the duration of each run, but the movement of the samplers from point to point shall be kept on schedule, and any outage time for the samplers shall be accurately recorded If gas flow rates are determined from an integrating gas meter, a stop-watch is a necessity

75 **Balance and Drying Oven.** Any type of balance which is accurate to 0 5 per cent of the weight of the dust caught when weighed in the filter is satisfactory Standard weights shall be used The filters when empty or filled shall be dried in an oven to constant weight and then placed in a desiccator to cool before being weighed See Par 60 for the minimum ratio of weight of bag to weight of dust caught

76 **Sieves and Sieving Machine** 60-, 100-, 200- and 325-mesh sieves shall be used for the sieve analysis Additional sizes may be used by mutual agreement of the parties to the test Both National Bureau of Standards and Tyler screens are acceptable, but the report shall state which has been used Table 1 lists these two standards Wherever possible a mechanical sieving machine shall be used Lacking a sieving machine, it is best to have the sieve analyses made by some laboratory equipped with a machine Where the sieving must be done by hand, a method similar to that outlined in ASTM Specification D 197-30, Standard Method of Test for Fineness of Powdered Coal, should be used as a guide.

The accuracy of results of sieve analyses for particle sizes smaller than 325 mesh, 44 mu, is subject to doubt For that reason it will be desirable to check such evaluations by microscopic examination or by elutriation determination

TABLE 1 SIEVE SIZES AND APERTURE IN MICRONS

(1 in =25,400 mu)

Screen Number (Also Number of Mesh per Inch)		Size Opening, mu
National Bureau of Standards	Tyler	
10	9	2,000
12	10	1,680
14	12	1,410
16	14	1,190
18	16	1,000
20	20	840
25	24	710
30	28	590
35	32	500
40	35	420
45	42	350
50	48	297
60	60	250
70	65	210
80	80	177
100	100	149
120	115	125
140	150	105
170	170	88
200	200	74
230	250	62
270	270	53
325	325	44
400	400	37

77 Experience seems to indicate that no hard-and-fast rules for making the size analyses of dust samples will give reliable results for all types of dust Since dust differs greatly as to shape, density and its tendency to break or agglomerate, only a few general regulations will be specified—the actual procedure being left to the ingenuity of the person making the analysis to obtain reliable results The actual procedure followed shall be explained in detail in the test report Only operators experienced in making size analyses can expect to obtain reliable results

78 As a general guide to making the size analysis, the following general procedure shall be followed the size of the sample shall be reduced by means of a riffle sampler or by quartering It is not necessary to use exactly a whole number of grams The sample shall be dried in an oven and cooled in a desiccator before introduction into the sieves

To remove immediately most of the minus 325-mesh material which tends to block screen openings, the sample shall first be placed on the 325-mesh sieve and shaken and tapped for approximately 10 to 15 min The portion left on the 325-mesh sieve shall then be screened through the entire series for approximately 10 to 15 min The minus 325 material from this screening shall be combined with that from the first screening The sieves shall then be brushed with a soft brush, beginning with the 60-mesh, in order to cause any agglomerate undersize particles to pass to the sieve below, which in turn shall be brushed in the same manner Finally, the dust caught on each sieve and also that which passed through the 325-mesh sieve shall be weighed. The sum of the weights of all the sized samples should not differ from the weight of the original sample by more than 1 per cent

79 The size analysis of subsieve dust, i e , the dust which passes through a 325-mesh sieve, is a specialized job requiring unusual skill and long experience It is suggested that when subsieve analyses are desirable the sample be sent to a laboratory equipped to do this work Elutriation tests or the measurement of the dust particles under a microscope are the usual methods The physical characteristics of some dusts preclude the use of the elutriation method This can easily be determined by a person experienced in making such tests

SECTION 5, COMPUTATION OF RESULTS

80 Although this section is intended primarily to cover computation of results, it also covers the preliminary computations which are necessary for proper operation of the test equipment As explained in Par 68, the differential pressure to be maintained across the metering orifice in the sampling line is dependent upon the area of the inlet nozzle, the area of the orifice, the orifice flow coefficient, the velocity, pressure, and temperature of the gas in the duct, and the pressure and temperature of the gas at the orifice. The relationship is expressed by the following equation:

$$H_o = \frac{(A_n)^2 P_{sd}(t_o+460)}{(C_o A_o)^2 P_{so}(t_d+460)} \times P_{vd} \quad \text{.....in water at 68 F ...[1]}$$

By maintaining the orifice differential pressure computed from this equation the velocity of the gas entering the inlet nozzle (V_n) will be the same as the velocity of the gas passing close to the nozzle (V_d), which is the condition necessary for

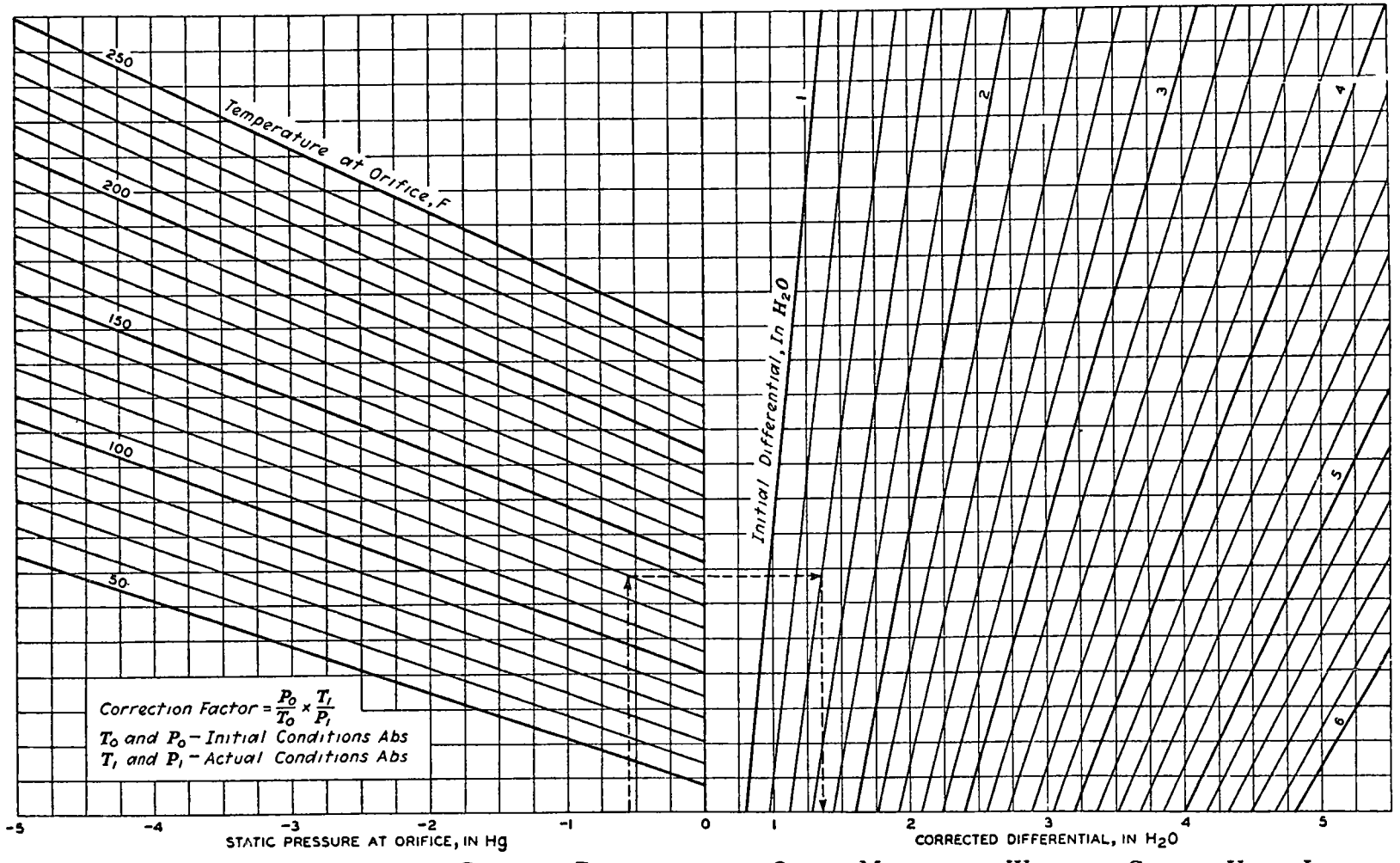

FIG 3 SAMPLE CHART FOR DETERMINING CORRECTED DIFFERENTIAL FOR ORIFICE MANOMETERS WHEN THE CONTROL VALVE IS ON THE DISCHARGE SIDE OF THE ORIFICE

(Note Initial conditions Based on Orifice pressure —0.5 in Hg, Temp 150 F)

correct sampling The values for all of the items in Equation [1] except the temperature, t_o, and pressure, P_{so}, of the gas at the orifice are known before the start of the test Past experience should indicate approximately what these values should be Using these assumed values of t_o and P_{so} the orifice differential pressure for each point for a given sampler can be computed from the following equation·

$$H_o = (\text{a constant})\frac{P_{vd}}{t_d+460}. \text{ in water at 68 F.} \quad [2]$$

After the test has been in progress for a short time, the actual temperature and pressure of the gas at the orifice can be read and the preliminary manometer setting corrected to give a more nearly correct rate of sampling This correction can be made conveniently by use of a curve sheet similar to Fig 3, which is merely an example As will be noted, this figure is plotted for a correction factor of unity (1 0) when the vacuum at the discharge of the orifice is ½ in Hg and the gas temperature at the orifice is 150 F From Equation [1], similar curves can be plotted with the correction factor unity at the orifice pressure and temperature most likely to exist at the beginning of a run For test apparatus designed to maintain constant orifice discharge pressure, the only unknown in Equation [1] is the orifice temperature, t_o

81 In dealing with flue gas, it is important to remember that the density is greater than that of air at the same pressure and temperature, due mainly to the CO_2 content

$$d_d = \frac{144\,P_{sd}}{(\text{Gas constant})(t_d+460)2\,036} \quad \text{.....lb per cu ft.. ..[3]}$$

For typical flue gas having 12 per cent CO_2 and a dew point at 97 F, the gas constant is 52 4 This value is usually sufficiently accurate. However, if desired, the exact value of the gas constant for the composition of the gas actually encountered may be used Using a gas constant value of 52 4, Equation [3] reduces to

$$d_d = \frac{1.35\,P_{sd}}{t_d+460}\text{... ..lb per cu ft .....[4]}$$

Similarly

$$d_o = \frac{1\,35\,P_{so}}{t_o+460}\text{.....lb per cu ft .. ...[5]}$$

Since the gas composition does not change in passing from the duct to the orifice, except for the dust which has been removed, the same gas constant shall be used in the orifice meter computations

82 The quantity of gas sampled can be obtained from the following equation

$$w_g = 3600\,A_o C_o T_o \sqrt{\frac{d_o d_w}{12}}\,\sqrt{2gH_o} \quad \text{. lb..[6]}$$

where $d_w = 62\,3$ density of water at 68 F

Using the standard value 32 2 for the acceleration of gravity, Equation [6] reduces to

$$w_g = 65800\,A_o C_o T_o \sqrt{d_o H_o}\text{.....lb.....[7]}$$

83 The dust concentration is the following ratio

$$m = \frac{w_r}{w_g}\,1000 \quad \text{.. lb dust per 1000 lb gas . [8]}$$

When more than one sampler is used and when their inlet nozzles are of the same size, the value of w_r is the sum of the weights of dust caught in all samplers used at the given cross section, and w_g is the sum of the weights of gas sampled This will give a weight-averaged value of m for the entire stream of gas passing the sampling cross section.

84 The velocity of the gas at each point where Pitot tube measurements are made can be computed from the following equation

$$V_d = 1096\sqrt{\frac{P_{vd}}{d_d}}\text{..... fpm.....[9]}$$

From the average velocity the quantity of gas flowing through the duct for the period of the run is

$$W_g = 60\,V_d A_d d_d T\text{.....lb.....[10]}$$

The value of d_d in this equation is the average value across the duct section.

Test Code for Determining the Dust Concentration in a Gas Stream

Section 6, Report of Results

85 The purpose of this table is to provide a convenient form for reporting results of tests It is not intended to serve as a guide for determining the readings that should be taken Some incidental readings which have no particular significance but which may be necessary for the computations, have been omitted These data may be included, or other data added, if desired The table is divided under headings which make it convenient for selecting those groups of items which are applicable Standardization of table forms is of great convenience to those who study or use reports It is, therefore, recommended that this table form be used with as few modifications as possible

General Information

1	Date of test	
2	Plant designation	
3	Location	
4	Owner	
5	Manufacturer	
6	Dust from (describe and identify source)	
7	Object of test	
8	Test conducted by	

Description, Dimensions, etc

9	Class of dust (from stoker or pulverized-fuel burner, etc)	
10	Cross-sectional area of duct at sampling station	sq ft
11	Position of duct (vertical, horizontal, or inclined) at sampling station	
12	General direction of gas flow in duct (up, down, or horizontal) at sampling station	
13	Number of points used for the Pitot and sampling traverses at sampling station	
14	Number of dust samplers used at sampling station	
15	Type of velocity-pressure tubes used	
16	Type of dust samplers used	
	(*a*) Inside diameter of inlet nozzle	in
	(*b*) Inside diameter of tube leading from nozzle to filter	in
	(*c*) Location of filter (inside or outside of duct)	
	(*d*) Kind of filter or other device used for separating the sampled dust	
	(*e*) Diameter of metering orifice	in
	(*f*) Kind of exhauster used	
	(*g*) Any other important features or dimensions of the sampler	

Test Data and Results

17	Run number	
18	Date and time of run	

19 Duration of run ..... hr
20 Conditions peculiar to run .....
21 Load, i e, gas flow rate .....cfm or lb per hr
22 Average velocity of gas at sampling station..... fpm
23 Average temperature of gas at sampling station ..... F
24 Static pressure of gas at sampling station .....in. Hg abs at 32 F

Pitot Tube and Dust Sampler Data

25 Sampling station
(*a*) Position .....1, 2, 3, etc
(*b*) Gas temperature in flue ..... F
(*c*) Velocity pressure in flue .....in. water at 68 F
(*d*) Gas velocity in flue ..... fpm
(*e*) Differential held on orifice manometer..... in. water at 68 F
(*f*) Gas temperature at orifice ..... F
(*g*) Gas pressure at discharge of orifice.....in Hg at 32 F
(*h*) Gas sampling rate ..... lb per hr
(*i*) Gas velocity in sampling nozzle..... fpm
(*j*) Outage time ..... hr
(*k*) Quantity of gas sampled during run ..... lb
26 Total quantity of gas sampled ..... lb
27 Dust sample weights
(*a*) Filter number .....
(*b*) Gross weight ..... g
(*c*) Tare weight ..... g
(*d*) Net weight ..... g
28 Total weight of dust from samples ..... g or lb
29 Dust concentration at sampling station .....lb dust per 1000 lb gas
(*a*) Expressing the quantity of gas volumetrically. ... grains of dust per cu ft at std density
30 Total weight of dust passing sampling station. ..... lb

Size Analysis of Dust Samples

31 Samples from sampling station
(*a*) Weight of sample ..... g
(*b*) +60 ..... per cent
(*c*) −60+100 .....per cent
(*d*) −100+200 ..... per cent
(*e*) −200+325 ..... per cent
(*f*) −325 ..... per cent
32 Detailed procedure used in sieving samples .....
33 Combustible content of dust samples ..... per cent
.....per cent
.....per cent
34 Any peculiar characteristics of dust .....

Fuel Analyses

35 Type and proximate analysis of fuel (as fired)
(*a*) Volatile matter ..... per cent
(*b*) Fixed carbon ..... per cent
(*c*) Ash ..... per cent
(*d*) Moisture .....per cent
(*e*) Sulphur (separate determination)

General Data

36 Barometric pressure .....in. Hg at 32 F
37 Sketch showing physical layout of dust source and ducting, location of testing equipment, and positions of sampling tubes

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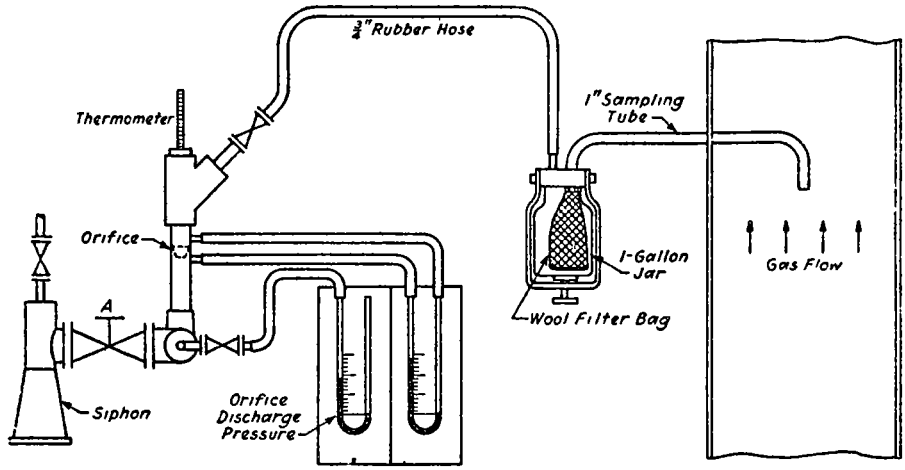

Fig. 4 Diagrammatic Sketch of Assembly of Apparatus Shown in Figs. 5 and 6

Note Valve *A* is intended to maintain constant orifice outlet pressure)

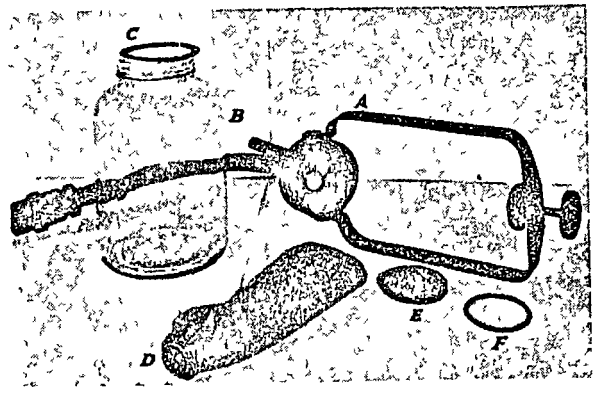

FIG. 5 COMPONENT PARTS OF SAMPLING JARS SHOWN IN FIG 6

(*A*) Metal frame and cap
(*B*) Glass jar
(*C*) Gasket
(*D*) Wool filter bag with adapter
(*E*) Spreader for bottom of bag
(*F*) Retaining spring for spreader

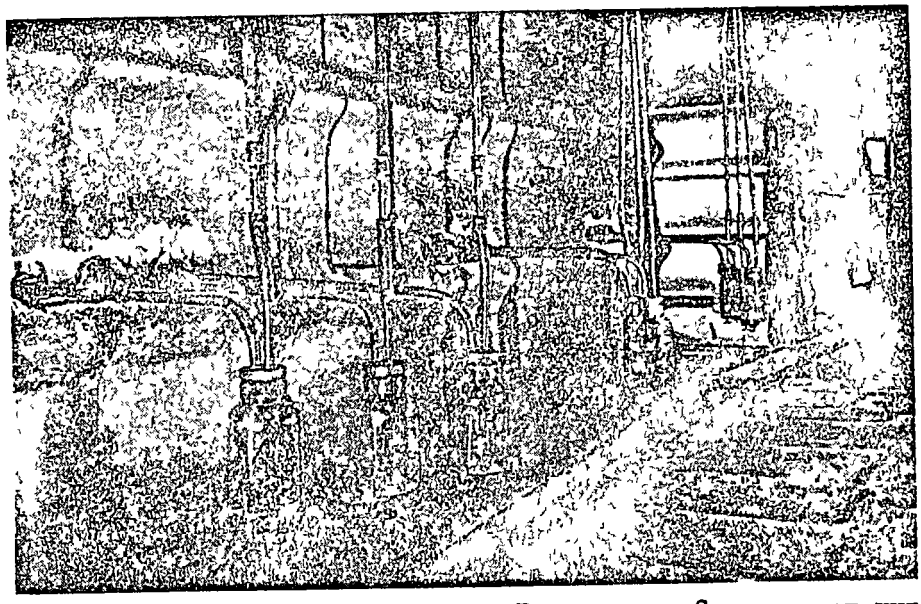

FIG. 6 SAMPLING TUBES AND JARS IN POSITION FOR SAMPLING AT THE CINDER CATCHER OUTLET

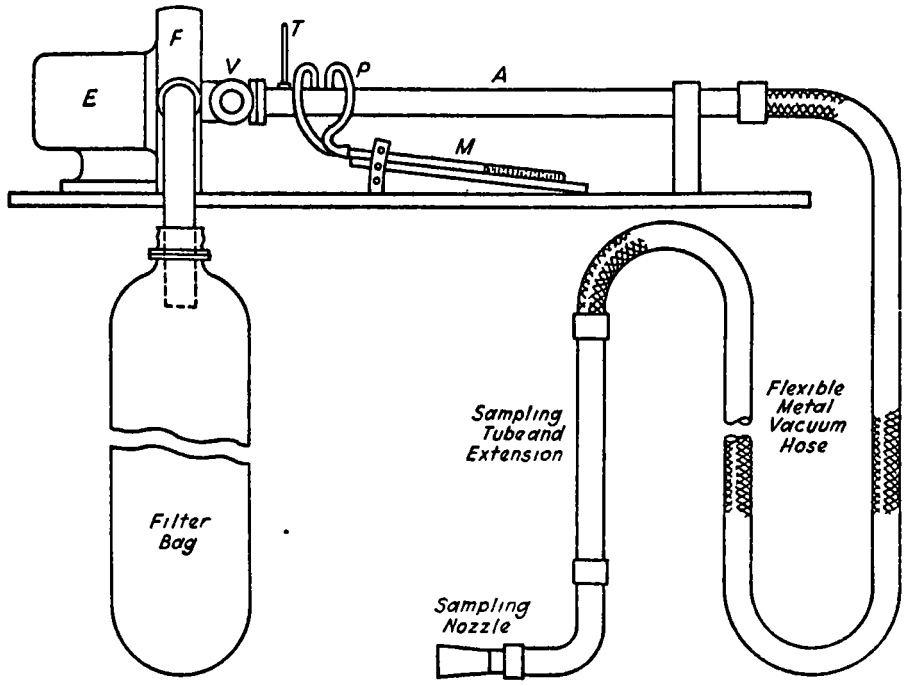

FIG 7 SKETCH OF A DUST SAMPLING APPARATUS WITH SUCTION FAN AND FILTER BAG

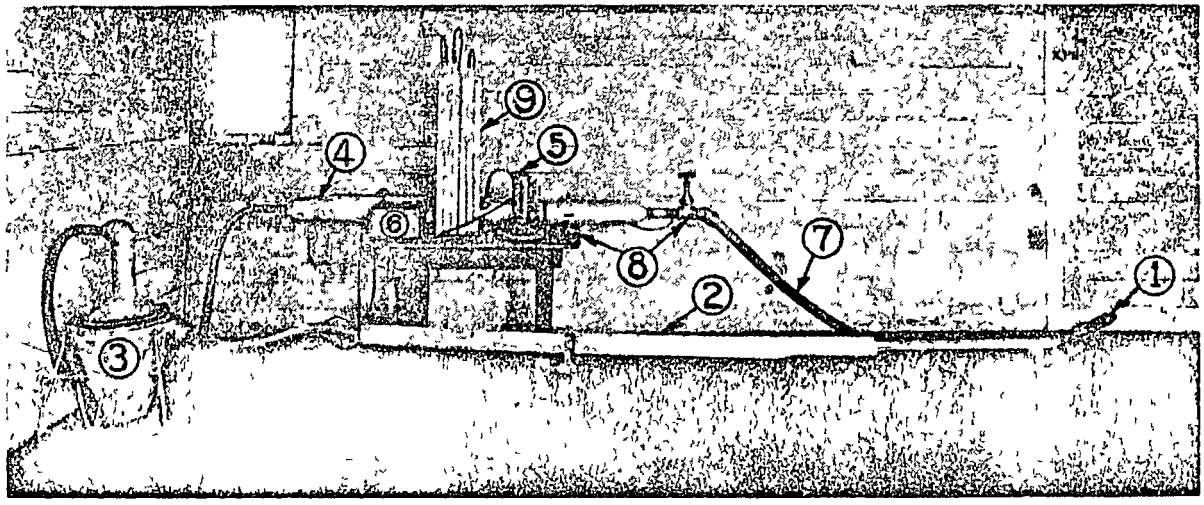

FIG 8 ASSEMBLY OF APPARATUS USED FOR SAMPLING OF DUST LADEN FLUE GASES

(1) Null-differential type sampling nozzle
(2) Sampling pipe, insulated between flue wall and cyclone collector (see 3) to prevent condensation of moisture in pipe
(3) Cyclone-type collector using paper filter insert at outlet The cyclone is insulated and provided with heating coil to prevent condensation within the cyclone Dust is deposited in glass jar at bottom of cyclone
(4) Orifice pipe containing orifice for volume measurement as well as pressure and temperature of sample gas
(5) Askania Minimeter connected by pressure tubes to inner and outer static-pressure connections of sampling nozzle
(6) Potentiometer connected to thermocouple for measurement of gas-sample temperature in orifice pipe
(7) Connecting hose to gas aspirator
(8) Gas sample flow-adjusting valves for regulation of sampling velocity, at inlet of sampling nozzle, to duct velocity according to indication by Askania Minimeter
(9) Manometers for measurement of differential pressure across orifice and pressure of gas in orifice pipe

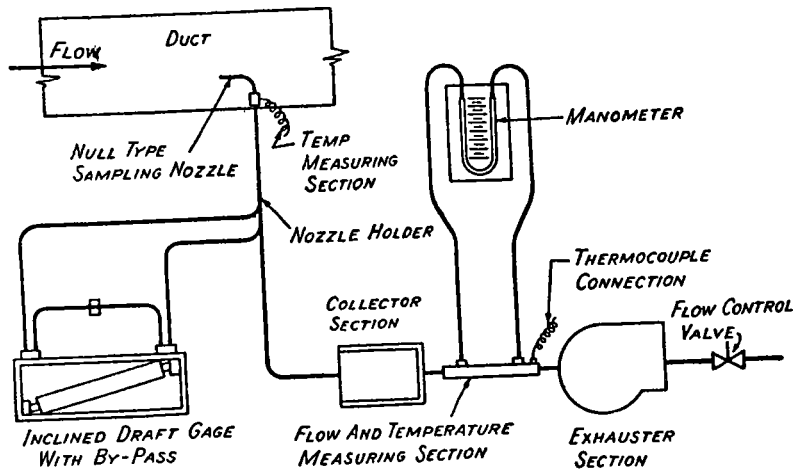

FIG. 9 SCHEMATIC SET-UP OF APPARATUS FOR NULL METHOD OF DETERMINING QUANTITY OF DUST IN A GAS STREAM

(This method eliminates the necessity of making gas velocity calculations It is based on the principle that the static pressure in the sampling tube will equal the static pressure in the duct only when the gas velocity in the sampling tube is equal to the gas velocity in the duct)

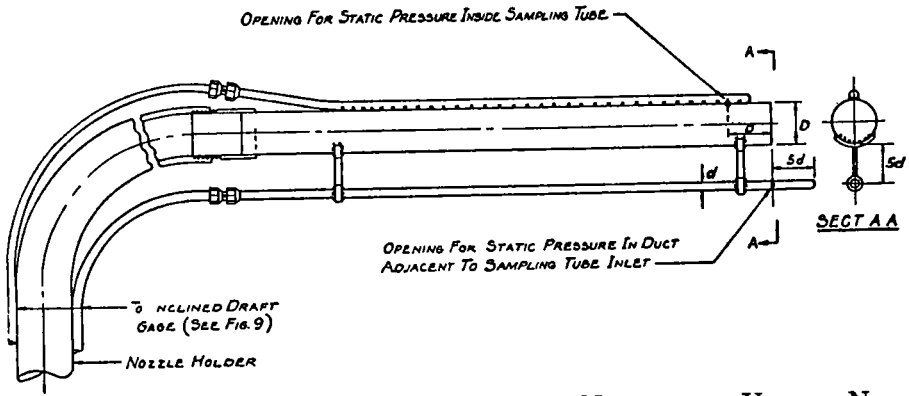

FIG 10 TYPICAL BALANCED TUBE SAMPLING NOZZLE FOR USE IN NULL METHOD OF SAMPLING

Reference
I—See Fig 2, Nozzle with Two Pitot Tubes or Two Static Tubes
II—See I & A, 1949, Part 2, Pressure Measurement, Chapter 2, Par 34 and Fig 2(a)

SECTION 8, APPENDIX

It would be highly desirable if this code could outline a simpler method for accurately determining the dust concentration in a gas stream Many such determinations are made each year and each requires the expenditure of a considerable number of manhours of labor and the use of a considerable amount of specially designed test equipment

The following illustrations show actual commercial installations and test results They illustrate the following facts which are well known to those experienced in making dust concentration determinations

1) Wide variations in gas velocities in ducts are to be expected in commercial installations
   Fig 11 shows a case where guide vanes were not practical and the gas velocities across the duct varied from 0 to 30 fps
2) Where the duct layout is favorable and properly designed guide vanes are installed, the gas velocity across a duct will be much more uniform
   Fig 12 shows a case where a favorable layout of ducts and properly designed guide vanes resulted in a maximum variation in gas velocity of only 2 22 to 1
3) Even though a favorable duct layout and properly designed guide vanes result in small variations in gas velocity across the duct, the variation in *dust concentration* across the same duct may be very large

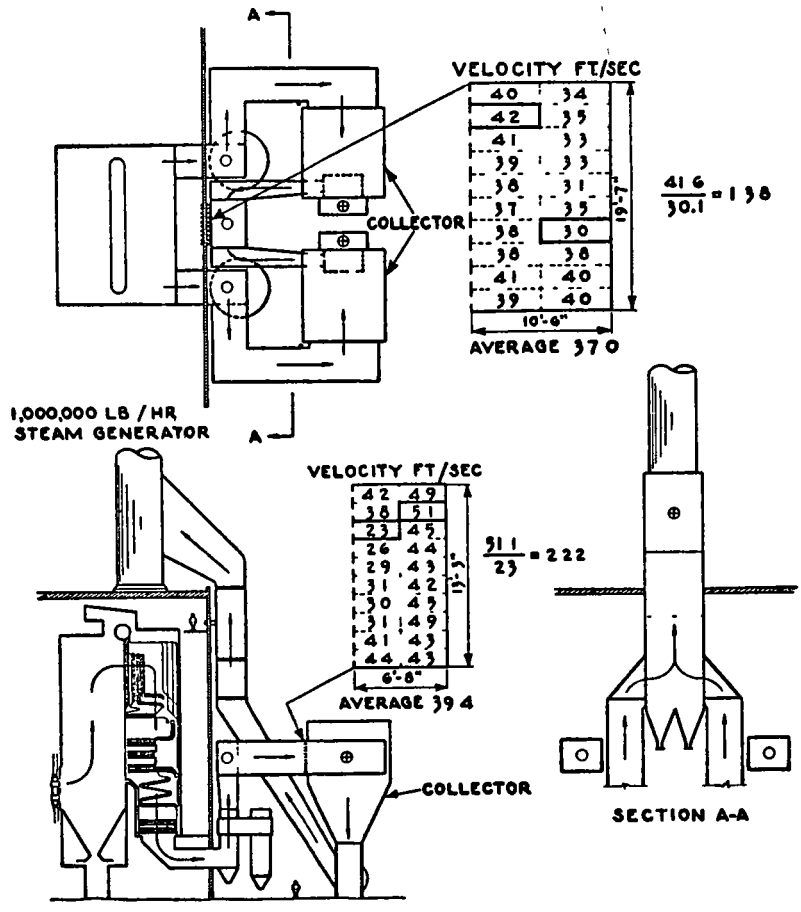
A
VELOCITY FT/SEC
40 34
42 35
41 33
39 33
36 31
37 35
38 30
38 38
41 40
39 40
10'-6"
19'-7"
AVERAGE 370
41 6 / 30.1 = 1 3 8
COLLECTOR
1,000,000 LB / HR
STEAM GENERATOR
A
VELOCITY FT/SEC
42 49
38 51
23 45
26 44
29 43
31 42
30 45
31 49
41 43
44 43
6'-8"
15'-3"
AVERAGE 394
51 1 / 23 = 2 2 2
COLLECTOR
SECTION A-A

FIG. 12

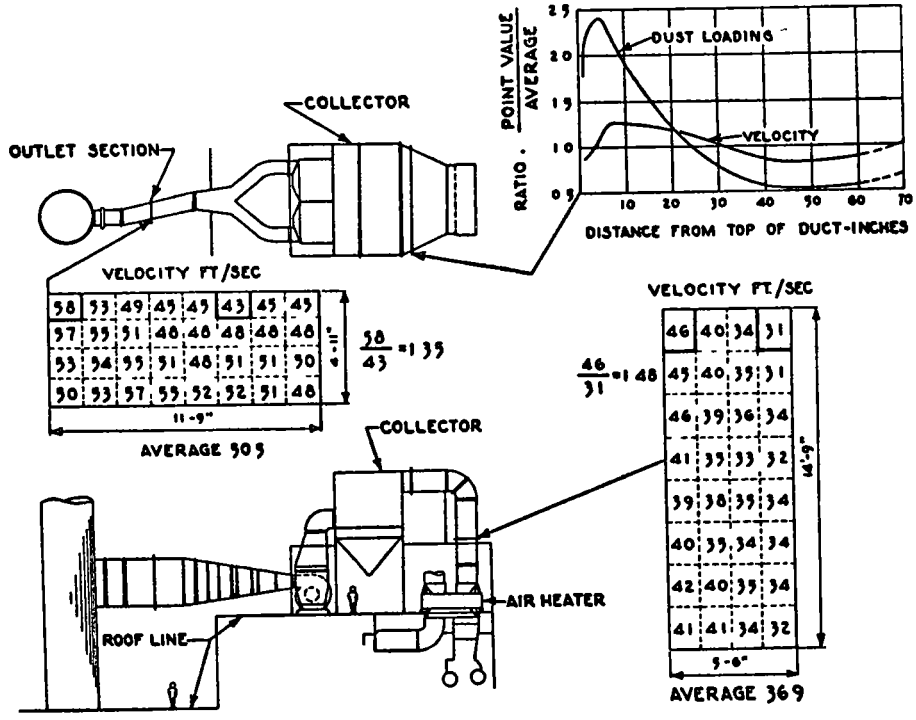
POINT VALUE / AVERAGE
RATIO .
2 5
2 0
1 5
1 0
0 5
DUST LOADING
VELOCITY
10 20 30 40 50 60 70
DISTANCE FROM TOP OF DUCT-INCHES
COLLECTOR
OUTLET SECTION
VELOCITY FT/SEC
58 53 49 45 45 43 45 45
57 55 51 46 46 48 46 46
53 54 55 51 48 51 51 50
50 53 57 55 52 52 51 48
11'-9"
4'-11"
AVERAGE 505
58 / 43 = 1 3 5
VELOCITY FT/SEC
46 40 34 31
45 40 35 31
46 39 36 34
41 35 33 32
39 38 35 34
40 35 34 34
42 40 35 34
41 41 34 32
5'-6"
14'-9"
AVERAGE 369
46 / 31 = 1 4 8
COLLECTOR
AIR HEATER
ROOF LINE

FIG. 13

Fig 13 shows a case where a favorable layout of ducts and properly designed guide vanes resulted in unusually uniform gas velocities, but the dust concentration varied about 5 to 1 from the top to the bottom of the duct

These illustrations show graphically why a simpler method than covered by this code may not give the facts Single point dust concentration determinations are useless except in very special cases which are seldom found in commercial installations

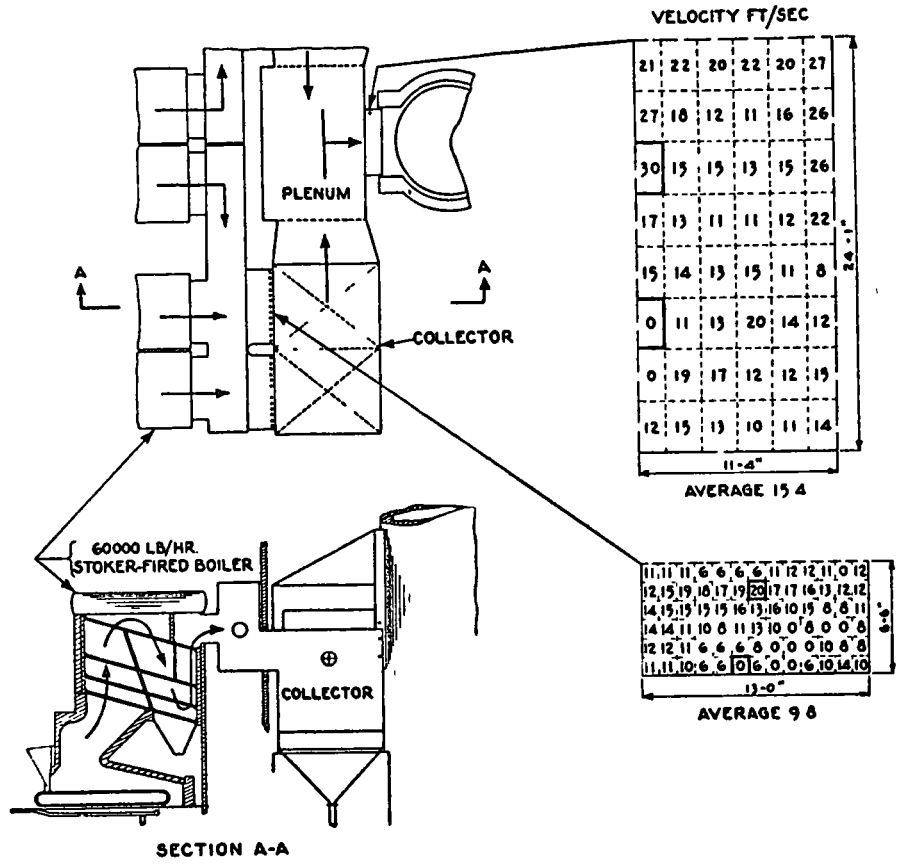

FIG. 11

ENVIRONMENTAL PROTECTION AGENCY
Air Pollution Control Office
January 18, 1971

5725 Dragon Way
Cincinnati, Ohio 45227

Dr Paul R. Harrison
Director, Technical Services Division
Department of Environmental Control
Room 500
320 N. Clark Street
Chicago, Illinois 60610

Dear Paul·

From the start of surveillance of urban air quality we have been faced with various questions regarding the pollutants to be measured, the number and type of stations needed, their location, instrumentation, frequency of sampling and the like. This has been the case in setting up Federal, State as well as local networks.

In the coming months, as part of the implementation plans for various pollutants, numerous networks will need to be designed and established To aid in these tasks and to increase the uniformity of network design and operations across the country we have expanded and updated our guidelines for network design. Prior to their finalization and distribution, we would like to solicit your comments in regard to this document.

Enclosed for your review is a copy of the document, "Guidelines: Air Quality Surveillance Networks". I would appreciate your sending comments as soon as possible to Mr. Sam Ozolins, Division of Air Quality and Emission Data, 5725 Dragon Way, Cincinnati, Ohio 45227.

Sincerely yours,

George B Morgan/plp

George B. Morgan
Director, Division of Air Quality
and Emission Data

(1) Enclosure

DRAFT

GUIDELINES: AIR QUALITY SURVEILLANCE NETWORKS

Division of Air Quality and Emission Data

Environmental Protection Agency

Air Pollution Control Office

December 17, 1970

GUIDELINES: AIR QUALITY SURVEILLANCE NETWORKS

INTRODUCTION

Air Quality Control Regions (AQCR) have now been designated for most of the major metropolitan areas in the country. For these regions and also in other areas an inherent part of the control efforts is the development of an air quality surveillance program. In some areas, existing networks will be modified or expanded; in others, new surveillance programs must be developed. Although current efforts are concerned primarily with sulfur dioxide and particulates, regional surveillance programs will ultimately be expanded to include other pollutants as well.

The guidelines presented here will assist State and local agencies in setting up air quality surveillance programs. The development of an air quality surveillance program includes 1. determining the number and location of sampling sites, 2 selecting appropriate instrumentation, 3 establishing a data information system, 4. and the like. Because no rigorous mathematical or other methods are available for determining the number and location of sampling sites, experience and judgement are essential.

The selection of the system must by necessity involve a trade-off between what is considered desirable from a strictly technical point of view and what is feasible with the 2. available resources. An ideal network will in

almost all instances require more resources than are available. In light of this, the design discussed in this paper centers on a Minimally Adequate Surveillance Network - a network less than ideal, yet capable of meeting the major surveillance requirements. The basic differences between a minimally adequate surveillance network and one of high technical quality are that the minimal network has fewer stations, takes fewer samples, and operates fewer and perhaps less sophisticated instruments. Designers of the network should attempt to maximize the effectiveness of the minimally adequate network through careful selection of sampling sites, scheduling of variable sampling frequencies, and possible use of mechanical (integrated) as well as automated (continuous) samplers.

Because of limited resources, some air quality control regions, may be required to build up to an adequate surveillance network over a period of time. The surveillance network established under conditions of limited resources would be the starting point upon which a future network could be built. In such cases a schedule for expansion should be compiled early to allow for systematic buildup and to guide the allocation of resources.

This report deals with four major aspects of regional surveillance: (1) objectives of surveillance, (2) design of a minimally adequate surveillance network, (3) laboratory requirements, and (4) data acquisition and analysis.

OBJECTIVES OF REGIONAL SURVEILLANCE

Regional air quality networks are inherent parts of implementation plans,

which are currently required for sulfur oxides, particulates, carbon monoxide, hydrocarbons, and oxidants. Generally, surveillance networks for all of these pollutants must be established in a region. In the future surveillance will be expanded to include lead, fluorides, polycyclic organic matter, and nitrogen oxides. Although each pollutant requires separate analysis, the collection of samples can be generalized into two groups: (1) a particulate network, which is the source of information for suspended particulates, lead, polycyclic organics, and fluorides; and (2) a gas network which consists of sampling devices for CO, HC, SO_2, NO_x, and oxidants. The need for surveillance for each pollutant will depend on the amount of pollution present within the region. For example, whereas one region may require extensive surveillance of, say, fluorides, the relative absence of this pollutant in another region may preclude a routine surveillance effort.

Air quality surveillance within a region must provide information to be used as a basis for the following actions:

1. To judge compliance with and/or progress made toward meeting ambient air quality standards.
2. To activate emergency control procedures to prevent air pollution episodes.
3. To observe pollution trends throughout the region including the nonurban areas. (Information on the nonurban areas is needed to evaluate whether air quality in the cleaner portions of a region is significantly deteriorating.)

4. To provide a data base for application in evaluation of effects; urban, land use and transportation planning; development of abatement strategies; and development and validation of diffusion models.

DESIGN OF AN AIR QUALITY SURVEILLANCE NETWORK

An air quality surveillance program is composed of three distinct but interrelated elements: networks, laboratory support, and data acquisition and analysis. With automatic (continuous) instrumentation the need for routine laboratory support is eliminated, but a problem of data transmission, validation, and reduction is introduced. Network design entails such considerations as the number and type of stations needed, their location, frequency of sampling, and the like. The kind of network specified for a given region will also determine the requirements for laboratory and data acquisition and analysis procedures.

The two general types of networks required for regional air quality surveillance are (1) a particulate network, and (2) a gaseous network. The particulate network should be composed primarily of Hi-Vols and tape samplers. The Hi-Vols are used to determine total suspended particulates (TSP), and, by fractionation, lead, polycyclic organics, and fluorides. Tape samplers provide an indication of suspended particulate loading over periods of less than 24 hours, primarily for use during air pollution episodes. The total particulate network design, i.e. number and location of Hi-Vol stations, will most likely be determined by the sampling requirements for

TSP. The extent to which the Hi-Vol samples are analyzed for the particular constituents depends upon local circumstances. It is important to note that when practical field techniques are perfected for measuring the respirable fraction of TSP, this will become a primary measurement.

The gas network may be composed of a mixture of mechanized and automated sampling devices. For some pollutants, such as sulfur dioxide, oxides of nitrogen, and oxidants, both types of samplers may be used. Where pollution levels are substantial, the urban core network will typically be composed of automatic sampling stations, with the mechanical stations being relegated to areas of lower concentrations.

Information Required for Network Design

Knowledge of the existing pollution levels and patterns within the region is essential in network design. 1, The areas of highest pollution levels must be defined, together with 2. geographical and temporal variations in the ambient levels. Isopleth maps of ambient concentrations derived from past sampling efforts and/or from diffusion modeling are the best tools for determining the number of stations needed and for suggesting the station locations. 3, Additionally, information on meteorology, topography, population distribution, present and projected land uses, and pollution sources is extremely helpful in network design. In fact, where isopleth maps are not available, such information, which can usually be obtained readily, provides the basis for initial design.

In the absence of isopleth maps, information on emission densities and/or land use can be used together with wind-rose data to pinpoint areas of expected maximum concentrations. Topographical maps provide additional information on wind flows and pollution dispersion characteristics. Maps of population distribution are essential in locating stations for episode control or for collecting information on health effects.

If I get above info. who would he'p me?

In some cases adequate information for network design will not be available; the resulting networks will need to be modified as more information and experience are obtained.

Set up Consulting Center and train it as such. D. not let Local Administrators do it!!!

Network Size

The number of sampling stations required depends primarily on the existing pollution levels, their variability, and the size of the region. The number of sampling stations must be adequate to allow definition of the area or areas where ambient concentrations may be expected to exceed air quality standards. Information on air quality in other areas, including the non-urban portions of the region, should also be gathered.

A first approximation of the number of stations required in a region may be obtained from Figure 1, in which the number of stations is shown as a function of total population. The curves in Figure 1 show a spread suggesting a minimum and a maximum number of stations for each population class depending on the extent and degree of pollution. For example, a region of 1 million inhabitants with a severe SO_2 problem may require up

to 20 samplers whereas one of similar size with a minimal SO_2 problem would require only 10 samplers. Although the curves should provide good estimates for application to population-related pollutants, (usually from motor vehicles) such as CO, HC, NO_x, and oxidant, they do not necessarily apply as well to SO_2 and particulate matter. For the latter pollutants, industrial complexity and fuel-use patterns in the region strongly influence the pollution levels and thus affect network size regardless of the population.

Surveillance of SO_2 and NO_x requires an additional decision concerning the mixture of mechanical and automatic samplers. A first approximation can again be obtained from Figure 1. The curve for mechanical samplers provides the estimate for the total number of SO_2 samplers needed. The difference between the estimates for mechanical and automatic samplers is the actual number of mechanical samplers required.

Figure 1 is intended only as a general guide to network size. The curves are based on a qualitative evaluation of cities of different population classes in terms of their existing networks, pollution patterns, geographic distribution of sources, and the like. The relationship between population and network size was derived from such investigations combined with experience and knowledge. In general, population is a good index to network size and such data are easily obtainable. There are, however, certain situations, such as the relative absence of SO_2 pollution in the western portion of the United States, in which these curves are not applicable. In these cases additional information is essential before network size can be

determined.

Another approach for approximating the number of stations required within a region incorporates information on existing levels of pollution as a function of the area of the region. Where isopleth maps are available, they should be used for estimating network size. At the present time, use of the mathematical approach is limited to the design of surveillance networks for suspended particulates and sulfur dioxide.

The equation for estimating network size relates the number of stations to the degree of pollution and the land area of the region. It is based on the fact that more stations are needed in zones where ambient air concentrations may be expected to exceed the ambient air quality standards and that the concentrations influence the number of stations. The equation considers distinct areas: the area, X, where the pollution levels are higher than the ambient air quality standard, the area, Y, where pollution levels are above background but lower than the standard, and the area, Z, where existing concentrations are at background levels. In these calculations all air quality data are expressed in terms of annual averages. The total number of samplers, N, required for the entire region is obtained by summing the estimated numbers of samplers for each of the three subareas.

$$N = N_x + N_y + N_z \qquad \text{Equation 1.}$$

where

$$N_x = 0.25 \; \frac{C_m - C_s}{C_s} \; X \qquad \text{Equation 2.}$$

$$N_y = 0.025 \frac{C_s - C_b}{C_s} Y \quad \text{Equation 3.}$$

$$N_z = 0.001 \; Z \quad \text{Equation 4.}$$

and

C_m (ug/m^3) is the value of the maximum isopleth, with a contour interval of 10 ug/m^3.

C_s (ug/m^3) is the ambient air quality standard.

C_b (ug/m^3) is the value of the minimum isopleth, again with a contour interval of 10 ug/m^3. (Table 1. provides estimated background values for TSP and SO_2 for use when isopleth information is not available.)

X (square miles) is the area where concentrations are higher than the ambient air quality standard.

Y (square miles) is the area where concentrations are above background but less than the ambient standard.

Z (square miles) is the area where concentrations are at background levels.

Use of this equation requires the division of the region into three zones on the basis of isointensity lines representing the ambient air quality standard and the background value appropriate for the region. The land areas of each zone are determined from the isopleth map, as are the maximum and minimum concentrations in the region. Note once more that concentration values used in the equation are annual averages.

The equation was derived from an in-depth analysis of the relationship between pollution levels and patterns, geometric distribution of sources,

meteorology, and land area in the National Capital Interstate AQCR. The equation was verified by application to several other cities in the United States with different characteristics. As mentioned earlier, it is applicable only to sulfur oxides and TSP networks. The same general approach, with different constants, can be applied to determine the size of other pollutant networks. These constants will be developed when more data are available.

Station Location

Selecting the locations of stations and samplers involves decisions regarding (1) distribution of samplers within the region, and (2) specific site selection for each station. The first decision requires consideration of surveillance objectives and the overall pollution patterns, whereas selection of the particular site is concerned with representativeness of the area and with practical aspects, such as housing, power, and security.

The information required for selecting sampler location is essentially the same as that for determining network size, i.e. isopleth maps, population density maps, source locations. Following are suggested guidelines:

1. The priority area is the zone of highest pollutant concentration within the region. One or more stations are to be located in this area.
2. Close attention should be given to densely populated areas within the region, especially when they are in the vicinity of heavy pollution.

3. For assessing the quality of air entering the region, stations must also be situated on the periphery of the region. Meteorological factors such as wind direction are of primary importance in locating these stations.
4. For determining the effects of future development on the environment, sampling should be undertaken in areas of projected growth.
5. A major objective of surveillance is evaluation of the progress made in attaining the desired air quality. For this purpose sampling stations should be strategically situated to facilitate evaluation of the implemented control tactics.
6. At least one station must be adjacent to a site of the National Air Surveillance Network (NASN) for verification.
7 Some information on air quality should be available to represent all portions of the region.

The air quality surveillance network should consist of stations that are situated primarily to document the highest pollution levels in the region, to measure population exposure, to measure the pollution generated by specific classes of sources, and to record the nonurban levels of pollution Many stations will be capable of meeting more than one of these criteria, e.g. a station located in a densely populated area besides measuring population exposure could also monitor the effectiveness of controls on emissions from domestic space heating if such is part of the overall control strategy.

Although the sampler locations depend on many factors, some idea of sampler distribution may be obtained from Tables 2 and 3, which show sampler location as a function of network size. Table 2 summarizes distribution of mechanical samplers, such as Hi-Vols; Table 3 shows distribution of continuous samplers. With respect to locations shown in Tables 2 and 3 it will be necessary to consider wind patterns, source locations, and distribution of emissions in selecting approximate locations for these sites. For example, stations in the highly populated area should be so situated that they can accurately assess the pollution impact under different meteorological conditions. Although both types of stations follow the same general pattern, the tendency is for wider distribution of mechanical sampling stations.

Seemingly, the guidelines suggest that an independent network be developed for each pollutant under consideration. This is not necessary nor practical, especially with complex and expensive continuous samplers. It is likely that common sites, although not necessarily ideal for each pollutant, may be selected to provide adequate coverage for the pollutants of concern. Each pollutant, however, should be considered individually during the design phase to pinpoint pockets of high pollution that otherwise might be overlooked.

The final task in determining sampler placement is to find a specific location with the proper facilities for operating the sampler. Availability of space and power, accessibility, security, and representativeness of the

site should be ascertained for each chosen locale.

Sampling Frequency

The sampling frequencies for integrated devices and the averaging times for continuous devices are dictated by the ambient air quality standards. For example, if standards are set in terms of days, hours, or minutes, then the sampling frequency must be in days, hours, or minutes.

Although standards for TSP and SO_2 are typically prescribed in terms of annual averages and maximum daily concentrations, it is impractical to operate the entire network on a daily basis. Adequate coverage can be maintained with intermittent sampling at frequencies calculated statistically for desired levels of precision. Suggested sampling frequencies are presented in Table 4, which relates frequency of sampling to the degree of pollution, ranging from daily sampling in the highly polluted zones to once every sixth day in the nonurban zones. When sampling every sixth day there is greater chance of missing an occurence of slightly elevated pollution levels, but this risk is balanced by the lower probability of such an occurence in the nonurban areas. Twenty-four hour sampling should be consistent with calendar days, e.g. from midnight to midnight to allow comparison with standard meteorological summaries.

Sampling Site Characteristics

The preceding sections gave guidelines for the general distribution of sampling stations within a region. The selection of a particular site

for a single sampler or a complex station is equally important. It is essential that the sampler be situated to yield data representative of the location and not unduly influenced by the immediate surroundings. No definitive information is available concerning how air quality measurements are affected by the nearness of buildings, height from ground, and the like. We can, however, provide guidelines that should be considered in site selection:

1. Uniformity in height above ground level is desirable for the entire network within the region. Some exceptions may include canyons, high-rise apartments, and special-purpose samplers.
2. Constraints to air flow from any direction should be avoided by placing inlet probes away (at least 10 feet) from buildings or other obstructions. Inlet probes should be placed to avoid influence of convection currents.
3. The surrounding area should be free from stacks, chimneys, or other local emission points.
4. An elevation of 10 to 20 feet is suggested as the most suitable for representative sampling, especially in residential areas. Placement above 10 feet prevents most reintrainment of particulates, as well as the direct influence of automobile exhaust.

Methodology and Instrumentation

Information on types of instrumentation, their use, specificity, and associated costs is summarized in Table 5.

Development of instruments and techniques for sampling and analysis is progressing rapidly. Numerous instruments and techniques are now available for sampling and analysis. Standard methods are under development by the Air Pollution Control Office (APCO, formerly NAPCA) and the Intersociety Committee*. Until such standard methods are prescribed, the preferred methods of sampling and analyses are those for which a large body of data is available. Recommended reference methods are described in the Air Quality Criteria documents published by APCO. Acceptable methods for sampling and analysis are those that have been compared with standard or reference methods and have proved comparable in collection efficiency and in specificity. Whatever method is chosen, caution should be excercised before buying an instrument that has not been field tested or shown to be reliable.

Continuous production of valid data requires that instruments be properly maintained. This includes calibration prior to installation and on a routine basis thereafter. Most modern continuous instruments provide for automatic dynamic calibration at least daily. Dynamic calibration either by permeation devices or gaseous mixtures is preferred. Static calibration is subject to stoichiometric factors and does not take into account collection efficiency of the continuous sampling instrument.

LABORATORY OPERATIONS

Support of the surveillance networks will require laboratory operations ranging from very simple to highly complex. The requirements for laboratory

* Members societies are: Air Pollution Control Association, (APCA), American Council of Governmental Industrial Hygienists, (ACGIH), American Industrial Hygiene Association, (AIHA), American Public Health Association, (APHA), American Society of Mechanical Engineers, (ASME), American Society for Testing and Materials, (ASTM); and Association of Official Analytical Chemists, (AOAC)

support, in terms of size and complexity, will be specified by the pollutants of interest in the region, size of the networks, and the degree of pollution. The laboratory should be equipped for analyses of samples for at least TSP, SO_2, NO_2, and oxidant, and should provide for calibration of all collecting and measuring devices.

Some regions will require laboratory capability for analyses of lead, polycyclic organic matter, fluorides, and other pollutants. In large laboratories with requirements for a large number of analyses, automated laboratory procedures should be considered.

DATA ACQUISITION AND ANALYSIS

The ultimate success of a surveillance program depends on the utility of the data it produces. Utility implies that data be summarized in an appropriate format and be available when required. The design of a network must accompanied by design of a system of data acquisition and analysis that considers the flow of data and their use.

Design of data handling procedures, whether they be automated, manual, or both, will depend on the availability of a data acquisition system, network size, and time requirements for the data. Prevention of air pollution episodes requires that pertinent data be made available rapidly and in terms of hourly averages. For other activities the time delay may be of the order of weeks or months. Typically, data summaries would be made available within a month after the sampling period is completed. In-depth data

interpretation and complex data analyses require substantially longer periods of time and are needed less frequently. All data should be expressed in metric units reported preferably in the SAROAD format*.

To insure uniformity of data across the country and also to assist State and local agencies in data handling and analyses, APCO is pursuing development of a National Aerometric Data Information Service (NADIS). This service encompasses the operation of a National Aerometric Data Bank, the gathering of all aerometric data, and the provision for data dissemination in the form of summaries, computer software, and special analyses. Any data system design should consider the aims and requirements of NADIS so that the results from all surveillance operation are compatible.

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* SAROAD format - a standardized method used by APCO for handling aerometric data.

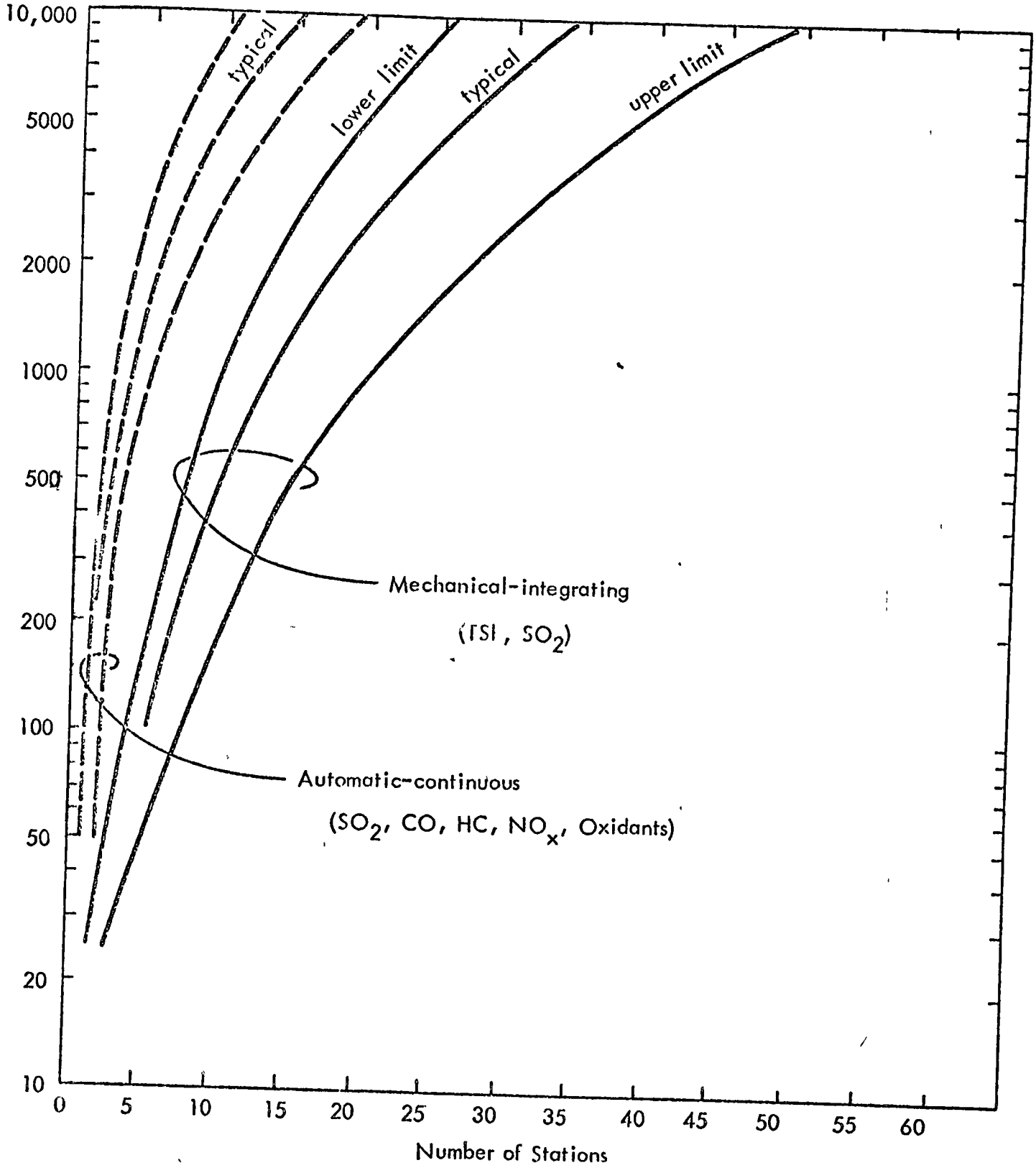


Figure 1. Number of stations versus region population.

Table 4. FREQUENCY OF SAMPLING BY INSTRUMENT TYPE WITHIN AREA

Type of Instrument	Frequency of Sampling: Areas above std.			Other urban areas				Nonurban areas			
	Con't.	Daily	Every third day	Con't	Daily	Every third day	Every sixt day	Con't.	Daily	Every third day	Every sixth day
Particulates											
Total suspended particulate[a]	M[b]		X	X			X				X
Lead	M		X	X			X				
Polycyclic organic matter	M		X	X			X				
Fluorides	M		X	X			X				X
Gases											
SO_2	M/A[c]	X	X	X			X				X
CO	A	X			X						
Total HC	A	X			X						
Non-methane HC	A	X[d]			X						
NO_2	M/A	X[c]	X	X			X				
NO_x	M/A	X	X	X			X				
Oxidant (O_3)	M/A	X[c]	X								

[a] Spot-tape samplers provide an indication of TSP on a less than 24-hour basis.

[b] M represents mechanized or integrated samplers.

[c] A represents automatic or continuous samplers.

[d] Where oxidant standards are based upon 3-hour (6-9 a.m.) measurements of HC and NO_x, the requisite data may be obtained from either continuous instruments or mechanized samplers.

Table 5. Classification of Air Pollution Sampling Techniques

Type	Use	Specificity	Common Averaging Time	Relative Cost	Required Training of Personnel	Remarks
MECHANIZED						
Hi-Vol	Integrated quantification	Total suspended particulate and multiple specific pollutants	24 hours	Moderate	Moderate	Detailed chemical analysis of Hi-Vol and gas samples requires sophisticated laboratory, trained chemists, and cost is high.
Gas Sampler	Integrated quantification of gas	SO_2, NO_2, total oxidants, etc.	24 hours	Moderate	High	
Spot Tape Sampler	Relative soiling index	Unknown	2 hours	Low	Low	Provides only a rough, relative index of particulate soiling.
AUTOMATIC						
Gas	Continuous analysis of gaseous pollutants	Single gas or group, of related gases	Continuous sample integration usually 1 - 15 months	Moderate to high	Moderate to high	Continuous measurements allow use of any desired averaging time by computation. Accuracy is generally better than other methods. Calibration is simplified. Data are available instantaneously.
Particulate: Soiling (Automatic tape)	Continuous analysis of soiling rate	Unknown	(Same as above)	Moderate	Moderate	

[a] Low - $0-$500; Moderate - $500-$2000, High - above $2000.

[b] Low requires common maintenance, Moderate requires a technician, High requires an experienced technician or professional with professional support staff.

CHAPTER I

AIR FLOW MEASUREMENTS

One of the most important parameters required for accurate air sampling and analysis is sample volume. However, convenient and reliable measurement of this parameter is one of the more difficult aspects of air sampling. This brief discussion is designed to touch on several of the more important aspects of air flow measurement so that the reader might have an idea of the complexities involved in determining air volumes and flow rates. Mathematical manipulations presented here will not necessarily be rigorous and will require some external study by the reader for a complete understanding. However, the points are presented in such a way that they will give the reader a practical basis on which to build a reasonable understanding of the principles involved.

The first portion of this chapter will deal with the fundamentals of air flow measurement. It will be assumed that the reader has some knowledge of fluid mechanics and is familiar with incompressible flow. The transition between incompressible (water) flow and compressible (air) flow is relatively painless and should cause few problems. After the fundamentals have been presented, a brief discussion of several of the major types of air flow measuring devices will be included.

Euler's Equation (one dimensional)

The one dimensional Euler's Equation takes the form

$$\frac{dP}{\rho} + VdV + gdz = 0 \qquad (1)$$

where P = pressure

ρ = density

V = gas velocity

g = gravitational constant

z = height above datum

For incompressible flow this equation is usually divided by g to give

$$\frac{dP}{\gamma} + \frac{V}{g}\,dV + dz = 0 \qquad (2)$$

where γ = specific weight (/g)

Integration of this equation yields

$$\frac{P}{\gamma} + \frac{V^2}{2g} + z = \text{Constant (termed total head)} \qquad (3)$$

which is one form of the more familiar Bernoilli's Equation.

For compressible flow, the term gdz is normally dropped since the weight of a compressible fluid is small, and the equation is written

$$\frac{dP}{\rho} + VdV = 0, \text{ or} \qquad (4)$$

$$\frac{dP}{\gamma} + V\frac{dV}{g} = 0 \qquad (5)$$

Integration of this form of the equation yields

$$\frac{V_2^2 - V_1^2}{2g} = \int_2^1 \frac{dP}{\delta} = \frac{P_1}{\gamma_1}\,\frac{K}{K-1}\left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{K-1}{K}}\right] \qquad (6)$$

since $P_1/\gamma_1^{\,K} = P_2/\gamma_2^{\,K}$

and K = the Adiabatic exponent (C_p/C_v)

Pitot Tube Equation

Equation 6 can be used in a slightly different form to demonstrate the relationship between stagnation pressure and air velocity. This is the principle that allows the pitot tube to be used to determine air velocity (see figure 1).

In a compressible system, the acoustical velocity (a) may be determined by:

$$a = \sqrt{KP/\rho} = \sqrt{gKP/\gamma}$$

Substitution into Equation 6 yields:

$$\frac{V_2^2}{a_1^2} = M_1^2 + \frac{2}{K-1}\left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{K-1}{K}}\right] \qquad (7)$$

where M = Mach number = $\frac{V_1}{a_1}$

At stagnation, $V_2 = 0$ and $P_2 = P_s$. Therefore:

$$\frac{P_s}{P_1} = \left[1 + M_1^2 \frac{K-1}{2}\right]^{\frac{K}{K-1}} \qquad (8)$$

Expansion by the binomial theorem yields

$$P_s = P_1 + 1/2\, \rho V_1^2 \left[1 + 1/4\, M^2 + \ldots\right. \qquad (9)$$

For low velocities (M very small) the latter terms in this expression are insignificant and the equation reduces to

$$V_1 = \sqrt{2\,\frac{P_s - P_1}{\rho}} \qquad (10)$$

Therefore, the difference between the stagnation pressure (P_s) and the system (ambient) pressure (P_1) as measured by a pitot tube can be used to determine the gas velocity at low speed (V 0.3 M) if the gas density is known. Thus the pitot tube which indicates the difference between stagnation pressure (velocity pressure) and static pressure can be used for velocity determinations.

Orifice Equation

The Euler's Equation may also be utilized to show the principles which make air flow measurements by orifice meters possible. From continuity:

$$\frac{dA}{A} + \frac{d\rho}{\rho} + \frac{dV}{V} = 0 \qquad (11)$$

A = area

This equation may be combined with the modified Euler equation:

$$\frac{dP}{\rho} + VdV = 0 \qquad (4)$$

Since acoustical velocity (celerity) = $a = \sqrt{\frac{dP}{d\rho}}$ (12)

it can be shown that

$$\frac{dA}{A} = \frac{dV}{V} \quad (M^2 - 1) \qquad (13)$$

Analysis of this equation shows that an interesting phemomenon occurs. For increasing velocity $\frac{dV}{V} > 0$ in subsonic flow ($M < 1$) a decrease in area is required to produce an increase in velocity. At sonic velocity, ($M = 1$), $\frac{dA}{A}$ must equal zero indicating that sonic flow in a compressive fluid will only occur at a minimum section (a throat) in a flow system. This is a very useful fact indeed

From the Euler Equation developed earlier:

$$\frac{V_2^2 - V_1^2}{2g} = \frac{P_1}{\gamma_1} \frac{K}{K-1} \left[\left(\frac{P_1}{P_2} \right)^{\frac{K-1}{K}} - 1 \right] \qquad (6)$$

and $$M_2 = \frac{V_2}{a_2} \quad , \quad a_2^2 = KgP_2/\gamma_2$$

it follows that:

$$M_2^2 = \frac{2}{K-1} \left[\left(\frac{P_1}{P_2} \right)^{\frac{K-1}{K}} - 1 \right] \qquad (14)$$

where subscript 1 refers to a point upstream of the orifice and subscript 2 refers to a point in the throat. Since velocity in a throat can never exceed acoustic velocity, a pressure difference greater than that required to produce acoustic velocity will not cause an increase in air flow rate above the acoustic flow rate. Substituting $M = 1$ into Equation 14 yields

$$\left(\frac{P_2}{P_1} \right)_{\text{acoustic}} = \left(\frac{2}{K+1} \right)^{\frac{K}{K-1}} \qquad (15)$$

For air (K = 1.4), equation 15 becomes:

$$\left(\frac{P_2}{P_1}\right)_{\text{acoustic}} = \left(\frac{2}{2.4}\right)^{\frac{2}{0.4}} = 0.53 \qquad (16)$$

Therefore, for a pressure ratio equal to or greater than 0.53 across a throat section, sonic flow will be produced. The mass flow (G) at sonic velocity will be

$$G = \frac{A_2 P_1}{\sqrt{T_1}} \sqrt{\frac{gK}{R}\left(\frac{2}{K+1}\right)^{\frac{K+1}{K-1}}} \qquad (17)$$

since $G = A_2 \rho_2 V_2$, (18)

$$V_2^2 = \frac{P_1}{\gamma_1}\,\frac{2gK}{K-1}\left[1 - \frac{P_2}{P_1}\right]^{\frac{K-1}{K}} , \qquad (19)$$

$$\frac{P_2}{P_1} = \left(\frac{2}{K+1}\right)^{\frac{K}{K-1}} \quad \text{at acoustical velocity,} \qquad (20)$$

and

$$\gamma_1 = \frac{P_1}{RT_1} \qquad (21)$$

where T = absolute temperature

R = universal gas constant

For slower throat velocities where the upstream velocity (V_1) cannot be ignored (i.e. orifice meters) and:

$$G = \frac{A_2}{\sqrt{1 - \left(\frac{P_2}{P_1}\right)^{2/K}\left(\frac{A_2}{A_1}\right)^2}} \sqrt{\frac{2gK}{K-1} P_1 \gamma_1 \left[\left(\frac{P_2}{P_1}\right)^{2/K} - \left(\frac{\rho_2}{\rho_1}\right)^{\frac{K+1}{K}}\right]} \qquad (22)$$

However, for convenience this expression is normally written

$$G = \frac{YA_2\gamma_1}{\sqrt{1 - \left(\frac{A_2}{A_1}\right)^2}} \sqrt{2g\left(\frac{P_1 - P_2}{\gamma_1}\right)} \qquad (23)$$

where Y is an expansion factor which describes the compressibility of the fluid. Y is a function of the three variables P_2/P_1, A_2/A_1, and K. Values of these parameters can be determined once for all for a given fluid and included in tables or graphs. (See Figure 2)

For incompressible flow the orifice equation reduces to

$$G = \frac{A_2\gamma_1}{\sqrt{1 - \left(\frac{A_2}{A_1}\right)^2}} \sqrt{2g\left(\frac{P_1 - P_2}{\gamma_1}\right)} \qquad (24)$$

or

$$Q = \frac{A_2}{\sqrt{1 - \left(\frac{A_2}{A_1}\right)^2}} \sqrt{2g\left(\frac{P_1 - P_2}{\gamma_1}\right)} \qquad (25)$$

and can be applied to water measurements.

Chapter II

AIR MEASURING INSTRUMENTS

A wide variety of devices is available to determine the size of sample collected for a given air contaminant analysis procedure. These devices include air quantity meters which measure air volume at a given temperature and pressure or the mass flow of air without regard to actual air volume and rate meters which monitor the air flow rate during the sample period. There are advantages and disadvantages

associated with each type of air metering device. In order to make a decision concerning which device will best meet the needs of a particular sampling problem, a basic understanding of the operation of the various types of instruments is required.

Basic Volumetric Samplers

Primary and secondary standard air flow measuring instruments are normally the air quantity type meters. These meters measure the total volume of air passing through them normally by some type of displacement method. The spirometer is a type of air volume meter which is normally used as a primary standard. The device consists of a counterbalanced cylinder which can be lowered into a water bath. As air flows into the cylinder, it displaces the water and the cylinder rises. The air volume is indicated on a calibrated scale by a pointer attached to the cylinder. After a calibration test, a valve may be opened to discharge the air collected in the cylinder, lowering it use again. Precise calibration of the scale on the spirometer is possible since the exact dimensions of the cylinder are known. The counterbalance system prevents significant pressure buildups which could cause errors in volumetric readings A diagram of a typical spirometer is shown in Figure 3. The devices range in size from several hundreds of cubic centimeters to several cubic feet capacity.

A less exotic calibration device is the water displacement bottle. These bottles may be used to estimate the volumetric flow of a gas by measuring the amount of liquid it replaces. Water or other suitable fluid may be drained from a bottle, so that the gas of interest is drawn in through the meter to be calibrated to displace the liquid removed. By measuring the amount of liquid removed or the rate of liquid removal, the flow rate or volume of air sampled may be determined. This procedure is quite sensitive to pressures and should not

be used in a situation where significant back pressures are developed. In addition, the water flow rate is not constant, but dependent on the hydraulic head so that accurate rate determinations are difficult.

Wet Test Meters

The wet test meter is a relatively accurate volumetric test device often used as a secondary standard. The accuracy of this type of device is usually claimed to be within one and one-half percent. The meter consists of a series of immersible compartments mounted radially around a shaft. As the shaft rotates, the compartments are filled or emptied, depending on their position in the meter. The entry and exit ports for air flow are located so that entering air displaces water in one of the completely submerged compartments thus causing rotation. Simultaneously, a counterpart compartment is immersed, expelling air through the exit port. The rotating shaft is connected to a clock-faced dial which records the amount of rotation. This dial meter is calibrated directly in cubic feet or liters for easy reading. Back pressures developed by such a device can range from several hundredths of an inch of water to several inches of water, depending on the size of the meter and the rate of air flow. A diagram of a typical wet test meter is shown in figure 4.

Dry Test Meters

The dry test meter is a volumetric air flow measuring device which consists of two or more compartments separated by moveable diaphragms which flex under pressure. By the judicious use of slide valves, incoming air is directed to a collapsed compartment. As the air flows into the compartment, the diaphragm moves, causing the compartment to expand. This movement in turn forces another diaphragm to collapse, expanding the air contained in that compartment. When a

compartment expands beyond a pre-determined point, the air flow is directed to a collapsed compartment. The movement of the diaphragms is used to drive a clock-face meter which reads directly in air volume units. The accuracy of the dry test meter is usually within two percent with head loss with back pressure levels in the one-tenth to several inches of water range. The dry test meter has several advantages over the wet test meter, which include:

1) smaller size and weight for a given flow capacity
2) greater flexibility since it can be used on soluble as well as insoluble gases
3) its resistance to corrosion since it does not contain water which would absorb acidic or caustic gases

The basic components of a dry test meter are shown in figure 5.

Mass Flow Meters

a. Rotameter

One of the most widely used types of air flow measuring devices is the rotameter. The rotameter consists of a tapered transparent tube containing a float. The float moves upward as the mass flow rate of the fluid through the tube increases. As the float rises, the annulus between the float and the tube walls increases, thus decreasing fluid velocity. At some point an equilibrium between buoyant forces, drag forces and the weight of the float is reached and the flow remains stationary. By careful control of the taper of the transparent tube the rate of change of the annulus can be designed to produce a uniform increase in float height as the fluid velocity increases. Thus the tube can be graduated linearly in volume units of fluid.

Figure 6 is a diagram of a rotameter showing the basic components. The forces acting on the float suspended in the tapered tube include:

1) the drag force (F_d) which can be determined by

$$F_d = \frac{CA_f \rho_g v^2}{2} \tag{26}$$

from Stokes' development of resistance to air flow;

2) the weight of the float which can be characterized by

$$F_f = V_f \rho_f g \quad , \qquad \text{and} \tag{27}$$

3) the small but perhaps significant buoyant force which may be characterized by

$$F_b = V_f \rho_g g. \tag{28}$$

where C = the drag coefficient (from Stokes' Law)

A_f = the projected area of the float

g = gravitational constant

ρ_g = gas density

ρ_f = float density

V_f = float volume

V = fluid velocity

The buoyant force and the drag force tend to hold the float up while the weight of the float tends to resist the movement of the float upward. At equilibrium the sum of the drag force plus the buoyant force will just equal the weight of the float. In these equations, all the terms are constant except a coefficient drag which is dependent upon the Reynolds number in the system. The density of the gas, which is dependent upon the pressure in the system, and the velocity of the gas which is dependent on the size of the annulus, the pressure of the system and the flow rate of gas. These equations can be combined to

give the typical rotameter equation

$$V_{air} = \frac{2V_f g(\rho_f - \rho_m)}{CA_{f\,m}}^{1/2} = \frac{Q_{air}}{A_A} \qquad (29)$$

where:

C is the drag coefficient for air flowing around the float and A_A is the annulus area of the meter.

It can be seen from this equation that the flow rate through the rotameter is a function of the area of the annulus (distance up the tube), the size of the float (which remains constant for any given tube), the size of the float (which remains constant for any given rotameter), and the density of the fluid flowing (since $_f - _a =$). Therefore, once a rotameter has been calibrated for a given fluid under typical flow conditions, the rotameter may be used as a direct measure of volume flow rate by simply observing the height of the float in the tube. If significant pressure, temperature or viscosity changes occur, these factors must be accounted for before the rotameter may be used in the given situation. Significant errors in flow rate can occur if corrections are not applied. For this reason, the rotameter should be placed near the beginning of a sampling train if at all possible, to minimize the pressure effect. Similarly, precautions should be taken to reduce viscosity and temperature effects when possible.

b. Orifice Meters

The orifice meter is often used as a primary standard. As indicated earlier, the flow, volumetric or mass, can be calculated precisely for a given orifice if the orifice characteristics and the pressure drop across the orifice are known. From equations 23 and 23 it is apparent that there is a logarithmic relationship between the

volume or mass flow rate and the pressure drop. Therefore, an orifice can be calibrated quite easily to give precise indications of fluid flow rates. Care must be taken to insure that the proper temperature, pressure and viscosity terms are used in the orifice equation since the flow is quite sensitive to these parameters. The expansion factor Y becomes important for high velocity (.3 Mach) and large constrictions. Tables and graphs containing precise values of the expansion factor are available.

c. Critical Orifice

As indicated earlier, when the pressure drop across an orifice reaches some critical point, the velocity through the orifice reaches acoustic velocity. Since acoustic velocity is the maximum velocity that can be reached in a non-expanding section, an increase in pressure drop will produce no further increase in air flow rate (see figure 6). Therefore, the critical orifice can be used as a flow device that is insensitive to upstream pressure or downstream vacuum. If the ratio of upstream pressure to downstream pressure exceeds .53, criticality is reached for a sharp-edged orifice. For larger pressure drops, no change in velocity will occur. These reliable and constant flow rate devices have found many uses in automatic sampling devices. They are easy to construct, durable and reliable.

Chapter III

AIR SAMPLING EQUIPMENT

A rapidly increasing variety of air sampling equipment is available for pollution determinations. This discussion will deal with the more basic types of equipment, the "old stand bys." Descriptions of the more complex and specialized types of equipment can be found in most equipment catalogs and manufacturers' literature

Glassware

Many types of glassware are used in sampling for atmospheric pollutants. These include impingers, bubblers, diffuser bottles, freeze-out traps and volumetric bulbs.

a. Impingers

Impingers are used for the collection of airborne particulate matter and gases. The impinger is a device which accelerates air flow through a nozzle and impinges the stream against a solid surface which is submerged in a scrubbing solution. Therefore, particles are removed partially by impaction and partially by entrapment in the liquid. The nozzle produces small bubbles, which allow increased contact area for the scrubbing of gases by the surrounding liquids, and the impaction allows particle inertia to separate the particulates from the air stream, increasing the probability of entrapment. There are several types of impingers in common use. The most common type is the midget impinger, which consists of a small tube with a volume of approximately 25 cubic centimeters and a nozzle .1 centimeter in diameter. The nozzle is placed 3-5 millimeters from the bottom of the tube which acts as an impinging surface. Ten to twenty-five millimeters of liquid are added to the impinger for collection of gases and particulates. A vacuum line is hooked to the outlet side of the impinger which creates negative pressure inside the flask. This pressure differential causes air flow to occur through the nozzle and through the absorbing solution. The device is designed to produce a flow of approximately 0.1 cfm under a 12-inch (H_2O) vacuum. However, this number should not be used as a method of volumetric measurement if at all possible. Small variations in nozzle size or tubing to the sampler and the pump can create significant changes in air flow at

a given pressure drop. Whenever possible, utilize volumetric flow devices to determine accurately the amount of air that has been sampled.

The Smith-Greenburger impinger is a much larger sampler with a volume of approximately 500 milliliters. A larger tube, equipped with an impaction target permanently affixed to the nozzle is employed. The principle of operation is the same as the midget impinger but higher air flows (up to 10 lpm) are possible. Several hundred milliliters scrubbing solution are added to the impinger and flow is produced by creating a negative pressure on the outlet side of the impinger. The Smith-Greenburger is normally used for gas scrubbing only since particulate collection and such a large volume of scrubbing fluid would make the sample unwieldy.

b. Bubblers and Diffuser Bottles

For certain applications, bubblers and diffuser bottles have been produced by modifying the midget or Smith-Greenburger type impingers. The modifications usually involve the addition of a frit to the end of the inlet tube of the scrubbing device and a change in the collecting tube shape. The purpose of this frit is to break the air stream into a large number of small bubbles, thus increasing the surface area of contact and the efficiency of pollutant collection. A wide variety of frits is available, ranging from very fine with a high pressure drop, to relatively coarse with almost no pressure drop. The choice of frit must be based on desired collection efficiency, the pressure drop and the amount of particulate matter in the gas to be collected.

Many special bubbler designs have been marketed in the last few years. Basically, these designs have been produced to maximize contact time and minimize scrubbing liquid volume (see figure 9). Consult test manuals for the type of design most appropriate for particular tests.

Open tube bubblers may also be used in situations where high sample volumes are required. These devices normally consist of large collecting tubes and open-ended air tubes which are submerged in the scrubbing liquid. These tubes (often 1 cm in diameter) produce large bubbles. However, at high flow rates these bubbles are broken effectively and good scrubbing efficiency can be achieved. Flow rates of 0.75 cfm are recommended.

c. Freeze-Out Traps

An effective but rather cumbersome method for sampling many atmospheric contaminants is through the use of freeze-out traps. These traps are essentially U tubes packed with a loose material such as glass wool, which are immersed into a refrigerant liquid such as acetone and dry ice. Some common freeze-out refrigerants and approximate temperature reached in the U tubes immersed in these liquids are listed below:

Refrigerant	Temperature
Ice	0°
Acetone & Dry Ice	-75°
Liquid Air	-147°
Liquid Oxygen	-183°
Liquid Nitrogen	-196°

Low flow rates (less than 1-2 liters per minute) are required for good efficiency. For high precision work, sample rates of 10ml per minute may be necessary. After collection, the condensed pollutant must be placed in a high pressure flask or other suitable container for transport to the laboratory for analysis. Sample clean up and analysis procedures will dictate the type of storage container to be used. Gases such as carbon dioxide and hydrocarbons can easily be sampled by this method. Strict sample collection and storage techniques must be followed to provide reproducible results.

Filtration Equipment

The most obvious way by which particulate material might be removed from an airstream is through the process of filtration. However, filtration is a much more complex process than the simple opening or sieving action that one would intuitively expect. Filtration is actually a combination of several processes which act together to produce relatively high efficiency of particle capture even when the openings in the filter media itself may be much larger than the particles captured.

Filters can be used for sampling large volumes of air at relatively high flow rates. Filtering apparatus are relatively inexpensive and easy to operate. The sampling procedure itself is easily understandable and adaptable and may be run effectively by careful technicians. Filters are available to meet a variety of criteria, including air temperature, allowable pressure drop, desired flow rate, required efficiency and necessary reproducibility. Filter media, however, cannot be handled excessively without damage or loss of sample.

Another disadvantage of filtration is that this method cannot be used as a size-segregating technique. Filter media normally do not have a sharp cut-off in sampling efficiency, i.e. a filter media will collect a wide size range of particulate materials with varying efficiencies so that a small number of large particles and a larger number of small particles may pass the filter media. In addition, there may be significant differences in the collection characteristics of filter media of the same type and even the same lot. These quality control problems can be minimized by a careful selection of manufacturer and filter type but the filter differences cannot be completely eliminated.

As one might expect, the extremely high efficiency filters require large pressure drops to insure reasonable air flow rates through the medium. Therefore, for high efficiency work, small samples must be utilized and these small samples can contribute to analytical problems associated with microsamples.

Basically, there are five processes which occur during filtration. These processes include a) sieving and direct interception; b) diffusional impaction; c) inertial impaction; d)gravitational impact; and e) electrical attraction. Each of these mechanisms plays a part in the removal of some portion of the particulate matter contained in the airstream flowing through a given filter medium. Therefore, they should be discussed separately before an overall view of filter collection can be stated.

a) Sieving and Direction Interception

Sieving occurs when the particle of interest has at least one dimension larger than the smallest opening in the filter material.

Sieving is important for large particles but is not normally the collection process of most importance. Direct interception occurs if particles smaller than the openings of the filter media are contained in an airstream flowing near enough to a collection surface to allow contact between the particle and the surface. Thus, if an airstream comes within a particle radius of a surface, the particle will be collected by interception. It is assumed that if any such contact is made, the particle will be removed from the airstream and remain in the filter medium. As velocity through a filter medium increases, the minimum distances between the collecting surfaces and the airstreams are decreased, so direct interception can increase slightly with airstream velocity if reentrainment is insignificant.

b) Diffusion

Diffusion occurs when there is a concentration gradient across any continuous medium. In the case of gases, the concentration gradient is caused by differences in the number of gas molecules in one portion of the system than in another portion of the system. In the case of particulate matter, the gradient results because the particulate concentration in the flowing gas near the surface is greater than the particulate concentration in the gas layer near the collection surfaces within the filter. Therefore, as a particulate-laden airstream flows through a filter, a concentration gradient exists between the pollutant-containing airstream and the relatively clean filter surface. A net movement of particles from the heavily-polluted airstream toward the filter surface occurs, resulting in removal of these particles from the gas stream. Diffusion is only effective for relatively small particles which do not have enough inertia to resist the random bombardment of gaseous molecules. Therefore,

diffusional processes are important only for the sub-micron particles. Normally, it is assumed that diffusional processes become unimportant for particles greater than two-tenths of a micron in diameter. The amount of diffusion which occurs will, of course, depend upon the residence time in the filter, the gas temperatures and concentration of gradient, the air velocity and the air viscosity. Diffusion is most important in filter media made of thick mats of material which rely on extensive residence time within the filter, and becomes significant at low flow rates.

c) Inertial Collection

Inertial collection is probably the most important mechanism occuring in an filter system. As the airstreams meander through the pathways provided by the filter media, the air is required to make many turns and bends. Particles contained in this airstream will have some inertia and tend to resist changes in direction. Therefore, as the airstream bends, the particles tend to leave the airstream and impact on the surfaces causing the bends. Again it is normally assumed that any particle which impacts will remain on the surface and will not be re-entrained. As the velocity of the airstream increases, the inertia forces also increase, causing sharper deviation from the airstream by the particles. Inertial collection efficiency increases with increased velocity through the filter media. However, care must be taken to prevent re-entrainment of the particles or actual distortion of the filter media itself. Therefore, there is a maximum velocity for a given filter system which cannot be exceeded without decreasing efficiency.

Inertial collection is most effective for larger particles with high mass and therefore high inertia. For this reason, particles

less than two or three microns in diameter cannot be collected with high efficiency by this mechanism. It is often assumed that particles smaller than .2 micron in diameter will not be collected by inertial means.

d) Electrical Efficiency

As a particle is moved through the air and as air is moved through a filter medium, electrical charges are generated. Oftentimes the airborne particles will receive a charge opposite to the charge of the filter and will be attracted to the filter surface by the relatively weak electrical forces. These types of forces tend to augment the diffusional impaction forces and increase efficiency of removal of small particles in the airstream. Even though this effect is real and significant in some situations, it should not be relied on to significantly increase efficiency under all circumstances. It is most effective in a situation in which low resistivity particles such as carbon are present in extremely dry atmospheres. In these cases electrical forces that are generated can be of importance. In other cases, however, these forces may play a very minor role in a filtration process.

e) Gravitational Forces

In general, gravitational forces have almost no effect in a typical filter system. There are cases where gravitational forces are relied on. These include very thick, sandbed filters, and very large mat filters where slow air velocities are utilized. In general, gravitational settling within the filter has relatively little effect on the overall collection efficiency.

If the overall collection efficiency of a filter system is plotted against face velocity or air velocity through the filter, a series of curves similar to those found in Figure 9 will result. It is evident that there is a point of minimum efficiency for a given filter system because of the contrasting relationship between face velocity and inertial collection and face velocity and diffusion collection. For this reason, care must be taken to insure that the particular filter system is operated in an area removed from this zone of minimum efficiency.

Filter Media

A wide variety of filter media are available for air sampling and analysis. These include cellulose filters, glass filters, plastic filters, membrane filters, mat filters, fabric filters and ceramic filters.

Cellulose

Cellulose or paper filters are useful in analysis where the filter material itself must be destroyed. Cellulose fibers can be digested completely in strong acid solutions and many types may be ashed at high temperatures, leaving little residue. These filters cannot be used under sampling conditions of extremely high temperature or in situations where condensation of water vapor may occur. In analysis, care must be taken to account for the binders that may be used to provide tensile strength and wear resistance. These binder materials are usually organic in nature and could affect the chemical analyses performed on the collected particulate materials. In general, cellulose fiber filters are slightly less efficient than glass fiber filters under the same pressure drop regime.

Finely-spun glass fiber is used to produce filter materials. These filters are quite popular for air sampling use. They are relatively inexpensive and efficient because of mat-type filter system which is produced when the fibers are compressed. These fibers are available with organic binder and without. If the filter is used without the binder, care must be taken in handling the filter to prevent the formation of openings in the filter surface thus rendering the filter inefficient. The glass fiber filters are brittle in general and must be handled carefully. Any bend or break in the fiber will open "short cuts" through the filter where much of the air will flow with little removal efficiency. These fibers cannot easily be destroyed by acids or high temperatures. Also, particles collected may be imbedded deep within the filter and unavailable for efficient radioactive counting or microscopic analysis. For this reason, the glass fiber paper may not be useful for many analytical tests that are available to identify various components of an aerosol sample. The glass fiber filter is most often used for the total mass measurement of an air sample and not for samples destined to be analyzed for components.

Membrane Filters

Cellulose esters (usually cellulose acetate) are often used as a filter medium. The filters are actually cast on an extremely smooth surface and exposed to a controlled air sphere which determines the dry characteristics of the acetate and therefore the pore structure of the media. The thin membranes which result have a uniform pore size and therefore can be used for sampling of airborne particles. By choosing the proper pore size, the head loss vs. efficiency relationship can be approached for the job at hand. Particles collected by

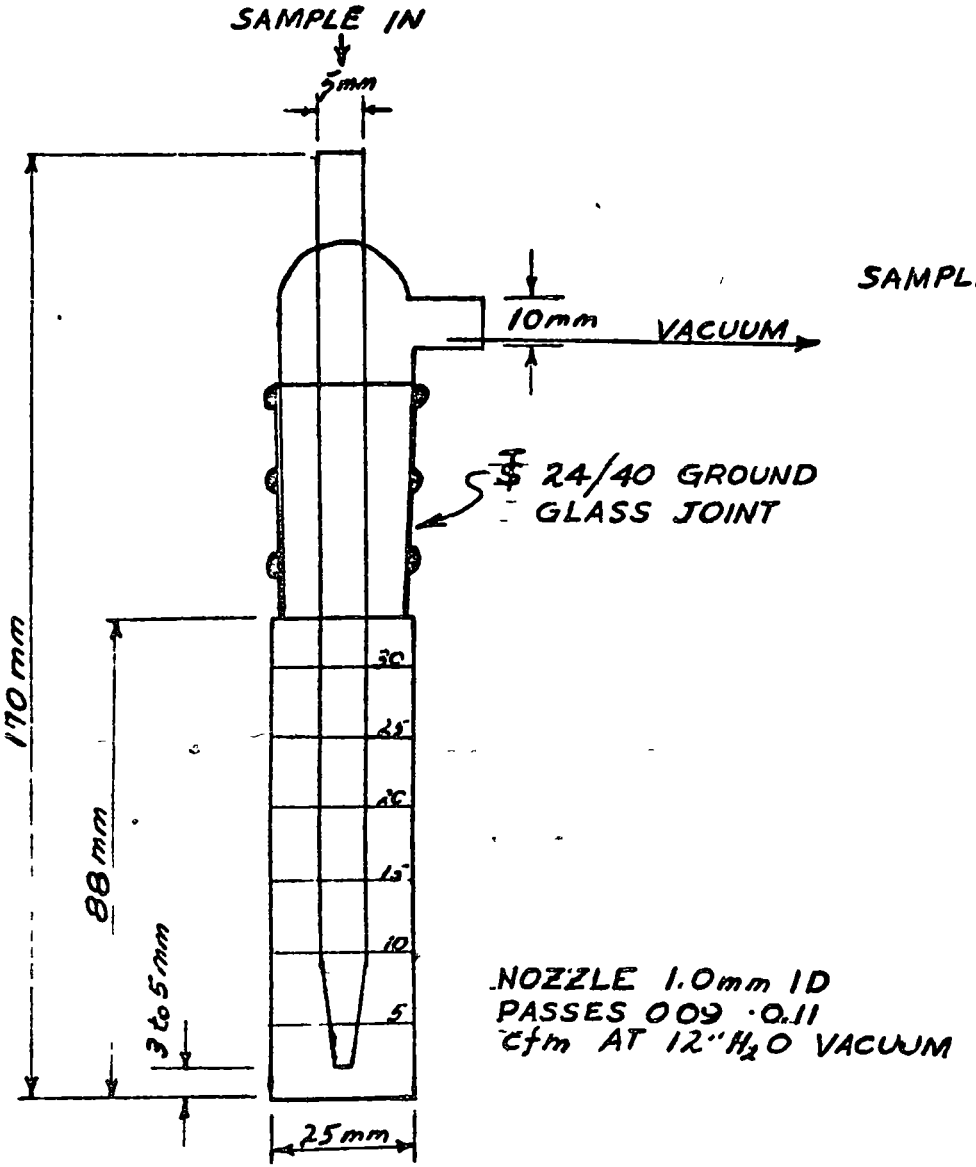
these filters are much smaller than the normal pore size given. This is probably because electrical and diffusional effects are quite important in filter systems of this type. In addition, the pores through the filter are not straight and present a tortuous path for the air flow, thus increasing the probability of collection by inertial impaction. These filters are noted for the high headloss required to move air through the system. Therefore, they cannot be used where large sample volumes are required. In addition, filters are expensive enough to prohibit the use of large filter areas to obtain good sample volumes. In general, membrane filters greater than 5 centimeters in diameter are rare.

The particles collected by membrane filters tend to build up on the surface, but some inertial collection occurs and particles are impacted within the filter media. The filter samples can be used for direct microscopic analysis and radiation counting since the majority of the particles collected are on the surface. If the filter is emerged in an oil with an index of refraction similar to the filter material, the filter will become transparent to light, making it even more attractive for microscopic analysis. Alternately, the acetate may be dissolved by the addition of cyclohexanol or equivalent solvent, thus producing a transparent specimen for microscopic analysis.

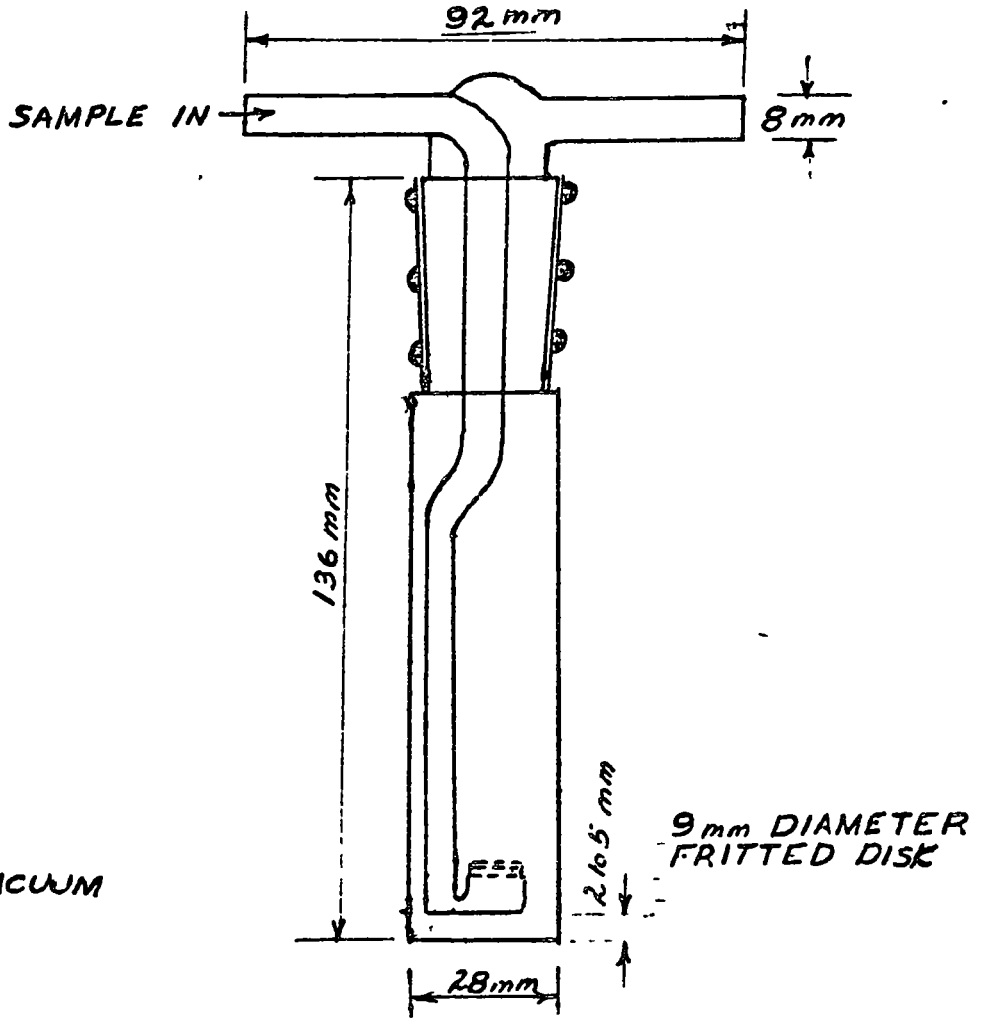
Specialty Filters

Ceramic and fabric filters are available for particular sampling situations. In general, ceramic filters are used where high efficiency is not required and where high temperatures or corrosive conditions exist. These filters are difficult to clean and expensive but are quite useful when the circumstances require resistant materials.

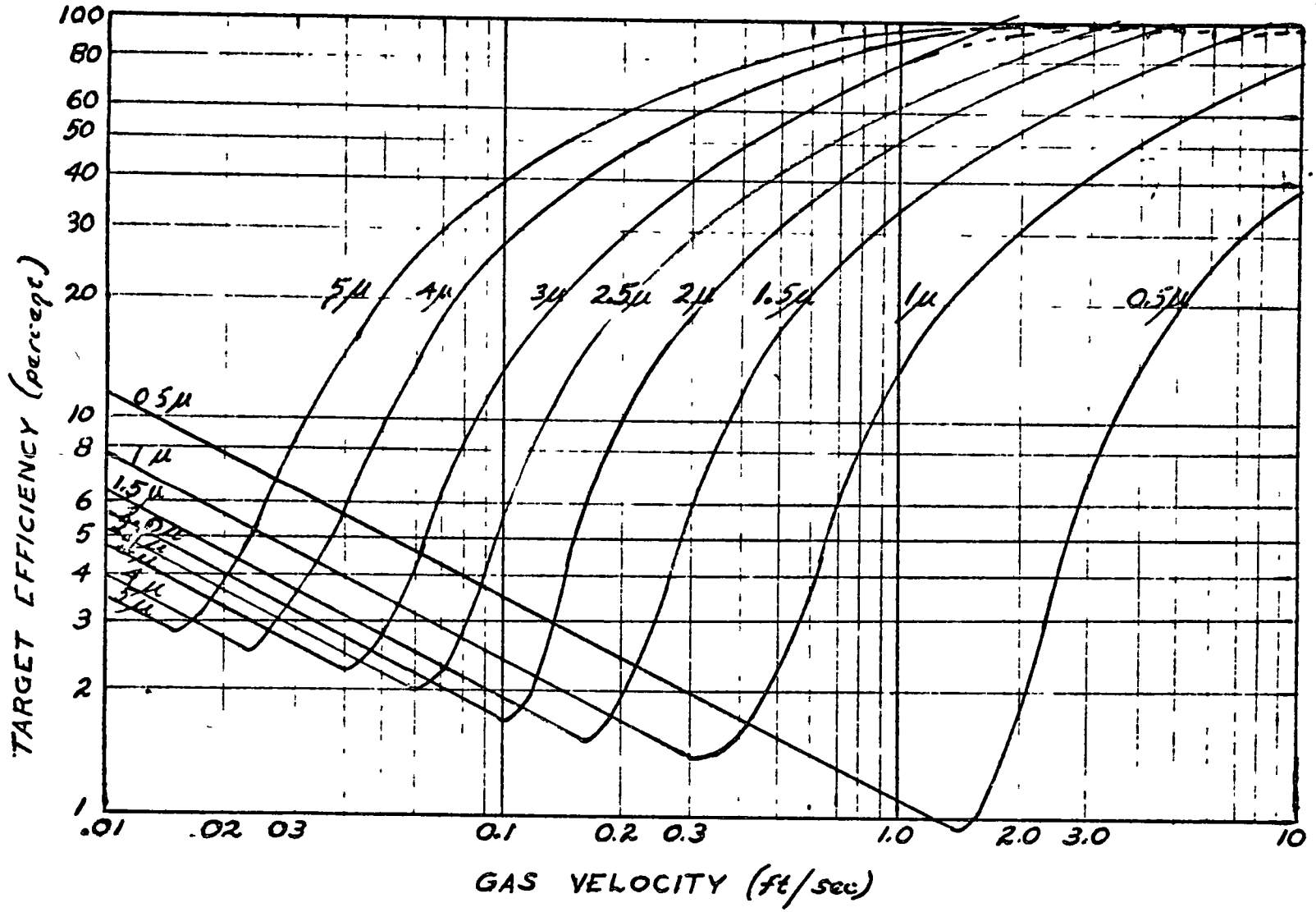
Fabric filters such as cotton fibers, wools and felts can also be used for high efficiency collection. These filters have a high head-loss since they rely upon a thick mat for collection. Face velocities on these filters are usually relatively low providing for long residence time within the filter.



All Glass Midget Impinger



All Glass Midget Bubbler
(fritted disk diffuser)



Target Efficiencies at Various Air Velocities for

Different Diameter Particles

(ρ_p = 2.0 g/cc - Fiber Diameter 10μ)

High Volume Sampling

One of the most widely used and perhaps misused air sampling methods is the determination of suspended particulate matter by the high volume sampler. This test is performed by passing large volumes of air through an 8" x 10" fiberglass mat type filter with a vacuum-cleaner type suction pump. Flow rates of 50-65 cubic feet per minute (1.6 to 2.0 cubic meters per minute) and sampling periods ranging from 3 hours to 24 hours are used. The large volumes of air sampled by this test produce a significant mass of particulate matter and reduce the effect of small errors such as weight loss due to filter handling, variations in flow rates due to voltage fluctuations, and inaccuracies in weighing techniques. In theory, the high volume sampling method should be an excellent test procedure for determining atmospheric particulate loadings. However care must be taken in using this method to insure reliable results.

The following procedure should be used to minimize inaccuracies in the high volume sampling method:

a) Determine the initial weight of an equilibrated (allowed to reach room conditions by 4-24 hours exposure) 8" x 10" glass fiber filter. A special balance platform should be used so that the filter to be weighed need not be bent or folded. Folding or creasing of fiberglass pads break the fibers and produce large openings in the mat, rendering the filter inefficient. An analytical balance capable of weighing to 1/10,000 of a gram should be used if possible. After weighing, place the filter in a high volume sampler located in an open area. An open area may be defined as one which has no man-made or natural topographical features which will interfere with normal air movements. As a rule of thumb, an area is considered open if you can raise your arm to a 30^{o} angle and sight along your arm as you rotate 360^{o} without your line of sight intersecting any tree, building, hill, etc.

The high volume sampler should be equipped with a shelter designed to prevent the entrance of large particulates. Since the high volume test is designed to determine suspended particulates, larger short-residence time particulates included in the sample will significantly bias the results. If

a sheltered sampler is not available, open-faced samplers may be taken. However, the particulate levels obtained may be considerably larger than the levels that can be obtained with a sheltered sampler and this fact should be reported with the results.

b) The sampler should be run for a minimum of 3 hours and a maximum of 24 hours in excess of 50 cfm. The volume filter should be sufficient to yield the weight of at least 30 units in the last digit recorded by the weighing apparatus. This would require the collection of at least 3 milligrams of particulate if a .0001 gram analytical balance is used. The flow rate should be noted at the beginning and ending of the sampling period and the average flow taken as the mean. Normally the flow rate will not vary more than 5 to 10% during the sampling period due to the buildup of particulates on the filter surface. If variations are less than 10%, exotic averaging schemes are probably not worthwhile. However, if excessive flow rate changes have occurred, some method should be used to determine the actual flow rate during the sampling period.

c) After the sample is obtained, the filter mat should be carefully removed from the holder, placed in an envelope and returned to the laboratory. In order to preserve the sample, it is best to fold the filter pad along the long axis before inserting it into the envelope. In the lab the filter should again be equilibrated from 4 to 24 hours in the same environment and reweighed to determine the weight gain.

d) The suspended particulate loading of the atmosphere can be calculated by dividing the total mass of particulate matter collected by the total air volume sampled. The particulate level should be reported with the micron grams per cubic meter of air at standard conditions (70° F, 29.92 inches of mercury).

In some cases, sections of the filter are used to determine the magnitude of various components of the suspended particulates. These tests include the determination of the magnitude of the benzene soluble fractions, the suspended nitrates, suspended sulfates, cyclic hydrocarbons, and heavy metals including lead, copper, zinc, etc. It is normally assumed that the particulates collected

will be uniformly distributed all over the entire filter surface so that any strip or section of the filter surface will be representative of the entire filter sample. Past data indicates that this is a valid assumption.

There are several problems associated with the high volume sampling method which should be emphasized:

a) The location of the sampler is extremely important. If a sampler is near the ground surface in an area where dusty conditions exist, the exhaust from the motor can impinge on the ground surface in such a way as to stir up a large amount of dust which can be collected on the filter.

b) Circulation cells can be set up under low wind conditions, allowing the same air to be filtered several times.

c) Large errors can result if the filter is located at a higher elevation, such as the roof of a building. The particulate loading sampled can be quite different from the particulate loading near the ground surface where most activity occurs that generates suspended particulates. Therefore, particulate samples collected in a city which requires rooftop sampling may yield much lower results than particulate samples at street level in a city with suspended particulate loading.

d) A sampler placed in an area where considerable activity occurs will produce results much different than the sampler placed away from normal traffic patterns. Thus the choice of high-volume filtering site becomes extremely important. The location of the filtering site should be chosen with care to insure that the sample is not biased by close proximity to particular sources which emit large volumes of particulate matter, or by amount of activity very near the sampling site. It should be a measure of ambient conditions, not a source monitor.

The high volume sampling test has become routine and is accepted by almost all air pollution control agencies as a standard test. However, in many cases the sampling techniques used and the equipment used are by no means standard and the results should not be considered comparable. Tests to determine

the reproducibility and comparability of high volume sampling tests indicate that differences as great as 10% should be considered reasonable. Therefore, caution is the watchword while conducting the high volume sampling and interpreting or comparing the results obtained.

A second type of filter sample often used as a measure of air pollution levels is the spot sample. This type of sample is taken by pulling air through a small spot, usually one-half inch in diameter, on a filter paper tape. This tape is automatically advanced at one or two hour intervals by a timer switch connected to a drive motor. Therefore, a large number of samples will be taken automatically without att tion by technicians. The particulate loading of the atmosphere sampled is determined not by weighing but rather by measuring the reduction in light transmission caused by the material collected on the spot. This measurement is accomplished by shining light from a known source through the spot to a photocell and observing the amount of light attenuation. The normal unit of measure for spot sample information is the Coefficient of Haze Unit or COH's. The data is usually reported in COH's for 1,000 linear feet of sample. The number of linear feet of the sample is determined by dividing the volume of air sample by the area of the spot. The number of COH Units for a given sample may be calculated by:

$$\text{COH's} = \frac{100 \times \text{optical density}}{\text{sample length}}$$

$$\text{Optical Density} = \ln \frac{I_0}{I} = \text{logarithm of the ratio of the original light intensity to the attenuable intensity}$$

COH Units greater than one-tenth per thousand feet are considered indicative of a clean atmosphere. Readings greater than one COH per thousand feet of sample indicate relatively dirty atmospheres.

There are some disadvantages to this test which make it subject to considerable question. Different types of materials will scatter light in different ways, causing wide variations in COH Units for given aerosol concentrations. In fact, very oily particles can affect the index of refraction of filter paper in such a way as to actually increase light transmission rather than decrease it, thus rendering the test useless.

In addition, particle size, shape and refractive index cause marked variations in the relationship between particulate mass and light attenuation. The test is used mainly because it is inexpensive to obtain data and it is quick and easy to perform.

The results can be used as indications of air pollution levels rather than actual measures of the dirtiness of the atmosphere. Attempts to correlate spot sample data with high volume data from several locations affected by different pollutant sources have not produced usable results.

The paper tape sampler can be modified especially by using tapes impregnated with certain reactive compounds that will give an indication of the concentration of a given class of air pollutants. For example, paper tapes impregnated with dilute solutions of lead acetate can be used to estimate the average hydrogen sulfide content of the air sampled. Paper impregnated with a lime solution will react with fluorine present in the air and indicate the average fluorine content. These types of tests are semi-quantitative at best and should not be used as precise measures of air pollution levels. These are indicator techniques and suffer from lack of sensitivity, varying degrees of efficiency and a low response time requiring lone sampling periods. On the other hand, these tests are simple to run, easy to analyze and inexpensive to obtain. Therefore, they are usable for routine air monitoring and may provide useful information to local network sampling systems.

GEORGE KIMURA

METHODS FOR DETERMINATION OF VELOCITY, VOLUME, DUST AND MIST CONTENT OF GASES

BULLETIN WP–50

SIXTH EDITION

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PREFACE

In order to determine the performance of an existing gas handling or gas cleaning system, to evaluate the necessity of installing a cleaning system, or to obtain information for the design of a cleaning system, it is necessary or desirable to obtain a measure of the concentration and character of the dust in the gas stream, and accurate data regarding the temperature, velocity, and volume of the gas stream itself

The purpose of this bulletin is to outline a standard method of procedure for the study of gas streams contained in industrial flue systems, and of the suspended matter (suspensoids) carried by these gases. In addition, various other methods are mentioned, as no one procedure is applicable to all situations Many industrial processes are of such a specialized nature that it is necessary to start with some such standard procedure as described herein, and alter it to develop a procedure to suit the individual conditions.

NOMENCLATURE

a =Area of nozzle in square inches.

A =Effective area of flue in square feet.

CF =Cubic feet

CFM=Cubic feet per minute

D =Diameter of flue in inches

d =Diameter of sampling nozzle in inches.

F_d =Orifice disc factor

F_s =Pitot tube correction factor.

g =Acceleration due to gravity in feet per second per second.

G_d =Specific gravity of gas referred to that of air

h =Velocity head in equivalent feet of gas column in the flue.

H =Velocity head draft gauge reading in equivalent inches of water.

Hg =Mercury

M_c =Meter rate correction factor

M_m =Volume of moisture remaining in metered gas at meter conditions in cubic feet.

P_a =Absolute pressure in inches mercury.

P_b =Barometric pressure in inches mercury

P_m =Suction at meter in inches mercury.

P_s =Absolute pressure in flue in inches mercury

R_m =Meter rate in CFM (dependent on velocity of gas in flue and size of nozzle).

T =Duration of test in hours.

T_m =Temperature at meter in degrees absolute

T_s =Flue gas temperature in degrees absolute

W_t =Weight of dust separated from gas sample in grams.

V_m =Volume of gas sample as measured by the gas meter in CFM at meter conditions.

V_o =Volume of flue gas in CFM at flue conditions

V.P. =Vapor pressure of water in inches of mercury.

V_s =Flue gas velocity at some given point in feet per second.

V_t =Total gas sampled converted to flue conditions in CF.

V_v =Volume of water vapor condensed in cubic feet converted to meter conditions (vapor state).

V_w =Volume of water condensed in cubic centimeters (liquid state).

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FORMULAS

(1) BASIC FLOW EQUATION

$$V_s = \sqrt{2gh}$$

(2) GAS VELOCITY IN FLUE—Using standard Pitot tube

Assume gas density equivalent to air, and flue pressure equal to one atmosphere.

For temperature in °F absolute

$$V_s = 2\,90\ \sqrt{HT_s}$$

For temperature in °C absolute

$$V_s = 3.90\ \sqrt{HT_s}$$

(3) GAS VELOCITY IN FLUE—Using standard Pitot tube

For temperature in °F absolute

$$V_s = 2\,90\ \sqrt{\frac{29\,92}{P_s} \times \frac{1\,00}{G_d} \times HT_s}$$

For temperature in °C absolute

$$V_s = 3.90\ \sqrt{\frac{29\,92}{P_s} \times \frac{1\,00}{G_d} \times HT_s}$$

(4) GAS VELOCITY IN FLUE—Using Type "S" Pitot tube

Assume gas specific gravity equivalent to air, and flue pressure equal to one atmosphere.

For temperature in °F absolute

$$V_s = 2\,90\ F_s\ \sqrt{HT_s}$$

For temperature in °C absolute

$$V_s = 3\,90\ F_s\ \sqrt{HT_s}$$

For Pitot tube as shown in Figure 5, $F_s = 0.83$

(5) GAS VELOCITY IN FLUE—Using orifice disc meter

Assume gas specific gravity equivalent to air, and flue pressure equal to one atmosphere.

For temperature in °F absolute

$$V_s = 2\,90\ F_d\ \sqrt{HT_s}$$

For temperature in °C absolute

$$V_s = 3\,90\ F_d\ \sqrt{HT_s}$$

For orifice as described in Figure 6, values of F_d can be obtained from Figure 7.

(6) GAS VOLUME IN FLUE

$$V_o = V_{s\ avg} \times A \times 60$$

(7) CONVERSION OF FLUE GAS VOLUME TO STANDARD CONDITIONS OF 29.92 INCHES MERCURY PRESSURE AND 0° CENTIGRADE (32° FAHRENHEIT)

For temperature in °F absolute

$$V\ std = V_o \times \frac{P_s}{29.92} \times \frac{492}{T_s}$$

For temperature in °C absolute

$$V\ std = V_o \times \frac{P_s}{29.92} \times \frac{273}{T_s}$$

(8) METER RATE—Dry gas—Isokinetic sampling

$$R_m = 0\,33 \times \frac{T_m}{T_s} \times V_s \times d^2 \times \frac{P_s}{P_b - P_m}$$

(9) CONVERTING CONDENSATE TO VAPOR VOLUME—Meter conditions

For temperature in °F absolute

$$V_v = 0\,00267 \times \frac{V_w \times T_m}{P_b - P_m}$$

(10) CONDENSATE CORRECTION FACTOR FOR METER RATE

$$M_c = \frac{V_m}{V_m + V_v}$$

Corrected $R_m = R_m \times M_c$

(11) MOISTURE IN METERED GAS AT METER CONDITIONS

$$M_m = \frac{V.P \times V_m}{P_b - P_m}$$

V P.=vapor pressure of water at meter temperature

(12) PER CENT MOISTURE BY VOLUME IN FLUE GAS

$$\% \text{ Moisture} = \frac{V_v + M_m}{V_v + V_m} \times 100$$

(13) CONVERTING SAMPLED VOLUME TO FLUE CONDITIONS

$$V_t = (V_m + V_v)\frac{T_s}{T_m} \times \frac{P_b - P_m}{P_s}$$

(14) GAS SPECIFIC GRAVITY FROM CHEMICAL COMPOSITION—Referred to air

Gas Density=(%A×M W ofA)+(%B×M W.ofB) + ... (%Z×M W.ofZ)/28 95

(15) CALCULATION OF PER CENT MOISTURE FROM RELATIVE HUMIDITY

$$\% \text{ Moisture by volume} = \frac{\text{V P.} \times \%\text{Rel. Humidity}}{P_s}$$

V P.=vapor pressure of water at flue temperature

Example

Wet bulb=128°F

Dry bulb=210°F

Relative humidity from psychrometric chart=12.5%

Water vapor pressure at 210°F=28 75" Hg

Vapor pressure at 12.5% relative humidity=28 75× 125=3 59" Hg

Pressure in flue=27 8" Hg

$$\% \text{ Moisture by volume} = \frac{3\ 59}{27\ 8} = 13.0\%$$

(16) CALCULATION OF DUST LOADING FROM BALANCED TUBE METHOD DATA

$$\text{Pounds per hour} = 0.318 \times \frac{A \times W_t}{a \times T}$$

SECTION ONE

DETERMINATION OF VELOCITY AND VOLUME OF GASES

Where existing flues or ducts are concerned, it is necessary to determine the velocity and temperature of the gas stream in order to determine the volume carried by the flue *

In making dust determination, it is necessary that we have a knowledge of both the "carrier gas," that is the air or gas that is transporting the suspensoid, and the suspensoid, which may be a dust, fume or mist

Since the volume of gas passing any given cross-section of a flue is the product of the average velocity of that gas and the area of the cross-section, the determination of the gas volume involves measuring the area of cross-section and determining the average velocity of the gas

VELOCITY DETERMINATION

The velocity of the gas is usually determined by means of a Pitot tube and differential pressure gauge Where velocities are very low (less than 10 feet per second) and where great accuracy is not required, an anemometer may be used For gases moving in small pipes at relatively high velocities or pressures, orifice disc meters or venturi meters may be used and are valuable as continuous or permanent measuring devices Where no gas measuring instruments are available, the gas volume sometimes may be roughly approximated by calculation based on stoichiometric relations, especially in connection with operations involving combustion

CHOICE OF STATION

In choosing the location for the measuring of volumes, two things should be kept in mind First, the necessity of making the velocity determination at a point or cross-section where the gas flow is as uniform as possible, and second, the convenience of setting up the testing equipment

In order to insure a uniform gas flow, it is desirable to choose the point of test in a straight section of the flue, away from bends, or other points of disturbance of gas flow A distance equal to eight times the inside diameter of the flue is usually taken as sufficient to overcome any such disturbing effects, but a preliminary survey should be made with the Pitot tube to determine fluctuations in velocity

Having decided on the sampling location, the cross-section of the flue is laid out in a number of equal areas, the center of each area being the point where the measurement is to be taken. It should be the aim to make the number of areas large enough to insure a reasonably accurate measurement of the average velocity over the entire cross-section At the same time, it should be remembered that where there is a large fluctuation in the velocity at any one point from time to time, it is better to make many observations at a few points than a few observations at many points Table No 1, Equal Area Zones for Round Flues, is given in the Appendix

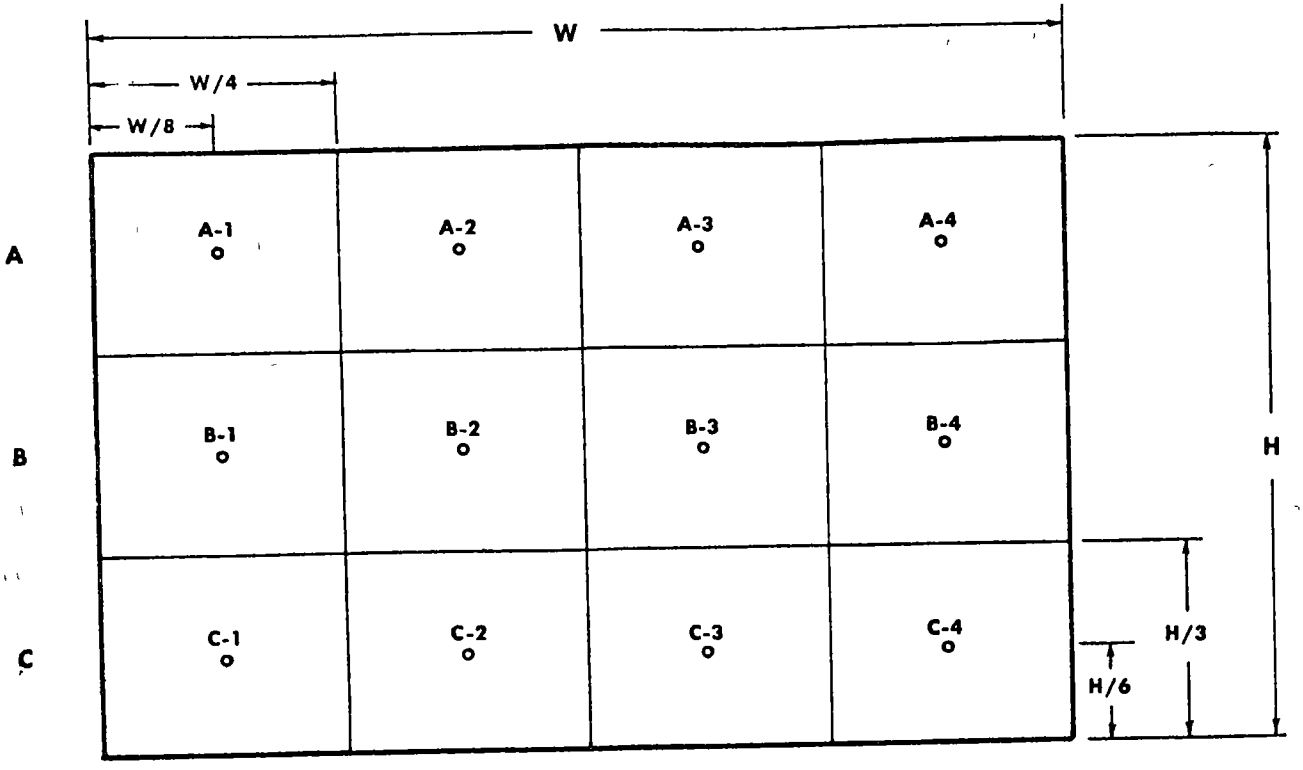
ARRANGEMENT OF AREAS

Having selected the location at which to make the test, it is desirable to make openings in the flue large enough to permit insertion of the Pitot tube and sampling tube For example, if this is a vertical round steel flue 54 inches in diameter, two 2 inch openings 90° apart should be provided so that the flue can be traversed in two directions A suitable closure should be provided at each opening

Referring to Table 1, divide the flue into four equal areas, the distance from the center of the flue to the center of each area being R_1—R_2—R_3—R_4 Measure from the end of the Pitot tube a distance of 27 inches This would be the center when the tube is inserted in the flue to this point From this point, measure both ways on the Pitot tube and mark distances R_1—R_2—R_3—R_4 with tape wrapped around the tube or some other marker which will hold its position during the traversing Lay off the sampling tube in the same manner

*NOTE In this bulletin the word "flue" will be used throughout to designate both "stacks" and what we usually think of as "flues," a stack being considered as a vertical section of the flue

Fig. 1 TYPICAL RECTANGULAR FLUE WITH TRAVERSE LAYOUT



If the station chosen has fairly uniform flow, the minimum number of test points may be determined as follows

Cross-sectional Area Square Feet	Number of Test Points
Less than 2	4
2 to 25	12
Greater than 25	20

EQUIPMENT

The following equipment is necessary for the Pitot tube traverse:

Pitot tube—Standard Pitot tube, or Special Pitot tube

Differential gauge—Inclined draft gauge

Gauge fittings—Nipple adapters Rubber tubing and clamp.

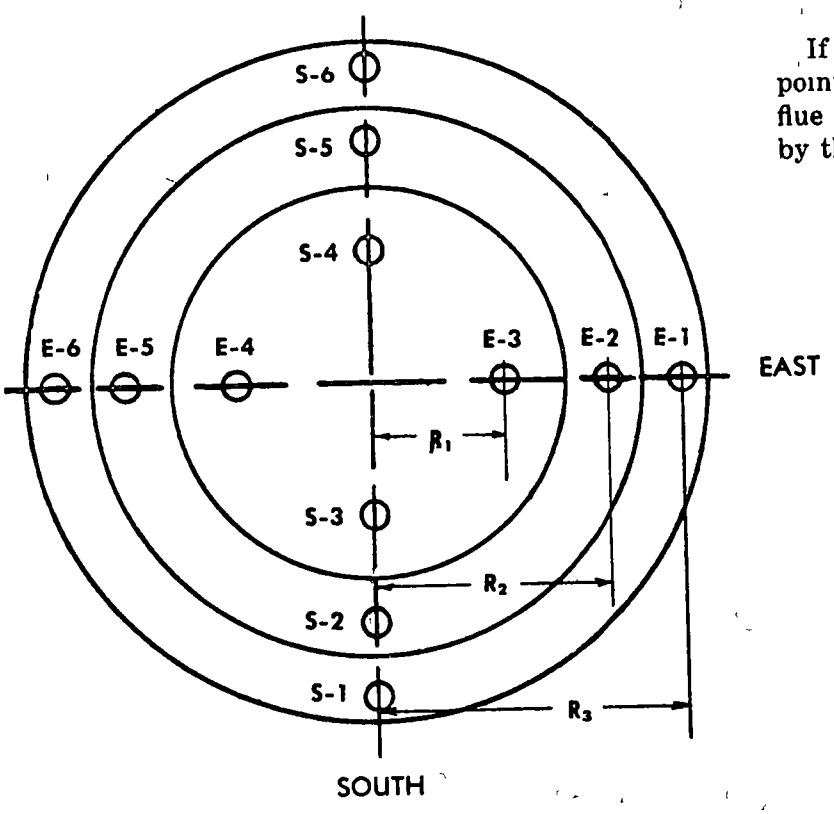
Gauge liquid—The liquid supplied with each gauge should be used In cases of emergency, a mineral oil of specific gravity 0 83 may be used

Thermometer—Standard mercury thermometer, reading above maximum temperature of the gas

or

Pyrometer—Standard base metal couple pyrometer.

Fig. 2 TRAVERSE POSITIONS IN ROUND FLUES



If the table below does not have enough points, the distance R from the center of the flue to any given test point, n, is calculated by the formula

$$R_n = d\sqrt{\frac{2n-1}{4N}}$$

d = Diameter of flue

N = Number of readings across a diameter

n = The n'th point from the center

R_n = Distance from center of flue to n'th test point, numbered from the center consecutively. In the diagram, n=1 for E-3, E-4, S-3, and S-4.

NOTE Using compass points to designate stations helps to orient the test locations

EQUAL AREA ZONES FOR VELOCITY TRAVERSE

% of flue diameter from circumference to test point

Point No	Number of Areas				
	2	3	4	5	6
1	6 2	4.4	3 3	2 2	2 0
2	25 0	14.7	10 5	8 2	6 7
3	75.0	29 4	19 5	14 5	11 8
4	93.8	70 6	32 1	22 7	17 7
5		85 3	67.9	34 4	25 0
6		95 6	80 5	65.6	35 4
7			89.5	77 3	64 6
8			96 7	85 5	75 0
9				91 8	82 3
10				97.8	88 2
11					93.3
12					98 0

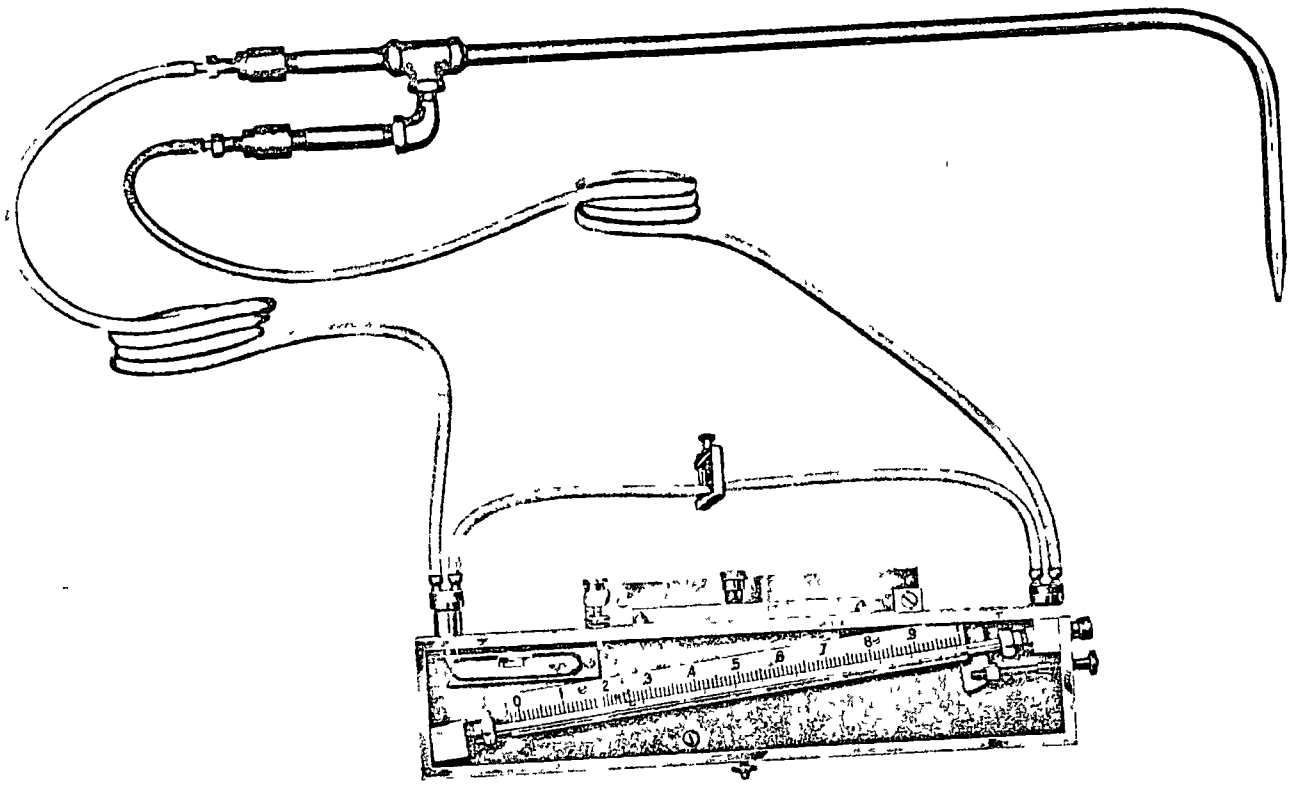


Fig. 3 VELOCITY TRAVERSE ASSEMBLY

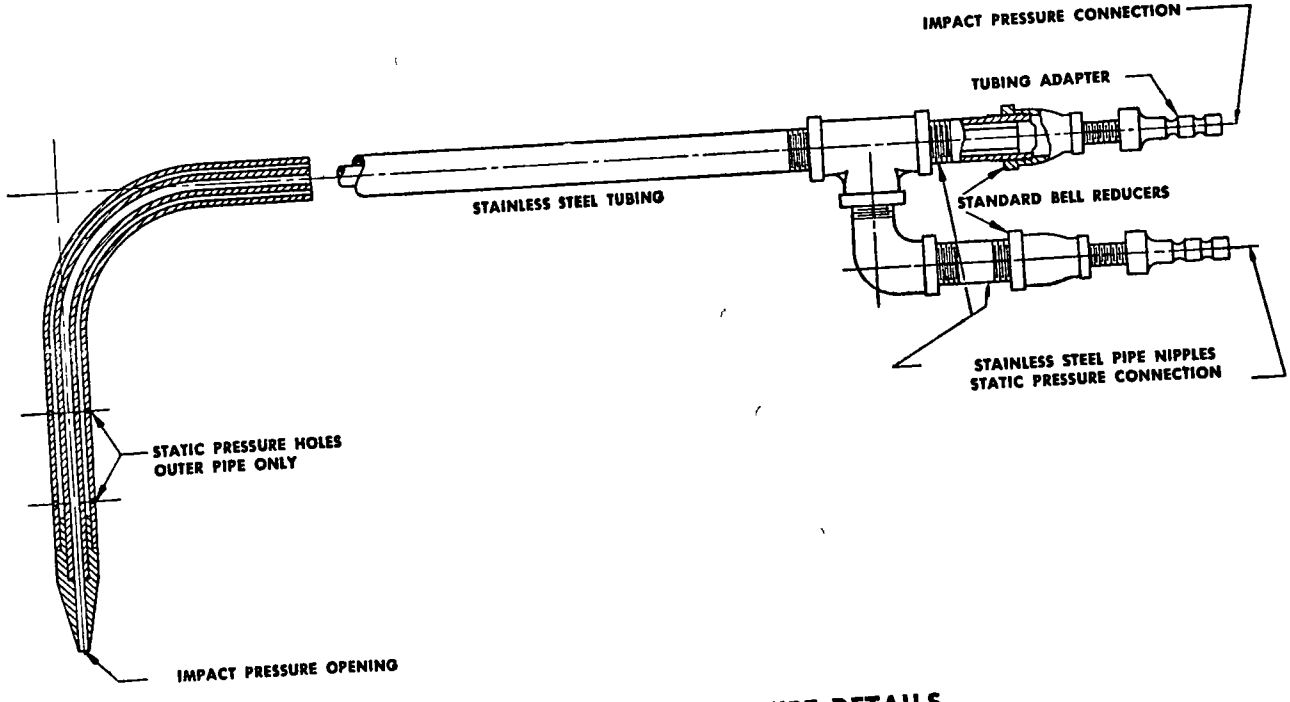


Fig. 4 STANDARD PITOT TUBE DETAILS

TECHNIQUE

In setting up the draft gauge, the two adapters are screwed in tightly and a suitable length of rubber tubing is connected to one terminal of each This bypass tube should be first passed through the tube clamp so that it can be closed off The gauge is then fastened to some convenient support or set on a firm level surface and leveled The gauge liquid is then poured in until it reaches a level at which the meniscus rests at the zero on the gauge Slight additional adjustment can be made in some gauges by moving the scale plate The Pitot tube is then connected to the gauge and the zero point read with the clamp on the bypass tube open, and the other tubes pinched off This is noted as the zero reading or the gauge is adjusted to read zero The Pitot tube is then inserted in the flue at the desired point and the bypass clamp closed The opening around the Pitot tube should be closed by calking with waste or some similar means When making a reading, the Pitot tube must always point directly into the flow of gas *

The reading of the draft gauge is noted at each point of measurement and the differences between this reading and the zero reading is the measure of the velocity pressure at the points of measurement. When the flow of gas is quite regular, it should be possible to estimate the reading to within 005 inches on the gauge Frequent checks of the zero reading are advisable

The temperature of the gas in the flue is noted, either by means of a thermometer or pyrometer Several readings of temperature should be taken If a smaller number of readings with the Pitot tube are made, one temperature before and one after will suffice using the mean in calculations If, however, a large number of Pitot readings are made extending over more than 15 minutes, then several temperature readings should be made at say 15 minute intervals and the mean between any two used for velocity calculations on readings falling in that interval

The relation of the pressure of the gas in the flue to atmosphere is usually measured. If within the range of the gauge, it may be referred to the atmospheric pressure outside the flue by reading the draft gauge with the "static" side of the Pitot tube connected to the gauge and the other end of the gauge open to the atmosphere If more than a pressure of 1" vwc exists, then a "U" tube gauge should be used. Care should be taken to protect the open end of the gauge connection from air currents This can conveniently be done by placing a loose ball of cotton or cotton waste over the opening.

For accurate work, it is also necessary to determine the density of the gas, or its specific gravity referred to some standard gas, such as air This can be calculated from its chemical composition. For ordinary combustion gases, it is often sufficiently accurate to assume that the density of the gas is the same as that of air, i e , that its specific gravity referred to air is 1 00

CALCULATIONS

The basic formula expressing the velocity of a moving gas, as measured by this method, is

(1) $V_s = \sqrt{2gh}$

Wher

V_s is the velocity of the gas in feet per second

g is the acceleration due to gravity in feet per second per second.

h is the height in feet, of a column of the gas in question, which would be equivalent in pressure to the velocity pressure indicated by the gauge reading.

With the pressure of the gas equal to 29 92 inches of mercury, and the density equal to that of air, the formula may be simplified to read

(2) $V_s = 2\,90 \sqrt{HT_s}$ (for temperatures in °F expressed in °absolute)

or $V_s = 3\,90 \sqrt{HT_s}$ (for temperatures in °C expressed in °absolute)

Where

H is the gauge reading in equivalent inches of water

T_s is the absolute temperature of the gas (absolute temperature=degrees Centigrade +273, or degrees Fahrenheit +460)

*NOTE When using equipment in flues following electrical precipitators it is advisable to electrically ground the inserted tubes, since these may become charged from the gas stream with a static charge which while not dangerous, is very uncomfortable to the operator

If the pressure of the gas differs from 29 92 inches of mercury, or if its density is different from that of air, then formula (2) must be modified to read

(3) $V_s = 2\ 90 \sqrt{\frac{29\ 92}{P_s} \times \frac{1\ 00}{G_d} \times HT_s}$ (for temperatures in °F absolute)

$V_s = 3.90 \sqrt{\frac{29\ 92}{P_s} \times \frac{1\ 00}{G_d} \times HT_s}$ (for temperatures in °C absolute)

Where
P_s is the absolute pressure of the gas in inches of mercury in the flue being tested.
G_d is its specific gravity referred to air

In order to illustrate the use of formula (3), the following example from actual practice is given·

In the roaster flue of a smelter situated in the mountains, the prevailing absolute pressure of the gas P_s was 26 5 inches of mercury Its specific gravity G_d was 1 02 Substituting these values in (3), this becomes

$V_s = 2\ 90 \sqrt{\frac{29\ 92}{26\ 5} \times \frac{1\ 00}{1\ 02} \times HT_s}$ (for temperatures in °F absolute)

or $V_s = 3\ 05\sqrt{HT_s}$
which then, expresses the velocity in terms of feet per second for the temperature and velocity pressure of the gas for that location

The calculations necessary for a complete velocity determination are given in the following example from another plant Here, the measurements were taken at a point in the stack where the pressure of the gas was practically that of the atmosphere as read on the barometer.
The specific gravity of the gas was 1.00
The barometer reading was 29.1 inches.
Hence, using formula (3)

$V_s = 2\ 90 \sqrt{\frac{29\ 92}{29\ 1} \times \frac{1\ 00}{1\ 00} \times HT_s}$ (for temperatures in °F absolute)

or $V_s = 2\ 94\ \sqrt{HT_s}$
The temperature of the gas was 218°F or 218°+460=678°F absolute
One of the differential readings of the draft gauge was 0 035, hence,
$T_s = 678$ and $H = 0\ 035$
Therefore
$V_s = 2\ 94\ \sqrt{0\ 035 \times 678}$
or
$V_s = 14\ 3$ feet per second, which is then the velocity at the point considered

Having noted the gauge reading at the center of each of the equal areas previously laid out, the velocity is calculated for each point The average velocity for the entire cross-section is then the mean of these individual velocities (The square root of the Pitot readings may be averaged but not the Pitot readings)

When it is necessary to determine this average velocity day by day, and the flue is very large, it is not always possible to take readings at all the points outlined In such cases, it is sometimes practical to select one convenient point in the cross-section, usually near the point where the sampling tube is placed as a permanent measuring point Then the ratio between the velocity at this point and the average velocity of the cross-section is determined from a few complete velocity determinations This ratio being known, the average velocity of the cross-section can be approximated from the readings taken at this one point. Frequent checks, however, should be made of this ratio

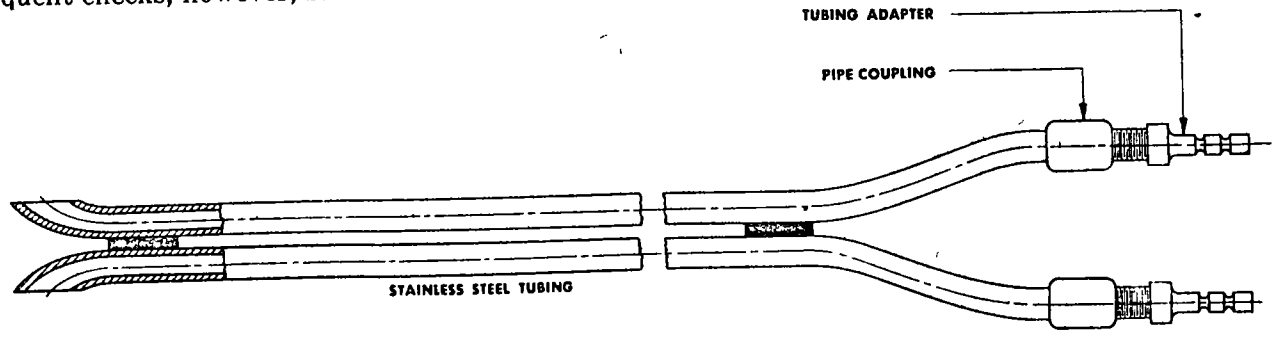


Fig. 5 TYPE S PITOT TUBE (SPECIAL)

SPECIAL PITOT TUBES FOR DUSTY OR WET GAS

In the discussion above, it has been assumed that the Standard Pitot Tube or one of similar construction, was employed Where the gases are nearly saturated with some condensable constituent or carry heavy dust loads, this tube tends to stop up Here, the Special Pitot Tube (Type S) may be used.

This Type S Pitot tube does not give the true static pressure, and a correction factor F_s must therefore be added to the formula (2), which then becomes

(4) $V_s = 2.90\ F_s \sqrt{HT_s}$ (for temperatures in °F absolute)

$V_s = 3\ 90\ F_s \sqrt{HT_s}$ (for temperatures in °C absolute)

The value of the factor F_s must be determined from comparison with a Standard Pitot tube For the type Pitot tube illustrated, F_s averages 0 83 for velocities up to 50 feet per second. For very accurate work the individual Pitot tube should be calibrated at the velocity range being measured

ORIFICE DISC METER

When determining the velocity of gas flowing through relatively small pipes or ducts, an orifice disc may be more convenient than the Pitot tube for obtaining the velocity pressure Such an arrangement is outlined in Figure 6.

One arrangement of an orifice disc would be a plate of thickness not in excess of 1/50 of the pipe diameter having an accurately cut central, circular opening and may conveniently be located in an existing flanged joint The gauge connections should be located so that the distance from the orifice disc on the upstream side is 2½ times the pipe diameter D and 8 times the pipe diameter on the downstream side For other types see the standard references on the subject

The orifice diameter should be such as to give a suitable gauge reading They shall not be used with a diameter ratio greater than 0 7 The throat diameter shall not be less than 0.75 inches

The basic formula expressing the relation between gas velocity through the orifice and the pressure differential is the same as with the Pitot tube

(1) $V_s = \sqrt{2gh}$

With orifice discs, however, a factor must be introduced, the value of which depends only on the ratio of the pipe or duct diameter D to the orifice diameter d, hence, where the gas pressure is at standard atmospheric pressure, or 29 92 inches of mercury, and the gas density is equal to that of air, then the formulae for temperatures in °F and °C become

(5) $V_s = 2\ 90\ F_d \sqrt{HT_s}$ (for temperatures in °F absolute)

$V_s = 3.90\ F_d \sqrt{HT_s}$ (for temperatures in °C absolute)

Here, as with the Pitot tube, H is the gauge reading in inches of water

The numerical constants 2 90 and 3.90 may be corrected for other pressures and densities as in equation (3).

Values of the factor "F_d" for gauge connections located as indicated above, and for the different ratios d/D of the orifice and pipe diameters are given in Figure 7.*

USE OF THE ANEMOMETER

Where the gas velocity is much less than 10 feet per second, the differential gauge reading resulting from the Pitot tube pressures is ordinarily too small to permit accurate measurement In such cases, an anemometer can be used to advantage. The instrument is usually calibrated to read directly in feet of gas flow It is, therefore, only necessary to insert the anemometer in the proper position at the point for measurement for some definite time (preferably measured by a stop watch). The difference in the anemometer reading for one minute represents the velocity of the gas at that point in feet per minute. The instrument is hard to keep in adjustment under field conditions and should be carefully calibrated before each use. It should not be used in hot, dirty, or corrosive gas.

*NOTE For extreme accuracy, all orifice meters should be carefully calibrated

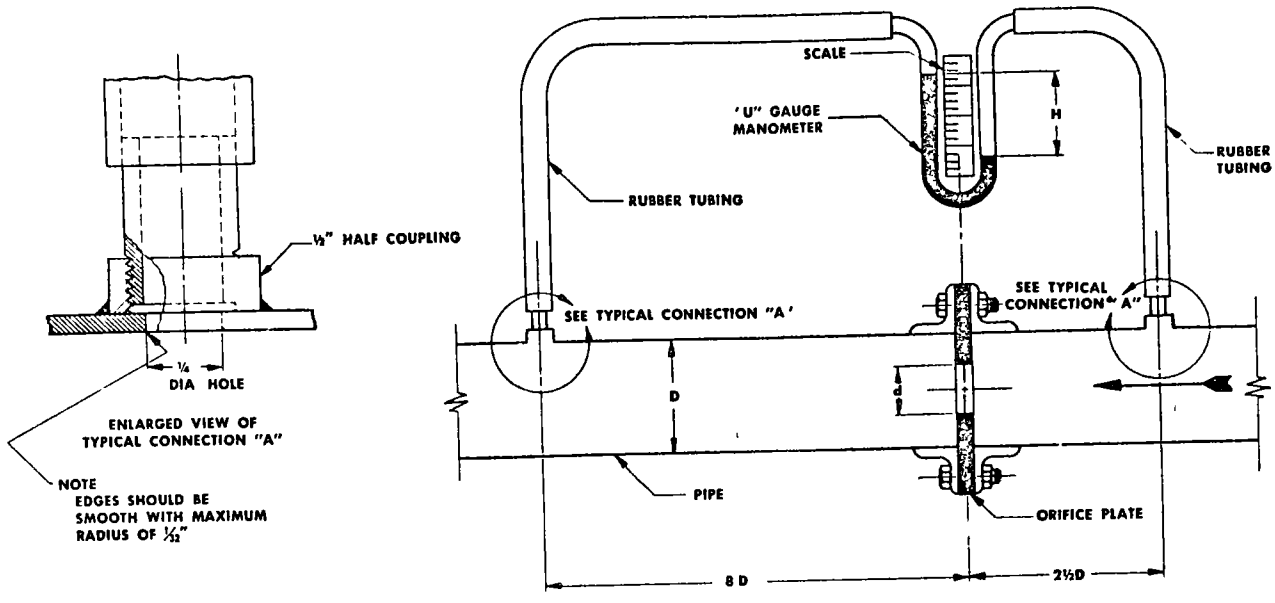


Fig. 6 ORIFICE DISC METER

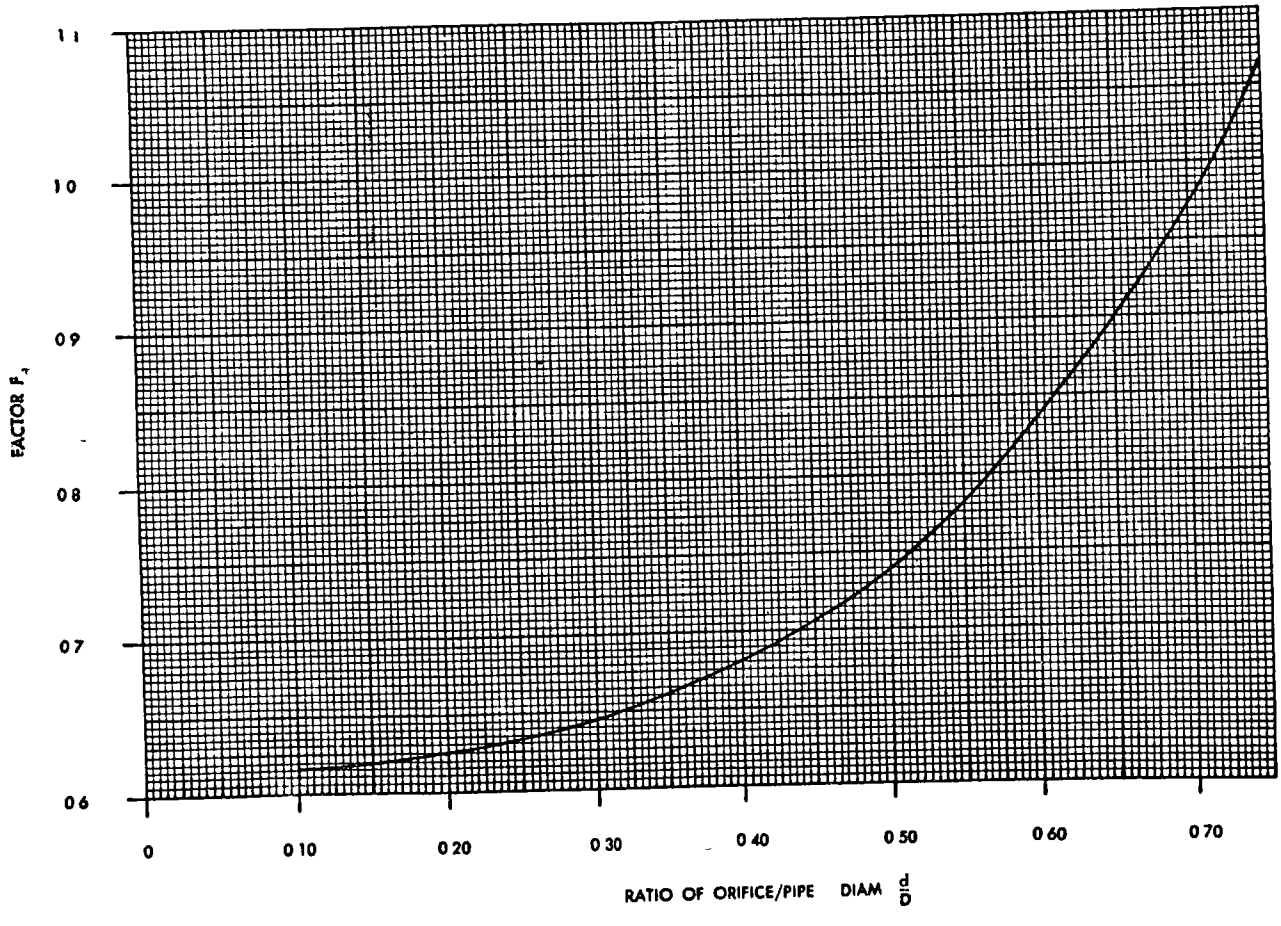


Fig. 7 ORIFICE DISC FACTOR

CALCULATION OF GAS VOLUME

As has been noted, the volume of gas passing any cross-section in the flue in unit time is the product of the average velocity over that cross-section and its area In measuring the area of the cross-section under consideration, care should be taken to allow for any deposit of dust which might have accumulated there Then the product of this "effective" area in square feet, and the velocity of the gas in feet per second, will give the volume of gas passing in cubic feet per second It is customary to multiply this value by 60 so as to express the volume in cubic feet per minute

(6) $V_o = V_{s\,avg.} \times A \times 60$

V_o = Volume of flue gas in CFM at flue conditions

A = Effective area of the flue in square feet

When the volume only is sought, and no dust determination made, it is sometimes desirable to express this volume in cubic feet per minute under standard conditions, that is, at the pressure of 29 92 inches and a temperature of 0°C or 32°F For this purpose, the following formula may be used

(7) $V_{std} = V_o \times \frac{P_s}{29\,92} \times \frac{492}{T_s}$ (for temperatures in °F absolute)

$V_{std} = V_o \times \frac{P_s}{29\,92} \times \frac{273}{T_s}$ (for temperatures in °C absolute)

Where

V_{std} is the volume under standard conditions (29 92" mercury and 0°C or 32°F)

V_o is the volume found under flue conditions.

P_s is the absolute pressure in the flue in inches of mercury

T_s is the temperature in the flue in degrees absolute

DETERMINATION OF GAS VOLUME FROM GAS ANALYSIS

In some cases, particularly with large stacks or flues, the gas flow fluctuates at such a rate that neither the Pitot tube nor the anemometer give correct average results In such cases, the gas volumes can often be determined by chemical means, in that the total input into the system of some constituent is determined and the flue gases then analyzed for this constituent

For example, in cement mills, one can determine the total weight of CO_2 introduced into the gases from the fuel input and the limestone calcination, and calculate the volume of CO_2 at flue conditions thus produced Then, determining the percentage of CO_2 in these flue gases, the gas volume can be calculated Where the CO_2 analyses are carried out by the ordinary Orsat method, the volume thus calculated will not include the water vapor which must be determined by separate analysis Gas analysis should be made at a point in the flue where volumes are desired

SECTION TWO

DETERMINATION OF CONCENTRATION AND NATURE OF SUSPENSOIDS

In measuring the amount of solids or liquids in the form of dust, mist, or fume which pass with the gas through a flue, either one of two methods may be used. In the usual method, which may be called the "Dust Concentration Method," the gas volume is first measured, and then the dust concentration, i.e., the weight of suspended matter or suspensoid carried by a unit volume of gas, is determined

In the Balanced Tube Method, the amount of solids or liquids carried by the gas is determined without necessarily measuring the gas volume. A null nozzle is used, but it should be calibrated before any testing is to be done

DUST CONCENTRATION DETERMINATION

Having determined the volume of gas passing in unit time, as described in Section One, then if the weight of suspensoid carried by a unit volume of this gas is determined, the total weight passing in any given time can be calculated.

Determination of the suspensoid concentration consists essentially of withdrawing a measured amount of gas from the flue and separating the suspensoid from the gas and determining the amount of suspensoid separated from the measured amount of gas. The type of suspensoid and the temperature and moisture content of the carrier gas will determine the method to be used in making this separation

SELECTION OF FILTERING MEDIA

The most generally used methods of separating the suspensoid from the carrier gas sample are by passing the sample through the following:

1. Paper filter thimble.
2. Glass cloth filter.
3. Alundum thimble.
4. Tar camera.
5. Membrane filter
6. Impinger.
7. Electrofilter, based on the Cottrell Precipitator.

The same gas measuring equipment can be used with any of these filters.

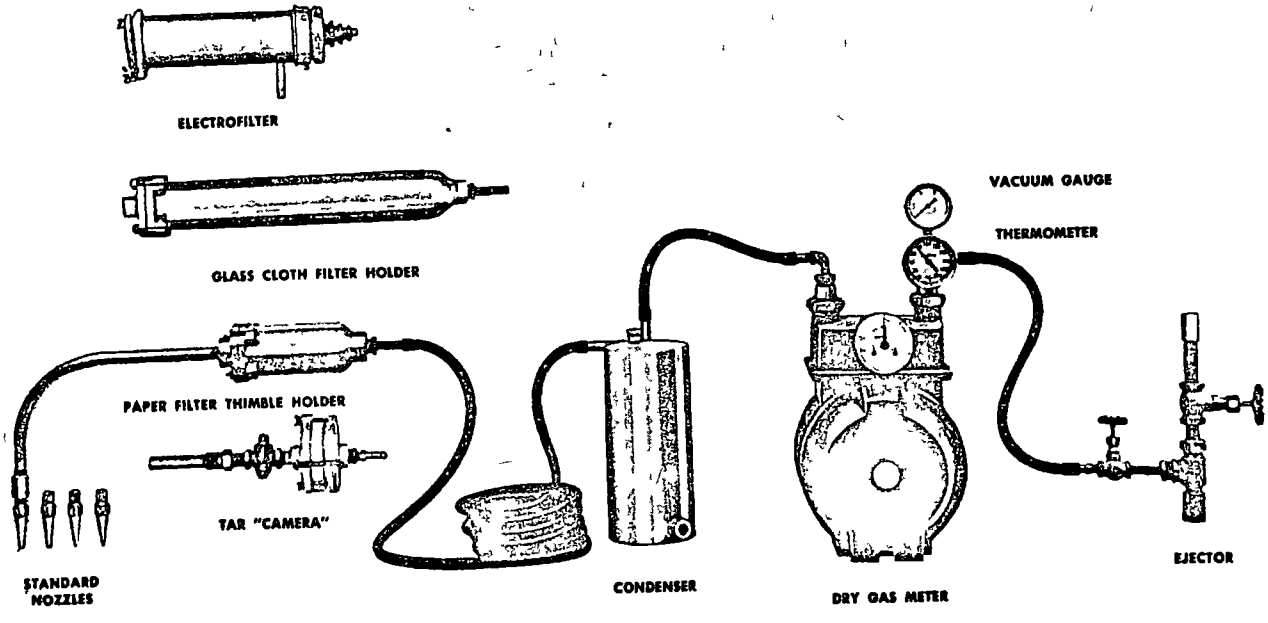


Fig. 8 FILTRATION APPARATUS ASSEMBLY

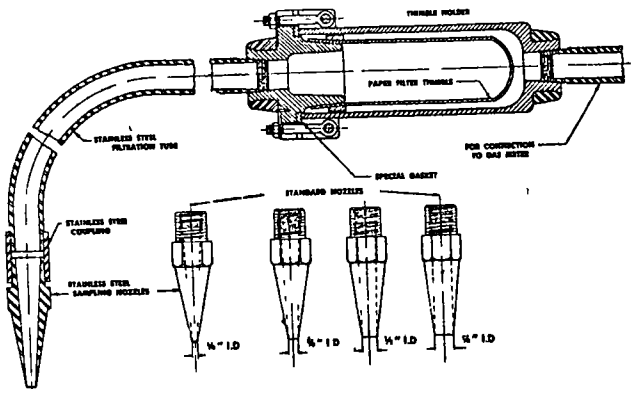


Fig. 9 PAPER FILTER THIMBLE HOLDER

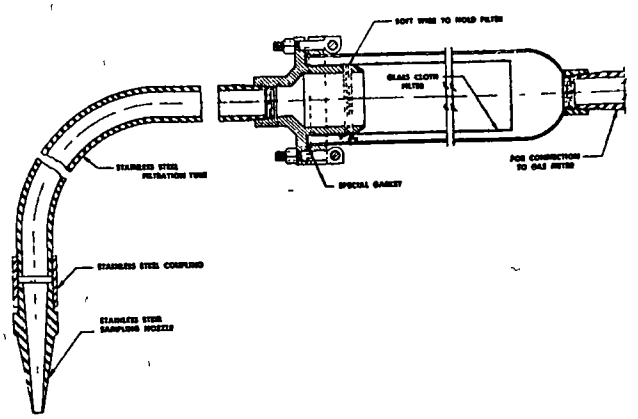


Fig. 10 GLASS CLOTH FILTER HOLDER AND NOZZLE ASSEMBLY

PAPER THIMBLES

Paper thimbles are widely used, being accurate, inexpensive and convenient to use These are extraction thimbles 43 x 123 mm such as made by Whatman or J. Green, and are used with the special thimble holder shown in Figure 9.

This thimble is normally used at temperatures up to about 300°F and suction pressure up to 4 inches of mercury if kept dry. Temperatures and pressures higher than this are apt to break the thimble and spoil the test If temperatures higher than 300°F are encountered, the gas must be cooled before reaching the thimble This can be done by using a long sampling tube, allowing the thimble holder to be placed at an appropriate distance outside the flue

The paper thimble will not stand wetting, and when sampling gas with a high percentage of moisture, it is necessary to keep the thimble holder at a temperature above the dew point of the gas If the gas temperature is below 300°F, the thimble holder can be placed inside the flue. If used outside the flue, the thimble holder can be preheated and then wrapped with cloth or appropriate insulation to retain the heat, or an electric heater may be used to maintain the temperature above the dew point.

The paper thimble is not suitable for use where extremely heavy dust loads are encountered since the dust soon clogs the filter.

GLASS CLOTH FILTERS

These filters are made of finely woven glass cloth and so far have not proven satisfactory for catching fume They work well on coarse dust and where samples are to be taken under heavy dust loading conditions They can be used very satisfactorily ahead of a paper thimble, the latter catching the fine particles that pass the glass filter

A filter holder similar to the one for the paper thimble, but larger, is used It can be used up to a pressure drop of 6 inches mercury and temperatures as high as 750°F. The filter should be kept dry as moisture will tend to clog the pores

ALUNDUM THIMBLES

Alundum thimbles are used where it is important to have high wet strength, chemical resistance, or high temperature resistance Also, where the water content of a gas is high, and condensation occurs, alundum may be oven dried to its original water content more accurately than paper.

Alundum thimbles that have fine enough interstices for efficient filtration generally have high resistance to flow It is usually necessary to determine the resultant vacuum and compensate for it when sampling at predetermined sampling rates When coarse thimbles are used, their efficiency should be checked by some secondary collector, as for instance a paper thimble, or membrane filter

Being able to withstand high temperature, this thimble may be inserted in the flue, just behind the sample nozzle When this is done, cleaning the sample pipe is eliminated, and the sample is collected dry.

TAR CAMERA

For non-aqueous mist, for example oil or tar mist, or mist carried by unsaturated gases where it is desired to collect the suspended matter free from additional water, the tar "camera" may be used Here, the suspended matter is retained on the filter medium The quantity can be determined either by weighing the filter before and after as in the ordinary filter thimble method, or by extracting the filter medium with a suitable solvent and then analyzing the solution, or separating the solvent and weighing the solids The tar camera is illustrated in Figure 11

It is essentially a flat paper filter through which the gas is drawn and the tar or oil retained by the filter The colorimetric or visual comparison method in which the filter paper is compared against a standard colorimetric chart is a quick method of determining the amount of tar or oil retained by the filter

This apparatus can be used to determine the efficiency of a collector. This is done by drawing a sample through a "camera" from the inlet of the equipment tested, and another from the outlet and continue the volume sampled from the outlet of the equipment until the colors are equal Efficiency can then be determined from comparison of volumes through the two filters

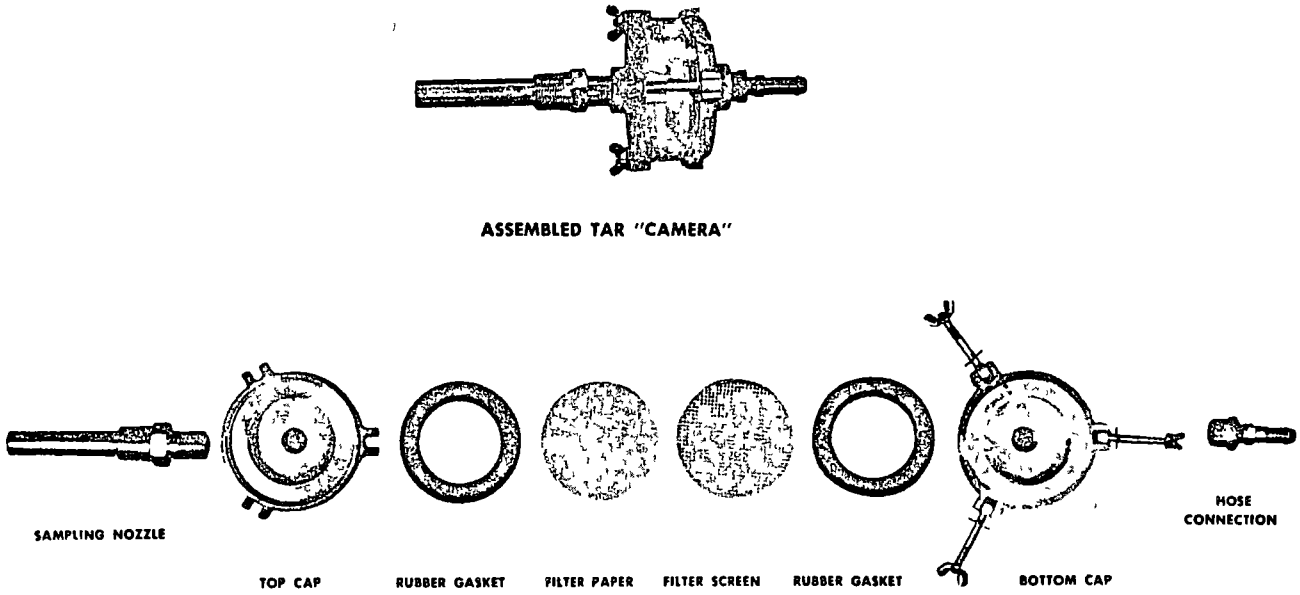


Fig. 11 TAR CAMERA FILTER

MEMBRANE FILTERS

Filters made of cellulose esters have been developed for the collection of extremely small particles such as colloids, bacteria, and radioactive materials. These filters are used in devices that are very similar to the Tar Camera The gas flow rates through these filters are fixed by the manufacturer's specifications, according to the pore size and porosity of the several types

Membrane filters are unique when compared to cellulose filters They may be soluble in organic solvents, or they may be ignited to a barely traceable ash When an appropriate immersion oil is used, some membrane filters are rendered transparent for examination of the sample under a microscope These properties are used to isolate samples for laboratory examination where extremely fine particles are important—sizes below one micron.

IMPINGERS

Most impingers are designed so that a high velocity jet of the gas being sampled impinges on a flat surface This flat surface is usually immersed in a liquid When a train of impingers is used, the first may be operated dry If a paper thimble follows the train, the last impinger should be operated dry, to trap mist from preceding impingers

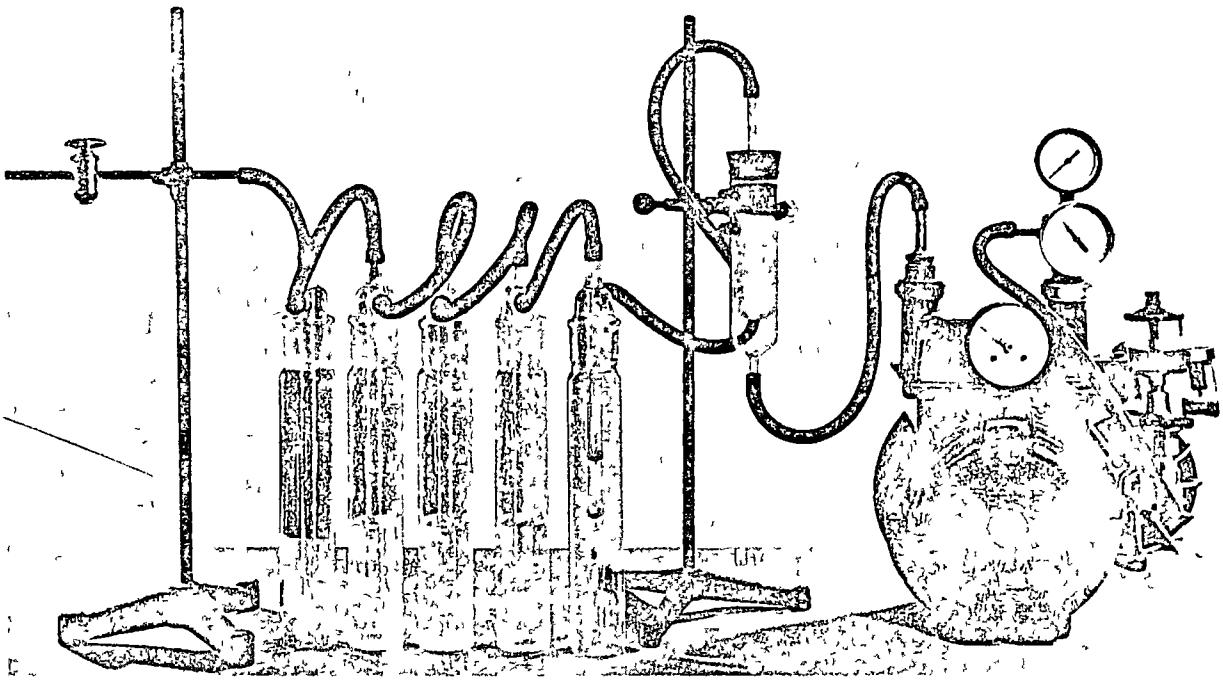


Fig. 12 IMPINGER TRAIN ASSEMBLY

Fig. 13 IMPINGER DETAILS

Where gases are hot, the impingers may be immersed in cold water In any case, liquid impingers will act as condensers Liquids in impingers are carefully measured before and after testing The final liquid will consist of liquid used to wash the sampling lines, initial liquid, and condensate The condensate volume is used to calculate extra gas flow, that was not measured by the gas meter. The solid sample is obtained by evaporating the liquid Where the dust is extremely fine and uniformly suspended in the liquid, a small sample of the suspension may be examined on special slides under a microscope to obtain the "dust count"

ELECTROFILTER

The electrofilter is a small, high efficiency Cottrell Precipitator through which the gas being sampled is drawn at a low velocity An aluminum cylinder 1½" I D is used as the collecting electrode A small wire running through the insulating bushing and down the middle of the cylinder is used as the discharge electrode A rectified voltage of approximately 20,000 volts is provided by a power pack using a vacuum tube rectifier and condenser system In general, precipitation is carried out with a 0 5 milliampere current and one foot per second gas velocity The meter rate of flow is held between ½ to 1 cubic foot per minute. The metal cylinder is weighed before and after the test run and the weight of the collected material thus determined

The efficiency of the electrofilter depends principally on the gas volume and can be made as high as generally required by keeping the gas vlocity through the field low The electrofilter collects solid particles of practically any size and can be used on certain higher temperature gases. This equipment has definite limitations as to design and use. An illustration of the electrofilter is shown in Figure 14

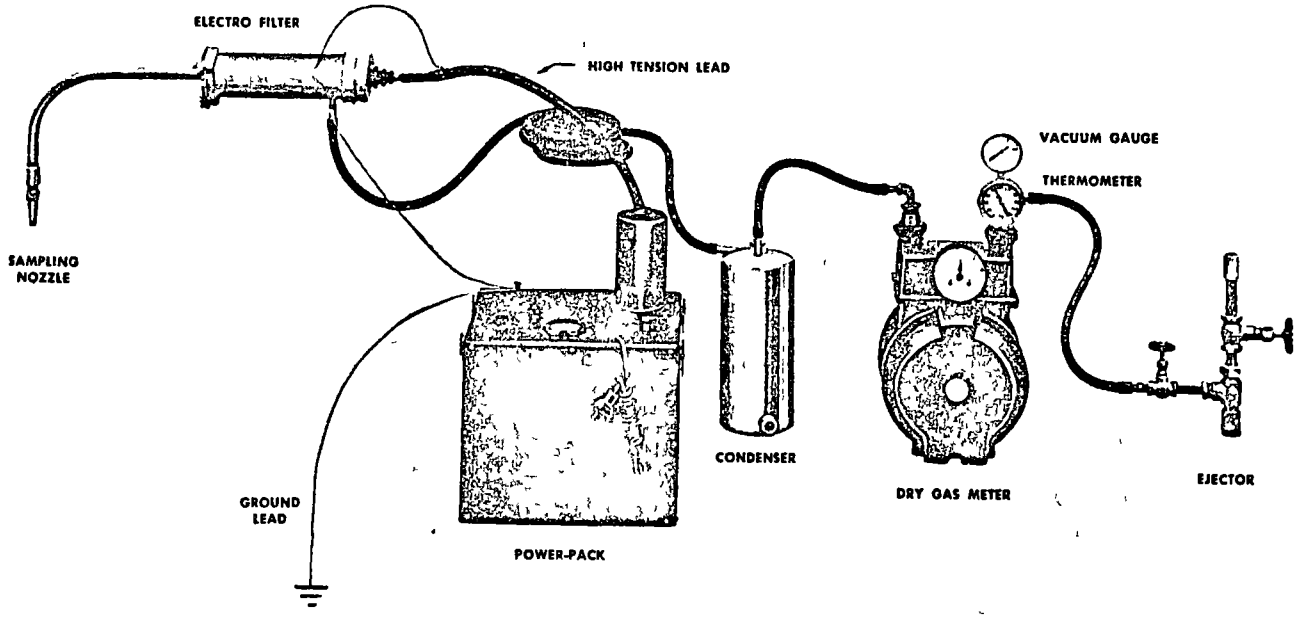


Fig. 14 ELECTROFILTER IN ASSEMBLY

GAS SAMPLING EQUIPMENT

The following equipment is used in the measurement and sampling of gas, and may be used with any of the filtering media described

To provide suction for drawing a sample of gas through the filter system, a motor driven pump or a steam or air operated ejector of the Pemberthy type may be used

To measure the sampled gas, either a dry type or wet type meter can be used A dry type found satisfactory is Sprague Test Meter No 1A with special index dials reading 1, 10 and 100 cubic feet per revolution.

To condense the moisture in the gas before it reaches the meter, a water cooled metal condenser is used unless the condensate is highly corrosive, in which case, a glass condenser should be used.

To extract a uniform sample of gas and suspensoid, a standard sampling nozzle is used A 1/4", 3/8", 1/2" or 5/8" diameter nozzle is most frequently used, although nozzles of any size can be made and used. The proper size depends on the velocity of the gas in the flue and the sampling rate to be maintained. Determination of proper size is described later under "Size of Sampling Nozzle."

To remove the suspensoids from the gas sample, the appropriate one of the filters previously described is used with its corresponding holder

To connect the sampling nozzle with the filter, a filtration tube made preferably of stainless steel or some material which is not subject to corrosion is used The tube should be bent with a smooth curve so that the sampling nozzle will face the current of gas It should be long enough to reach all sampling stations and project to the outside of the flue, where it should be fastened in the proper position Its length should be calibrated and permanently marked so that the sampling nozzle can be readily located at the various sampling stations

When the temperature of the gas is unduly high, it may be necessary to cool the gas before it reaches the filter This can be done by placing a water jacket around the sampling tube or by having this tube sufficiently long to obtain the necessary cooling from the air outside the flue

Gas with high humidity, on the other hand, may cool to below the dew point and moisture will condense in the thimble and ruin it In such cases, the gas should be heated, as for example by means of an electric heater placed around the sampling tube or filter thimble holder When, however, the temperature of such humid gas is not too high, it is often more convenient to place a filter thimble in the gas inside the flue Figure 8 is an illustration of a complete assembly of filtration apparatus

SETTING UP THE EQUIPMENT

An ejector should be first connected to the high pressure air or steam line and to the outlet side of the meter, a regulating valve being provided in the high pressure air or steam line to permit adjustment of the suction The connection between the meter and ejector is made by means of heavy rubber tubing A regulating valve is also convenient in this line. In the use of dry type meters, care should be taken to see that no condensate is present in the meter from previous use This may be checked by inverting the meter before connecting it If a pump is used, a suitable electric outlet must be available

In fitting up the meter, the manometer or vacuum gauge and thermometer unit should be placed in the meter outlet In this position, the thermometer will record more nearly the meter temperature than if placed in the inlet in the direct path of the hot gas. The inlet opening of the meter should be connected to the thimble holder, or condenser if one is used, by means of heavy rubber tubing

It is, of course, essential that all connections on the meter, as well as all those between the meter and the filter tube, be absolutely tight so as to prevent outside air being registered on the meter A simple test for tightness is to assemble all of the equipment and tightly block the sampling nozzle, then carefully apply suction until the gauge reads its maximum If the meter does not creep, the system is tight

WEIGHING THIMBLES AND DUST

For accurate work, the weight of dust collected in the filter thimble is determined by difference, that is, the thimble is weighed before and after the run Since the weight of the filter thimbles themselves is a variable quantity, on account of changes in their moisture content as the humidity of the atmosphere changes, it is necessary to allow for this in the determination Before weighing the empty thimbles, a sufficient number for the test, with one extra, should be placed in the weighing room so that all will be exposed to the same atmospheric conditions After reaching weighing equilibrium, they are marked with a pencil for identification and weighed One of them is left in the weighing room to be used as a standard, and the rest placed in dust-tight containers for convenience in transportation to and from the weighing room Wide-mouthed chemical reagent bottles or ordinary pint fruit jars may be used for this purpose.

After the run, the thimbles with the dust are again placed in their containers and carried back to the weighing room The thimbles are then again placed beside the standard thimble until they reach constant weight, then all the thimbles are weighed again. The door of the balance case should be left open during

the weighing, or the normal dessicant removed from the case, otherwise the thimbles will lose weight during the operation

The original weight of each used thimble should now be corrected for the change in weight found in the standard thimble and the difference in weight of each used thimble calculated for this corrected weight

The following example will serve to illustrate the procedure:

Weight of thimble No. 1 before run	7 560 gm
Weight of standard thimble before run	7 340 gm
Weight of thimble No. 1 after run	7 750 gm
Weight of standard thimble after run	7.410 gm
Change of weight of standard thimble=7 410—7 340 or	0 070 gm
Corrected weight of thimble No 1 before run 7 560+0 070 or	7 630 gm
Difference in weight of thimble No. 1=7 750—7 630 or	0 120 gm

This procedure is based on the assumption that changes in humidity will affect the weight of all the thimbles equally. While not absolutely true, the method is sufficiently accurate for ordinary work if thimbles of approximately equal weight be used, and if the collected material which remains in the thimble is not too hygroscopic. With very hygroscopic material, it is better to dry the thimble in a drying oven with a standard thimble, and weigh them in a weighing bottle before and after the test If the standard thimble loses more weight from the second heating, the oven is too hot and is destroying the paper

SELECTION OF LOCATION OF SAMPLING STATION

It is usually well to sample at the same section in the flue as that selected for velocity determinations If possible, this should be at least 8 diameters from any bend or point of disturbance It is usually necessary and always advisable to make a dust traverse as well as a velocity traverse to determine the average suspensoid load carried by the gas and from which a point of average loading or, a factor to be applied to readings at a given point, can be determined for use if sampling is to continue over an extended period

If only one or two samples are to be taken, an average reading can be obtained by moving the sample nozzle from station to station drawing gas through the meter for the same length of time at each station

Testing in vertical flues is preferable, but if this is not feasible, a horizontal flue may be used Care should be exercised to insure that there are no deposits of dust on the bottom of the flue in the vicinity of the test location. In laying out the equal areas for a sampling traverse, some of the areas may require subdividing There may be laminar flow of the dust due to flue configurations Heavier dust tends to segregate near the outer wall when going around a bend, and hence distribution may change in a matter of inches of traverse. When such subdividing is necessary, the times of filtration at these points are proportioned also. This segregation is due to the fact that dust travel is not governed by the same laws that affect gases Thus, it is easily possible to have the heaviest dust concentration in the area of slowest gas velocity

The maximum velocity at a selected location should not exceed the minimum velocity by more than 50%.

SIZE OF SAMPLING NOZZLE

The size of the sampling nozzle depends on the gas velocity and sampling rate to be maintained It should be large enough to give a suitable dust sample in a reasonable time, one gram being about the minimum desirable Sampling nozzle size to give an isokinetic sampling rate between ½ to 2 cubic feet per minute is best suited to the equipment described See "Calculation of Meter Rate for Exploratory Filtration Test" for method of calculation In no case should nozzles smaller than ¼" in diameter be used

ISOKINETIC SAMPLING

In order to insure accurate results, especially where sizable particles are present, it is necessary that the gas entering the nozzle be drawn through the sampling nozzle at approximately the same velocity as that of the gas passing the nozzle in the flue at the sampling point Calculation of meter rates must

consider the difference in temperature and pressure between the meter and the nozzle and the moisture content of the gas.

DURATION OF TEST

As a general rule, the longer the sampling period, the more accurate the test results.

Where cyclic operations such as precipitator rapping periods or furnace charging cycles are concerned, the test period should be set to cover one or more complete cycles.

Also, where volume variations are appreciable, the test period should be long enough to cover these variations In no case should the duration of test be less than 30 minutes, and 2 to 6 hours would be preferable

CENTER VELOCITY HEAD READING

In order to be informed of any changes of general volume and velocity through the flue which may occur from time to time, a Pitot reading should be taken at the center point (No. 1) after reading each other station If these center readings are found to be constant, they need not be recorded. They should never be considered in taking the average velocity for the areas However, if they vary materially, they should be recorded over a sufficient period of time to establish magnitude and duration of variations, from which can be estimated suitable traverse period both for volume and dust determintaion.

WET BULB AND DRY BULB TEMPERATURE READINGS

Where the temperature in the flue is below 212°F, wet and dry bulb readings may be taken directly in the flue Where the temperature in the flue is above 212°F, a simple method of obtaining wet and dry bulb readings for use with conventional psychrometric charts is to aspirate and cool a sample.

This can be done by inserting a length of ¾" standard pipe into the flue and fitting it with a standard "Tee" and a connection to a steam or air aspirator similar to the one used in the sampling equipment Insert a dry bulb thermometer with rubber stopper and a wet bulb thermometer in the Tee. Proper temperatures can be obtained by adjusting the length of pipe ahead of the Tee and by regulating the rate of

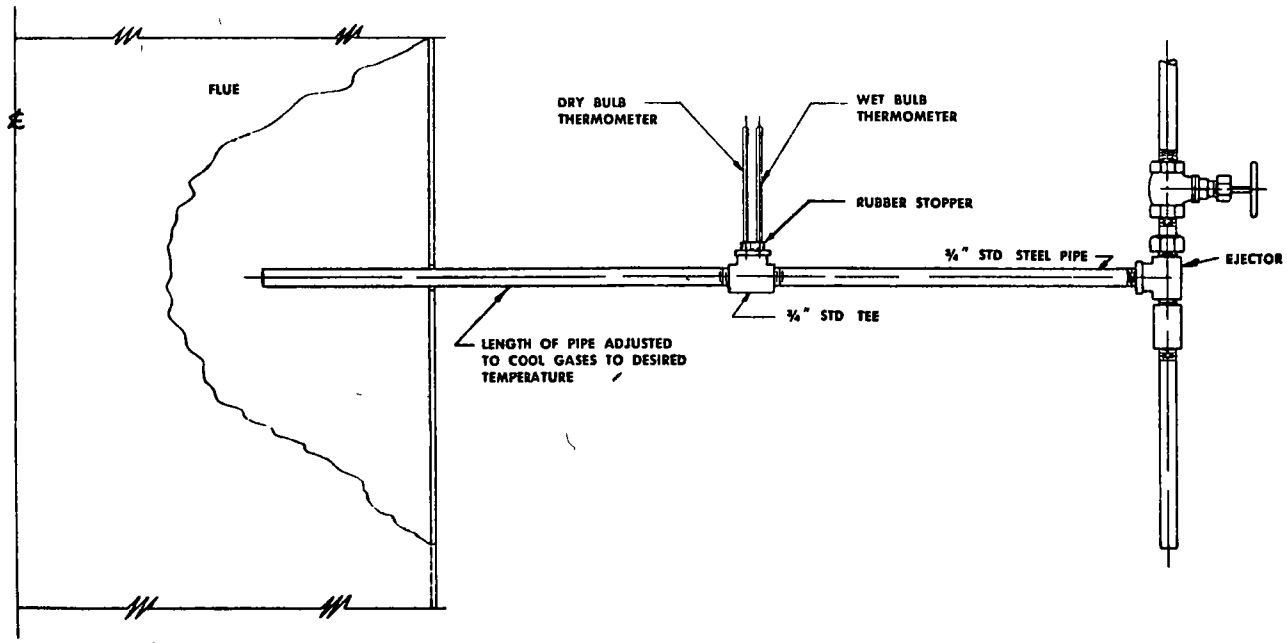


Fig. 15 GAS COOLER FOR READING DRY AND WET BULB TEMPERATURES

flow The rate of flow should be at least 600 feet per minute in accordance with tables computed from U S. Bureau of Standards data.

EXPLORATORY TEST

PRELIMINARY DATA

The following data can be collected before starting the actual test.

	Assumed Values for Sample Calculations
T_s=Flue gas temperature converted to degrees absolute	240°+460=700°F Abs.
P_b=Barometric pressure in inches of mercury	27 8″ Hg
P_s=Absolute pressure in flue in inches of mercury	27 8″ Hg
D =Diameter of flue in inches	54″
A =Area of flue in square feet	15 9 sq ft.
G_d=Specific gravity of gas referred to that of air	1.00
Wet bulb reading	128°F
Dry bulb reading	210°F

PRELIMINARY CALCULATIONS

In order to calculate the correct meter rate and establish length of test, it is necessary to know the velocity, temperaure, moisture, and approximate dust content of the gas in the flue These data can best be obtained from a preliminary test. This test should be made in the same manner as a regular test so that complete information can be acquired, operation of the equipment checked, and a sampling technique developed

Set up the velocity determination equipment as shown in Figure 3 and as described in Section One, page 5 and the gas sampling equipment as shown in Figure 8 and as described on page 15

For the exploratory test, some assumptions will have to be made Meter temperature will be assumed at atmospheric temperature Moisture content of the gas can be assumed from available plant information, or can be determined by a wet bulb dry bulb thermometer This will be checked later by the moisture condensed during the test plus that calculated to be carried by the saturated gas passing the meter Th velocity of the gas is first measured at the sampling point by means of a Pitot tube, and this also necessitates reading the temperature at that point A velocity traverse at this time is advisable See examples on page 19

ASSEMBLING EQUIPMENT

Insert a paper thimble in the holder and preheat the holder to about 212°F being sure that the valve between the ejector and the meter is closed Attach the rubber tube from the condenser inlet to the filter holder and insert the filtration tube in the flue to correct depth to reach the point for which the meter rate was calculated and clamp in place The sample nozzle must point directly into the moving gas stream Turn on the condenser water For convenience, set the meter dial pointers to zero For more detail see page 15

TEST PROCEDURE

With the air blowing through the ejector, gradually bring the meter rate up to that calculated, by opening the valve between the meter and the ejector Readings of the meter rate, volume, and vacuum should be taken at appropriate intervals

Care should be taken that the gas volume through the meter does not exceed two cubic feet per minute In five minutes or less, the meter temperature will have become constant (The meter should be protected from outside temperature changes by insulating) Operate exploratory test long enough to insure a weighable sample

As the test proceeds, dust packing in the thimble will increase the amount of suction required to maintain the proper meter rate and the valves should be adjusted accordingly This suction should not exceed 4 inches of mercury, and, if during the test the mercury suction pressure at the meter should

drop, it indicates that a leak has developed in the equipment or that the paper thimble has burst In this event, the test should be discarded, the source of the trouble located, and the test repeated

At the end of the test period, close the valve between the ejector and the meter, remove the sampler from the flue, and disconnect the rubber tube from the sampler Do not disconnect the rubber tube until the sampler has been withdrawn from the flue, because, if the flue is under considerable suction, a reverse flow would be set up through the thimble which might cause some of the collected material to be drawn out through the sampling nozzle and lost A sampler should be kept in an upright position and should be handled carefully. If the thimble is not to be immediately removed, or if the sampler is to be carried to another location, a rubber stopper should be provided for the sampling nozzle.

After the sampler has cooled, remove the outer case of the thimble holder, and holding the sampler in an upright position, rap the filter tube to knock any dust which may have settled in the tube into the thimble Since the thimble retaining ring may become loosened during heating and cooling of the thimble holder, be careful that rapping does not loosen the thimble and allow it to drop off Care should be taken to remove and include in the sample all dust from the inside of the sampling nozzle and tube, brushing of the tube may be found necessary. Remove the thimble and place it in a dust tight container for transport to the weighing room With a graduate calibrated in cubic centimeters, measure the amount of water collected in the condenser.

The following example indicates the data that should be recorded during the test and the calculations in which the data is used.

FLUE TRAVERSE POINTS

From Table No 1 for a 16 point traverse, the data on the four equal area zones for a flue 54" in diameter indicates the following dimensions:

From circumference to station E-1 1¾" to station E-5 36⅝"
From circumference to station E-2 5⅝" to station E-6 43½"
From circumference to station E-3 10½" to station E-7 48⅜"
From circumference to station E-4 17⅜" to station E-8 52¼"

DETERMINATION OF FLUE VELOCITY

The traverse can now be made with the equipment as arranged in Figure 3 Measurement of the velocity heads (H) at the selected points of the traverse should be recorded as shown in the second column of the following tabulation. The stations here are named after the location of the test port used (E for East, W for West)

Station	Velocity Head Inches Water	Square Root	Temp in °F	Velocity (ft/sec)
E-1	0 29	0 538	240°	41 4
E-2	0 30	0 547	240°	42 0
E-3	0 28	0 530	240°	40 5
E-4	0 27	0 520	240°	39 9
E-5	0 21	0 458	240°	35 2
E-6	0 23	0 480	240°	36 8
E-7	0 18	0 425	240°	32 6
E-8	0 19	0 436	240°	33 5
W-1	0 28	0 530	240°	40 5
W-2	0 29	0 538	240°	41 4
W-3	0 26	0 510	240°	39 1
W-4	0 26	0 510	240°	39 1
W-5	0 22	0 470	240°	36 0
W-6	0 22	0 470	240°	36 0
W-7	0 19	0 436	240°	33 5
W-8	0 18	0 425	240°	32 6

Average square root 0 488

Average velocity head $(H) = (0\ 488)^2 = 0\ 238$ inches water pressure.

GAS VELOCITY

The average velocity can now be computed using average velocity head (H_{avg}=0 238) in the following formula

(3) $V_{s\,avg} = 2\,90\sqrt{\frac{29\,92}{P_s}\times\frac{1\,00}{G_d}\times H_{avg}T_s}$

$= 2\,90\sqrt{\frac{29\,92}{27\,8}\times\frac{1\,00}{1\,00}\times 0.238\times 700}$

$= 38\,9$ ft /sec

The velocity at the individual points may be computed by the same formula using velocity head (H) at each particular point

If a gas analysis is available, and the gas specific gravity is not known, it may be computed as shown in the following example

Moisture=18%

By Orsat analysis
CO_2=10 0% Dry basis
CO =; 6 4% Dry basis
O_2 = 2 8% Dry basis
N_2 =80 8% Dry basis

H_2O	18×18	= 3 24
CO_2	82× 10 ×44	= 3 6
CO	82× 064×28	= 1 47
O_2	82× 028×32	= 0.735
N_2	82× 808×28	=18 5
		27.545

$G_d = \frac{27\,54}{28\,95} = 0\,95$

GAS VOLUME

The gas volume can be computed as follows

(6) $V_v = V_{s\,avg}\times A\times 60 = 38\,9\times 15\,9\times 60 = 37{,}200$ CFM

CALCULATION OF METER RATE FOR EXPLORATORY FILTRATION TEST

Having picked a 3/8" diameter nozzle for the test, assuming ambient temperature of 77°F (537° Abs) for the meter temperature, and assuming no moisture to be condensed, then a meter rate can be calculated Test station 11, being the point closest to the average velocity of the flue, is a suitable test point

(8) $R_m = 0\,\cancel{3}\,\frac{T_m}{T_s}\times V_s\times d^2\times\left[\frac{P_s}{P_b - P_m}\right]^*$

$R_m = 0\,33\times\frac{537}{700}\times 39\,1\times(3/8)^2$

$R_m = 1\,39$ CFM

*NOTE When the meter pressure varies more than 5% from the flue pressure, a correction factor should be applied as shown in dotted brackets

This formula will give the correct meter rate in cubic feet per minute to maintain a velocity through the sample nozzle the same as the gas velocity in the flue, providing no moisture is condensed out of the gas ahead of the meter. If part of this volume is condensed out as water before the gas enters the meter, the meter will not record total volume through the nozzle and a correction must be made for final correct rate as will be shown in final calculation on page 21 Generally, the absolute meter pressure will average over 5% less than the flue pressure, and an allowance will be required.

SUMMATION OF DATA FROM EXPLORATORY TEST

	Assumed Values for Sample Calculations
V_m = Volume of gas sample as measured by meter in cubic feet	115 cu ft.
W_t = Weight of dust filtered in grams	25 35 gms
T_m = Temperature of meter in ° absolute (average)	85°F + 460 = 545°F Abs
P_m = Suction at meter in inches of mercury (average)	2.33" Hg
V_w = Volume of water condensed in cubic centimeters (liquid state)	150 cc

DUST DETERMINATION TEST NO 1

SELECTION OF TEST DURATION

In the exploratory test, we collected 25 35 grams in 83 minutes Let us assume that the flue to be sampled has a cyclic period of 180 minutes, say precipitator rapping at 3 hour intervals Since a test period of 180 minutes with a 3/8" nozzle would give about 55 grams of dust, we might expect excessive suction with such a large sample, therefore, we would select a 1/4" nozzle for the actual test.

CALCULATION OF CORRECTED METER RATES

The calculation for the corrected meter rate for point W-3 using the data obtained in the exploratory test will serve as an example.

$$R_m = 0.33 \times \frac{T_m}{T_s} \times V_s \times d^2 \times \frac{P_s}{P_b - P_m}$$

$$R_m = 0.33 \times \frac{545}{700} \times 39\ 1 \times (1/4)^2 \times \frac{27\ 8}{27\ 8 - 2\ 3} =$$

$R_m = 0\ 685$ CFM (uncorrected for water vapor)

Converting condensates to vapor volume at meter conditions

(9) $$V_v = 0\ 00267 \times \frac{V_w \times T_m}{P_b - P_m}$$

$$V_v = 0\ 00267 \times \frac{150 \times 545}{27\ 8 - 2\ 33}$$

$V_v = 8\ 57$ CF

Calculating meter rate correction factor for condensed water

(10) $$M_c = \frac{V_m}{V_m + V_v}$$

$$M_c = \frac{115}{115 + 8\ 57}$$

$M_c = 0\ 93$

Corrected meter rate $= R_m \times M_c$
$= 0\ 685 \times 0\ 93$
$= 0\ 637$ CFM

FILTRATION TRAVERSE (INTEGRATED)

Assume that a single-test determination of the quantity of suspensoid carried by the gas stream is to be made, that is, under conditions existing on the date of the measurements, then a traverse sample should be taken

The cross-section of the flue to be sampled should be laid off in zones of equal area as for the velocity determination. For purposes of illustration, we will use the same cross-section as described in the previous

example for the exploratory test We again have four areas to be sampled and sixteen corresponding traverse points The meter rate should be calculated for each of these points as outlined above The sampling tube should be laid off in lengths the same as the Pitot tube was arranged

Having 16 points to sample, and having established a test duration of approximately 180 minutes, if we sample for 12 minutes at each station, we will consume 192 minutes which is sufficient

Proceed to assemble equipment as for exploratory test (page 18), and proceed with the test Readings of the meter rate, sampled volume and vacuum should be taken at appropriate intervals to give at least two readings for each traverse point After an elapsed time of 12 minutes, the clamp should be loosened, and the sample nozzle moved to the next traverse point and the meter rate readjusted to give sampling rate calculated at this point This procedure should be repeated for each of the traverse points. When sampling has been completed, remove and weigh the thimble following technique established in exploratory test

FILTRATION TRAVERSE (FOR CONCENTRATION FACTOR)

If sampling is continued over a lengthy period of time, as for control work, it may be desirable to make a quantity traverse and determine a quantity factor or establish an average point for continuous sampling In order to do this accurately, it will be necessary to use a separate thimble and take a separate sample at each of the traverse points If the suspensoid is very fine and light in nature, and if the velocity traverse indicates a fairly uniform gas velocity at the sampling cross-section, and if extreme accuracy is not required, it will suffice to reduce the number of sampling points, sampling at several points by taking a separate sample with a separate thimble at each point sampled The amount of suspensoid carried by the gas stream at each traverse point must be calculated and a factor obtained for some convenient point by dividing the value at that point by the average of all the values, or a point may be selected which has a value equal to the average of all the traverse points

DUST SAMPLE FOR PARTICLE SIZE ANALYSIS

Samples taken for particle size determination should contain a minimum of 7 grams of product, although for a limited quantity from special tests where large samples are impossible, samples as small as 2¼ grams can be submitted if several samples are avaiable, or specific gravity is known Since particle size determination requires special equipment and skill, it is usually best to submit the samples to Western Precipitation Corporation laboratories or some other laboratory suitably equipped Samples should be sent in air tight glass containers, and where thimbles are used, the thimble should be folded shut, and sent in a glass container. Containers and thimbles should be clearly marked to indicate company name, equipment being tested, and other designations that will indicate the unit, time, special conditions, and name of engineer making the tests Samples should be carefully packed and shipped to avoid breakage in transit

SUMMATION OF DATA TEST NO 1

	Assumed Data for Sample Calculations
V_m = Volume of gas sample as measured by the meter in cubic feet	105 cu ft.
T_m = Temperature at meter in degrees absolute	83°F+460=543° Abs (avg)
P_b = Barometric pressure in inches of mercury	27 8″ Hg
P_m = Suction at meter in inches of mercury	2.5″ Hg (avg)
V_w = Volume of water condensed in cubic centimeters (liquid state)	138 cc
W_t = Weight of dust filtered from gas sample in grams	23 gms.

VOLUME OF TOTAL GAS SAMPLED (METER CONDITIONS)

Converting condensate to vapor volume at meter conditions·
(Should there be no condensate, the volume as recorded on the meter, V_m, will be the total volume sampled and correction for water vapor, V_v, can be omitted)

(9) $$V_v = 0\ 00267 \times \frac{V_w \times T_m}{P_b - P_m}$$

$$V_v = 0\ 00267 \times \frac{1\ 38 \times 543}{27\ 8 - 2\ 5}$$

$$V_v = 7\ 92 \text{ CF}$$

Total gas sampled $= V_v + V_m$
$= 7\ 92 + 105$
$= 112\ 92$ CF

MOISTURE CONTENT OF THE GAS SAMPLED (BY VOLUME)

M_m = Volume of moisture remaining in metered gas at meter conditions in cubic feet

(11) $$M_m = \frac{V\ P \times V_m}{P_b - P_m}$$

Vapor pressure of water at 83°F = 1.138" Hg

$$M_m = \frac{1\ 138 \times 105}{27\ 8 - 2\ 5}$$

$$M_m = 4.72 \text{ CF}$$

(12) $$\%\ \text{Moisture} = \frac{V_v + M_m}{V_v + V_m} \times 100$$

$$= \frac{7\ 92 + 4\ 72}{7\ 92 + 105} \times 100$$

$$= 11\ 2\%$$

CONVERTING TOTAL SAMPLED GAS VOLUME TO STACK CONDITIONS

(13) $$V_t = (V_m + V_v) \times \frac{P_b - P_m}{P_s} \times \frac{T_s}{T_m}$$

$$V_t = (105 + 7\ 92) \times \frac{27\ 8 - 2\ 5}{27\ 8} \times \frac{700}{543}$$

$$V_t = 132\ 4 \text{ CF}$$

DUST CONCENTRATION

Dust concentration is generally referred to in terms of grains per cubic foot and pounds per hour To express the dust concentration in grains per cubic foot, divide the filtered dust weight (W_t) by the total sampled gas at stack conditions (V_t), and convert from grams to grains as follows:

$$\text{Grains/cubic foot} = \frac{W_t}{V_t} \times 15\ 43$$

$$= \frac{23}{132\ 4} \times 15\ 43$$

$$= 2.68$$

This can now be converted to pounds per hour.

From our Pitot traverse, we found that average gas volume was 37,200 CFM.

$$\text{Pounds/hour} = \text{grains/cubic foot} \times V_o \times \frac{60}{7000}$$

$$= 2\ 68 \times 37{,}200 \times \frac{60}{7000}$$

$$= 854$$

BALANCED TUBE METHOD

The method of determining the nature and amount of suspensoids carried by a gas stream without accurate determination of velocity or volume, is based on a relation of areas and velocities

If we have a flue of known cross-section, and if we draw out of that flue a sample of gas through a nozzle of known area at the same rate or nozzle velocity as that of the gas passing, then the suspensoids carried by the sample will bear the same ratio to the total suspensoids passing as the area of the nozzle bears to the area of the flue The sample may be filtered and weights determined by the same methods as those described for the Dust Concentration Method In order to draw the sample at the same rate of velocity as that of the gas velocity in the flue, a "Balanced Tube" is used as the sampling nozzle The balanced tube is based on the principle that if the velocity within the sampling nozzle is equal to that outside, the static pressures will be equal, and if the static pressures are not equal, then the velocities will not be equal

Experience has shown that relatively large variations in velocity may cause very small variations in static readings and that these small static variations may also be materially affected by small imperfections in the static openings. For this reason, and the fact that different characteristics are inherent in various designs, all null nozzles should be calibrated in the laboratory before using in the field.

The apparatus consists of a null sampling nozzle equipped with two auxiliary tubes, one connected to static openings inside the nozzle and one with openings outside in the flue, or to a secondary chamber opening to the outside of the nozzle These two tubes are brought out and connected to the two sides of a differential gauge An apparatus is shown in Figure 16 In operation, the sampling velocity or rate is

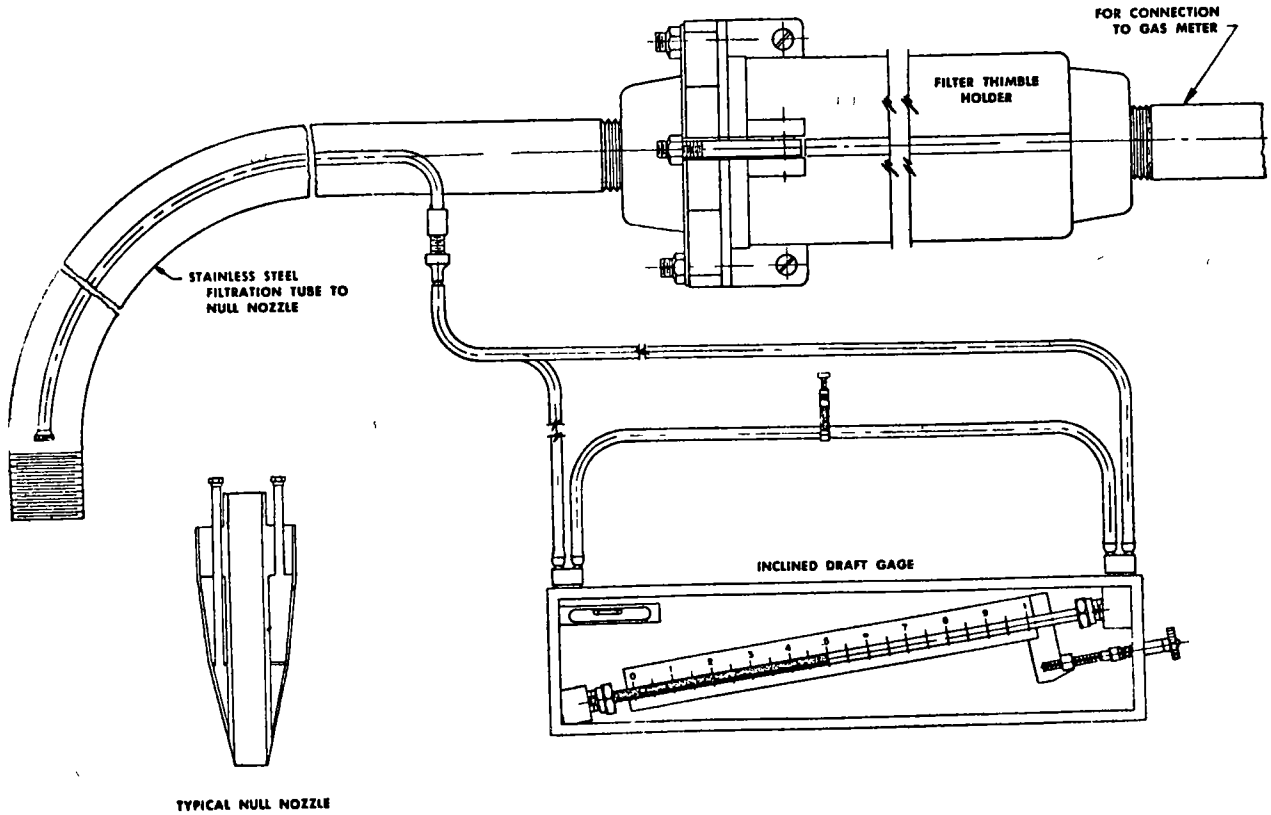


Fig. 16 TYPICAL BALANCED TUBE FILTRATION ASSEMBLY

adjusted until the gauge reads zero, or some predetermined point on the gauge at which the zero level has been established by calibration

The formula for determination of the suspensoids carried in pounds per hour is:

(16) Pounds per hour $= 0.318 \frac{A \times W_t}{a \times T}$

Where:

A = area of the flue in square feet

a = area of nozzle in square inches

W_t = Weight of material caught in grams

T = duration of the run in hours

DETERMINATION OF EFFICIENCY OF GAS CLEANING EQUIPMENT

Where the efficiency of gas cleaning apparatus is to be determined, any one of three methods may be used in the order of accuracy as follows:

First, by weighing the catch and sampling the gas leaving the apparatus. The dust caught during the time of the sample, divided by the sum of the dust caught and the calculated weight of the dust leaving the apparatus, gives the efficiency.

Second, by sampling the gas entering the apparatus and weighing the catch. The catch, divided by the calculated dust entering for a corresponding period of time, gives the efficiency.

Third, by sampling the gas entering the apparatus and the gas leaving the apparatus over simultaneous periods, and dividing the outlet concentration by the inlet concentration This gives per cent loss which, subtracted from 100, gives per cent efficiency.

TABLE I

EQUAL AREA ZONES FOR VELOCITY TRAVERSE

ROUND FLUES

Diameter in Inches	Area in Square Feet	Number of Equal Zones	Area of Each Zone in Square Feet	Radius to Stations in Zone A in Inches	Radius to Stations in Zone B in Inches	Radius to Stations in Zone C in Inches	Radius to Stations in Zone D in Inches	Radius to Stations in Zone E in Inches	Radius to Stations in Zone F in Inches
8	3491	2	1746	2	3 1/2				
10	5454	2	2725	2 1/2	4 3/8				
12	7854	2	3925	3	5 1/4				
		3	2618	2 1/2	4 1/4	5 1/2			
14	1 069	2	534	3 1/2	6				
		3	356	2 7/8	5	6 3/8			
15	1 227	2	6134	3 5/8	6 1/2				
		3	409	3	5 3/8	6 7/8			
16	1 396	2	7085	4	7				
		3	465	3 1/4	5 5/8	7 1/4			
18	1 767	2	883	4 1/2	7 7/8				
		3	589	3 3/4	6 3/8	8 1/4			
20	2 182	3	727	4 1/8	7 1/8	9 1/4			
		4	535	3 5/8	6 1/8	7 7/8	9 3/8		
22	2 640	3	880	4 1/2	7 3/4	10			
		4	66	3 7/8	6 3/4	8 5/8	10 1/4		
24	3 142	3	1 047	4 7/8	8 1/2	11			
		4	785	4 1/4	7 3/8	9 1/2	10 1/4		
26	3 687	3	1 229	5 3/8	9 1/4	12			
		4	922	4 5/8	8	10 1/4	12 1/8		
28	4 276	3	1 425	5 3/8	9 7/8	12 3/4			
		4	1 07	5	8 5/8	11	13 1/8		
30	4 909	4	1 227	5 3/8	9 1/4	11 7/8	14		
		5	982	4 5/8	8 1/4	10 5/8	12 1/2	14 1/4	
32	5 585	4	1 396	5 5/8	9 3/4	12 5/8	14 7/8		
		5	1 117	5	8 3/4	11 3/8	13 3/8	15 1/4	
36	7 069	4	1 767	6 3/8	11	14 1/4	16 3/4		
		5	1 416	5 5/8	9 7/8	12 3/4	15	17 1/8	
42	9 621	4	2 405	7 1/2	12 3/4	16 5/8	19 5/8		
		5	1 924	6 1/2	11 1/2	14 7/8	17 1/2	19 7/8	
48	12 51	4	3 13	8 1/2	14 5/8	19	22 3/8		
		5	2 50	7 1/2	13 1/8	17	20	22 7/8	
		6	2 085	7	12	15 1/2	18 3/8	20 3/4	23
54	15 9	4	3 98	9 5/8	16 1/2	21 3/8	25 1/4		
		6	2 65	7 1/2	13 1/2	17 1/2	20 5/8	23 1/4	25 7/8
60	19 63	4	4 91	10 5/8	18 3/8	23 5/8	28		
		6	3 27	8 3/4	15	19 3/8	22 7/8	25 7/8	28 3/4
66	23 76	4	5 94	11 7/8	20 1/8	26	30 3/4		
		6	3 96	9 5/8	16 1/2	21 3/8	25 1/4	28 1/2	31 5/8
72	28 27	4	7 07	12 3/4	22	28 3/8	33 5/8		
		6	4 71	10 1/2	18	23 1/4	27 1/2	31 1/4	34 1/2
78	33 18	4	8 29	13 7/8	23 3/4	30 3/4	36 3/8		
		6	5 53	11 3/8	19 1/2	25 1/4	29 7/8	33 7/8	37 3/8
84	38 48	4	9 62	14 7/8	25 3/8	33 1/8	39 1/8		
		6	6 41	12 1/4	21	27 1/8	32 1/8	36 3/8	40 3/8
90	44 18	4	11 04	16	27 1/2	35 1/2	42		
		6	6 69	13 1/8	22 1/2	29 1/8	34 3/8	39	43 1/4
96	50 27	4	12 57	17	29 1/4	37 7/8	44 3/4		
		6	8 38	14	24	31	36 5/8	41 5/8	46
108	63 61	6	10 60	15 5/8	27	34 7/8	41 1/4	46 3/4	51 3/4
120	78 54	6	13 09	17 3/8	30	38 3/4	45 7/8	52	57 1/2
132	95 03	6	15 84	19 1/8	33	42 5/8	50 1/4	57 1/2	63 1/4
144	113 10	6	18 85	20 7/8	36	46 1/2	55	62 3/8	70

TABLE 2

VAPOR PRESSURES OF WATER

In Inches of Mercury

Temp. Deg. F.	0	1	2	3	4	5	6	7	8	9
—20	0126	.0119	0112	0106	0100	0095	0089	.0084	.0080	0075
—10	0222	0209	0199	0187	.0176	.0168	.0158	.0150	.0142	.0134
—	0376	.0359	0339	0324	0306	0289	.0275	.0259	.0247	.0233
0	0376	0398	0417	0441	0463	0489	0517	0541	0571	0598
10	0631	0660	0696	0728	0768	0810	0846	.0892	0932	0982
20	1025	1080	1127	1186	1248	1302	1370	1429	.1502	1567
30	1647	1716	1803	1878	1955	2035	2118	2203	2292	2383
40	2478	2576	2677	.2782	2891	3004	3120	3240	.3364	3493
50	3626	3764	3906	4052	.4203	.4359	4520	4686	4858	5035
60	5218	5407	5601	5802	6009	6222	6442	.6669	.6903	7144
70	7392	7648	7912	8183	8462	8750	9046	9352	9666	9989
80	1 032	1 066	1 102	1 138	1 175	1 213	1 253	1 293	1.335	1 378
90	1 422	1 467	1 513	1 561	1 610	1 660	1 712	1 765	1 819	1 875
100	1 932	1 992	2 052	2 114	2 178	2 243	2 310	2.379	2 449	2 521
110	2 596	2 672	2 749	2 829	2 911	2 995	3 081	3 169	3 259	3 351
120	3 446	3 543	3 642	3 744	3 848	3 954	4 063	4 174	4 289	4 406
130	4 525	4 647	4 772	4 900	5 031	5 165	5 302	5 442	5 585	5 732
140	5 881	6 034	6 190	6 350	6 513	6 680	6 850	7 024	7 202	7 384
150	7 569	7 759	7 952	8 150	8 351	8 557	8 767	8 981	9 200	9 424
160	9 652	9 885	10 12	10 36	10 61	10 86	11 12	11 38	11 65	11 92
170	12 20	12 48	12 77	13 07	13 37	13 67	13 98	14 30	14 62	14 96
180	15 29	15 63	15 98	16 34	16 70	17 07	17 44	17 82	18 21	18 61
190	19 01	19 42	19 84	20 27	20 70	21 14	21 59	22 05	22 52	22 99
200	23 47	23 96	24 46	24 97	25 48	26 00	26 53	27 07	27 62	28 18
210	28 75	29 33	29 92	30 52	31 13	31 75	32 38	33 02	33 67	34 33
220	35 00	35 68	36 37	37 07	37 78	38 50	39 24	39 99	40 75	41 52
230	42 31	43 11	43 92	44.74	45 57	46 41	47 27	48 14	49 03	49 93
240	50 84	51 76	52 70	53.65	54 62	55 60	56 60	57.61	58 63	59 67
250	60 72	61 79	62 88	63 98	65 10	66 23	67 38	68 54	69 72	70 92
260	72 13	74 36	74 61	75 88	77 16	78 46	79 78	81 11	82 46	83 83
270	85 22	86 63	88 06	89 51	90 97	92 45	93 96	95 49	97 03	98 61
280	100 2	101 8	103 4	105 0	106 7	108 4	110 1	111 8	113 6	115 4
290	117 2	119 0	120 8	122 7	124 6	126 5	128 4	130 4	132 4	134 4
300	136 4	138 5	140 6	142 7	144 8	147 0	149 2	151 4	153 6	155 9
310	158 2	160 5	162 8	165 2	167 6	170 0	172 5	175 0	177 5	180 0
320	182 6	185 2	187 8	190 4	193 1	195 8	198 5	201 3	204 1	206 9
330	209.8	212 7	215 6	218 6	221 6	224 6	227 7	230 8	233 9	237 1
340	240.3	243 5	246 8	250 1	253 4	256 7	260 1	263 6	267 1	270 6
350	274 1	277 7	281 3	284 9	288 6	292 3	296 1	299 9	303 8	307 7
360	311 6	315 5	319.5	323 5	327 6	331 7	335 9	340 1	344 4	348 7
370	353 0	357 4	361 8	366 2	370 7	375 2	379 8	384 4	389 1	393.8
380	398 6	403 4	408 2	413 1	418 1	423 1	428 1	433 1	438 2	443 4
390	448 6	453 9	459 2	464.6	470 0	475 5	481.0	486 6	492 2	497 9
400	503.6	509.3	515.1	521.0	526 9	532 9	538 9	545 0	551.1	557 3

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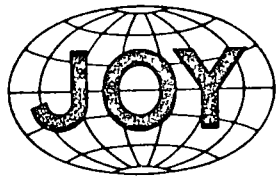

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Contaminación de la atmósfera en México por fuentes vehiculares

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RESUMEN

Se requieren medidas urgentes para reducir la contaminación causada por fuentes vehiculares En el Valle de México, el nivel de plomo en la atmósfera sobrepasa al de cualquiera de las grandes ciudades de Estados Unidos de Norteamérica, pero se puede abatir con medidas sencillas que no presentan ningún problema tecnico El nivel de monóxido de carbono, y muy posiblemente el de hidrocarburos, es también muy elevado, siendo una de las causas la altura sobre el nivel del mar La labor iniciada bajo el Programa de Estudio, Evaluación y Control de la Contaminación Ambiental deberá intensificarse, ampliarse y mantenerse en forma permanente.

ABSTRACT

Urgent measures are required to reduce the pollution caused by vehicular sources In the Valley of Mexico, the level of lead in the atmosphere exceeds that of any large city in the United States, however it can be abated with simple measures which do not pose any serious technical problem The level of carbon monoxide, and very possibly that of hydrocarbons, is also very high, one cause being the altitude above sea level The work begun under the Program for the Study, Evaluation, and Control of Environmental Pollution must be intensified and widened, as well as sustained continuously and permanently

1. INTRODUCCION

El control de las emisiones de contaminantes que provienen de diferentes clases de vehículos, particularmente de automóviles y camiones, constituye un reto formidable para las autoridades, centros de investigación e industrias automotrices, al que no podrán enfrentarse con efectividad sin la colaboración decidida de un publico que comprenda la gravedad de la situación y que este dispuesto a participar en un programa coordinado que reconozca las múltiples interrelaciones que entran en juego en este problema cuya amenaza se acrecienta día a día. La motivación del público para aceptar el papel que le corresponde, depende del conocimiento de los peligros de la contaminacion, y de la convicción de que los esfuerzos de cada persona serán valiosos.

Ha terminado la inactividad de las autoridades al crearse, por decreto presidencial, el Programa de Estudio, Evaluación y Control de la Contaminación Ambiental administrado por el Consejo Nacional de Ciencia y Tecnología (CONACYT) Este programa incluye un registro detallado de los niveles de contaminantes, procesamiento e interpretación de datos, investi-

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gaciones relativas, entre otras cosas, a efectos tóxicos, daños a la fauna y a la flora, sistemas de control de emisiones, y aspectos geofísicos, formulación de recomendaciones para las reglamentaciones que se implanten, y establecimiento de fuentes informativas para científicos y tecnicos, así como para el publico en general

A continuación se presenta un panorama general del problema de contaminación por fuentes vehiculares a traves de una breve exposición de cada uno de los principales contaminantes, indicando su efecto sobre la salud, datos sobre la concentración en la atmósfera del Valle de Mexico, forma de generación, límites legales de las emisiones en Estados Unidos (cuya legislación en esta área es de las más avanzadas), métodos de control, y consideraciones relativas a la situación en México

2. HIDROCARBUROS (HC)

Su efecto tóxico, en particular a largo plazo, no ha sido totalmente determinado, sin embargo, existen indicios de que algunos hidrocarburos tienen efectos cancerígenos En combinacion con óxidos de nitrógeno, intervienen en una reaccion fotoquímica en la cual los rayos solares actuan como catalizador y cuyo efecto es la produccion de "smog" Estos contaminantes causan irritacion en los ojos y dañan la vegetacion De un total de 17 millones de toneladas de HC emitidas en Estados Unidos durante 1965, 11 millones se debieron a los automóviles (ref 1)

Los dos métodos usuales para medición de los niveles de hidrocarburos son el de ionizacion de flama y el de deteccion de hexano normal por medio de un analizador infrarrojo El programa del CONACYT antes mencionado incluye un extenso plan de mediciones de este tipo en la atmosfera, sin embargo, actualmente no se cuenta con datos al respecto Se supone que el nivel de hidrocarburos en el Valle de Mexico es muy elevado debido a que, además de la alta concentracion de vehículos y la deficiente circulación de los mismos, se presenta el fenomeno del incremento en emisiones de hidrocarburos y monoxido de carbono de los motores de gasolina con respecto al nivel del mar, debido al enriquecimiento de combustible en la mezcla admitida en los cilindros por la reduccion en la presión atmosferica Este fenómeno se analizará posteriormente con mas detalle

Las diferentes formas en que un vehículo con motor de ciclo Otto emite hidrocarburos son por evaporacion que ocurre en el carburador y en el tanque de gasolina (20 por ciento), por el cárter debido a fugas provenientes de la cámara de combustion (20 por ciento), y por el escape debido a combustión incompleta (60 por ciento)

La evaporación se puede suprimir casi totalmente con un sistema cerrado en el cual los vapores se captan y condensan En Estados Unidos todos los automóviles nuevos están equipados con dicho sistema En México, las industrias automotrices aun no lo han incorporado en su producción

Las emisiones del cárter se pueden suprimir totalmente con la instalación de un sistema de recirculación del cárter a la admision Este sistema se conoce como "control positivo de ventilacion" (PCV) La reglamentación a este respecto varía en Estados Unidos de estado a estado En todos ellos es obligatoria la instalacion del sistema para la supresión de emisiones del carter en vehículos nuevos En el estado de California se exige, además, la instalacion de dicho sistema en todos los automóviles de modelo posterior a 1954 al efectuarse un cambio de dueño En los primeros cinco años de haberse impuesto dicho reglamento, se hicieron alrededor de dos millones de instalaciones de este tipo, con un costo aproximado de 200 pesos por unidad incluyendo la instalacion En Mexico, la mayoría de los automóviles nuevos tienen el sistema PCV, pero todavía no existe una reglamentación al efecto

El problema de emisión por el escape es el más difícil de resolver Algunos de los métodos para reducir la emisión de HC, incorporados en automóviles de producción o en vías de desarrollo, son los siguientes empobrecimiento de la mezcla combustible aire, precalentamiento del aire de admision, retraso del encendido, uso de reactores térmicos, reactores catalíticos, y quemadores, corrección altimetrica del carburador, reduccion del desplazamiento del motor, supresion de la alimentacion de combustible de baja velocidad al decelerar

Como se mencionó, la situación es particularmente grave en el Valle de Mexico por el efecto de la altura Debido a que la emisión de monoxido de carbono (CO) tambien se incrementa por la altura, en el análisis que se da a continuación se incluye este contaminante

En un motor de gasolina, la riqueza de la mezcla admitida en los cilindros, es decir, la relación de combustible aire en terminos de masa, varía con la densidad del aire que, a la vez, depende de la presión y la temperatura atmosferica Se puede demostrar que la relación se aproxima a la siguiente (ref 2).

$$R = c/\sqrt{d} \qquad (1)$$

donde R es la riqueza de la mezcla, d la densidad del aire, y c una constante Se ha supuesto una densidad fija del combustible así como una configuración fija de los conductos de aire y combustible

Si se supone una temperatura constante, d será proporcional a la presión atmosferica Tomando esa presión al nivel del mar como 760 mm Hg y en la ciudad de Mexico como 585 mm Hg, se encontrará mediante la ec 1 que R sufrirá un incremento de 14 por ciento aproximadamente en la ciudad de Mexico con respecto al nivel del mar

Se puede hacer una estimacion del aumento en emisiones de CO y HC de un automóvil debido al enriquecimiento de 14 por ciento en la mezcla aire combustible, suponiendo un ajuste inicial del carburador cerca del punto de economía máxima Para esto se utilizarán datos de las refs 2 y 3 En las páginas 402 y 403 de la ref 3 se presentan gráficas, correspondientes a una prueba de un motor V-8, de la variación de la presión media efectiva basada en la potencia al freno (bmep) y del consumo específico de combustible en la misma base (bsfc), con la riqueza relativa de la mezcla (F_r), es decir, la razón de R

al valor de R correspondiente a una proporción estoiquiométrica, manteniendose constantes la velocidad del motor y la posicion de la válvula de papalote controlada por el acelerador Considerando el caso en que esta ultima está totalmente abierta, se obtiene de las gráficas la siguiente información.

Valor mínimo de bsfc = 0 61 lbm/hp hr
Valor correspondiente de $F_r = 0\ 90$
Valor correspondiente de bmep = 64 7 lb/pulg^2

Si se considera ahora un aumento en F_r de 14 por ciento, se tendrá entonces, de las mismas gráficas

Valor incrementado de $F_r = 1\ 023$
Valor correspondiente bsfc = 0 66 lbm/hp-hr
Valor correspondiente de bmep = 67 8 lb/pulg^2

Estos datos estan basados en un ajuste óptimo del tiempo de encendido tal que se maximice el valor de bmep en cada caso Ahora bien, al enriquecerse la mezcla, si el combustible adicional se quemara completamente como para el punto de economía máxima (bsfc mínimo), se debería conseguir que

$$\text{bmep} = \frac{1\ 023}{0\ 90}\ (64\ 7) = 73\ 6\ \text{lb/pulg}^2$$

De ahí que la fracción no quemada del combustible adicional se estime como

$$x = \frac{73\ 6 - 67\ 8}{73\ 6 - 64\ 7} = 0\ 652$$

Otra estimacion de esa misma fracción se obtiene de la siguiente manera, el incremento en F_r de $1\ 023 - 0\ 90 = 0\ 123$ representa un aumento en consumo de combustible De este aumento se aprovecha solamente $0\ 123\ (1 - x)$, de ahi que el total de combustible aprovechado se representa por $0\ 90 + 0\ 123\ (1 - x)$ La razon entre el combustible aprovechado y el total consumido es aproximadamente igual a la razon de los consumos específicos para el punto de economía máxima y el de riqueza incrementada Entonces se tendrá

$$\frac{0\ 123\ (1 - x) + 0\ 9}{1\ 023} = \frac{0\ 61}{0\ 66}$$

lo que arroja $x = 0\ 626$. Se tomará un valor medio de $x = 0\ 639$

Las emisiones de CO y HC, en kilogramos por año, en el caso típico de un automóvil sin controles de emision, son aproximadamente como sigue

	Escape	Evaporación	Cárter	Total
HC	136 2	40 8	59 0	236 0
CO	772 0	—	—	772 0
Total	908 2	40 8	59 0	1008 0

correspondiendo a un consumo anual de 1 906 kg de combustible (ref 4)

Estas emisiones representan una pérdida de energía que se puede calcular utilizando valores caloríficos de 2 410 kcal/kg y 11 550 kcal/kg para CO y HC, respectivamente De ahí que las pérdidas de energía en kcal x 10^6 por año sean

	Escape	Evaporación	Carter	Total
HC	1 575	0 472	0 672	2 719
CO	1 861	—	—	1 861
Total	3 436	0 472	0 672	4 580

Si ahora se considera un enriquecimiento de la mezcla aire-combustible de 14 por ciento, y se toma en cuenta el desperdicio del combustible adicional representado por la fracción $x = 0\ 639$, así como el aumento en consumo de combustible debido al incremento en el consumo específico, se tendrá una perdida por el escape de

$$\frac{3\ 436 + 0\ 14\ (1906)\ (0\ 639)\ (11550) \times 10^{-6}}{1\ 14} \times \frac{0\ 66}{0\ 61} =$$

$= 5\ 130$ kcal x 10^6/año

lo que representa un incremento de

$$\frac{5\ 130 - 3\ 436}{3\ 436} \times 100 = 49\ 3\%$$

Es interesante comparar este resultado con las mediciones hechas por McMichael y Rose (ref 5) en automoviles en circulación en la ciudad de Denver (elevacion, 1 600 m), quienes observaron incrementos en emision de CO, con respecto al nivel del mar, de 50 por ciento (a 72 km/hr) hasta 70 por ciento (a 16 km/hr) y de HC de 10 por ciento (a 72 km/hr) hasta 70 por ciento (a 16 km/hr) Dicha comparacion se debe hacer utilizando los valores a la velocidad más alta (72 km/hr), ya que ese caso se acerca más a la condicion de plena carga supuesta en el presente análisis Por lo tanto, se considera un incremento en la pérdida de energía para la ciudad de Denver de

$$\frac{(0\ 50)\ (772)\ (2410) + (0\ 10)\ (136\ 2)\ (11550)}{3\ 436 \times 10^6} \times 100 = 31\ 6\%$$

Si se supone que los incrementos en CO y HC en Denver y en Mexico guardan la misma proporción entre sí, se tendrían entonces los siguientes resultados para los incrementos en emisión de HC y CO en México con respecto al nivel del mar

	Escape	Evaporación	Cárter	Total
HC	15 6%	0	0	9 0%
CO	77 9%	0	0	77.9%

Se hace hincapie en que estos valores corresponden a vehículos circulando a alta velocidad y que serían más elevados a baja velocidad

Con respecto al motor de ciclo diesel, es injustificada la fama que tiene de producir más contaminación que el de ciclo Otto, ya que el primero emite por el escape aproximadamente el 80 por ciento de HC y el 5 por ciento de CO que el segundo por unidad de energía entregada, además, la emisión por evaporacion de combustible es despreciable, y finalmente, no hay emision de plomo Sin embargo, las emisiones de óxidos de nitrogeno (NO_x) son mayores que en el caso del ciclo Otto El balance final, en peso total de emisión de HC, CO y NO_x por unidad de energia es favorable para el dísel, ya que la emision de este ultimo es solamente 12 por ciento de la del Otto (ref 6) La mala fama del dísel está fundada en las grandes emisiones de humo que muy frecuentemente se observan, sobre todo en Mexico Esto se debe a mal ajuste del motor Dicho humo es más molesto que tóxico

La reglamentación para vehículos nuevos existente en Estados Unidos permite un nivel máximo de 180 ppm (partes por millon) de HC en el gas de escape, que corresponde aproximadamente al 22 por ciento de la emisión de un automóvil sin control alguno (ref 6) En Mexico no existe reglamentación al respecto

3 MONOXIDO DE CARBONO (CO)

El monoxido de carbono es perjudicial por desplazar el oxíge no de la hemoglobina de la sangre, debido a su gran afinidad con ese compuesto

Existen mediciones, hechas en 1968, del nivel de CO en la atmosfera en la ciudad de Mexico (ref 7), las cuales revelan una concentracion del mismo orden que las más elevadas que se han registrado en las ciudades norteamericanas más contaminadas En la ref 8 se menciona la iniciación de un trabajo de muestreo de CO en la ciudad de Mexico y se hace la siguiente alarmante observacion

"Cabe señalar que las cifras preliminares obtenidas de las concentraciones de monoxido de carbono en el centro de la ciudad, son superiores a la concentración máxima permisible de 100 ppm que se fija en los ambientes de trabajo para una exposicion de 8 horas

Esta alta concentracion de CO en el centro de la ciudad parece, por lo tanto, ser producida por los vehiculos automotores en circulación, ya que son los principales emisores de este contaminante"

Como ya se ha dicho, la altura de la ciudad de Mexico es un factor adverso al problema de CO en la atmósfera, debido a su efecto sobre la emisión de este gas y a la reducción en oxígeno ambiental

Este contaminante es emitido por el escape y en general refleja mala combustión Se ha estimado (ref 1) que en Estados Unidos los automóviles contribuyeron con 60 de los 66 millones de toneladas de CO emitidas en 1965 El motor disel como ya se menciono, produce mucho menos CO que el motor Otto

La mayor parte de los métodos para la reduccion de emisión de HC por el escape son tambien efectivos para la reducción de CO

El limite legal de CO en el escape para vehículos nuevos en Estados Unidos es de 10 000 ppm, lo cual constituye aproximadamente 32 por ciento de la concentración en el escape de un motor sin controles (ref 6) En Mexico no existe reglamentación al respecto

4. OXIDOS DE NITROGENO (NO_x)

Como ya se indicó al hablar sobre hidrocarburos, estos y los oxidos de nitrogeno producen, mediante una reacción fotoquímica, compuestos que constituyen el "smog" El dióxido de nitrogeno (NO_2) es, en particular, tóxico para los humanos, animales y plantas, aunque los efectos a largo plazo no han sido correlacionados con las concentraciones existentes en la atmosfera Este contaminante afecta principalmente al sistema respiratorio

En el Valle de Mexico la concentración de NO_2 es relativamente baja cuando se le compara con ciudades norteamericanas Por ejemplo, segun la ref 7, el nivel medio anual para Mexico fue de 0 03 ppm durante 1969, mientras que en Los Angeles fue de 0 05 en 1964

En la ref 1 se indica que del total de 12 millones de toneladas de NO_x emitidas en Estados Unidos durante 1965, los automóviles contribuyeron con 5 5 millones

En un motor de combustión interna, los óxidos de nitrógeno se generan en la camara de combustion durante los periodos en que la presion y la temperatura son maximos Un enriquecimiento en la mezcla disminuye la produccion de estos compuestos Por lo tanto, es evidente que la altitud de la ciudad de Mexico es un factor favorable ya que, en forma directa, la menor presion atmosferica se refleja en presiones más bajas en la camara de combustion y, en forma indirecta, por el efecto de enriquecimiento de la mezcla mencionado anteriormente Esto se corrobora plenamente en la ref 5, donde se citan mediciones de emisión de NO_x de automoviles en la ciudad de Denver que arrojan valores de aproximadamente 50 por ciento de los correspondientes a nivel del mar

Los motores dísel, debido a la alta compresion y mezclas pobres utilizadas, emiten en promedio 40 por ciento más NO_x que los de ciclo Otto por unidad de energia entregada (ref 6)

Entre los sistemas para controlar la emision de NO_x se encuentran los convertidores catalíticos que, segun parece, todavía no han pasado de la etapa experimental Un obstaculo para su utilización es la gasolina con plomo, ya que este elemento acorta notablemente la vida útil de estos dispositivos Otro sistema consiste en recircular de 10 a 20 por ciento del gas de escape a la admisión para reducir la temperatura y presión máximas del ciclo de funcionamiento del motor La eficiencia

del motor se reduce considerablemente con el uso de este sistema

En Estados Unidos, el estado de California exigirá que para 1974 la emisión de NO_x de vehículos nuevos no exceda de 350 ppm, o sea el 25 por ciento de la emisión promedio sin control (ref 6) En México no existe reglamento al respecto

5. PLOMO

Se adiciona a la gasolina para aumentar su octanaje (índice de las propiedades antidetonantes) Aunque la toxicidad del plomo se reconoce como un grave riesgo en las industrias donde se utiliza esa sustancia, no se han demostrado aun sus efectos en el organismo debidos a niveles de concentracion como los que existen en la atmósfera de las grandes ciudades Sin embargo, la cantidad de plomo en el organismo de una persona expuesta a dicha atmósfera, segun investigaciones hechas en Estados Unidos, oscila entre 20 y 70 por ciento de lo que se considera el umbral de envenenamiento reconocido clínicamente (0 08 mg/100 ml de sangre) Los porcentajes más elevados ocurren en personas tales como agentes de transito y empleados de estacionamientos Inclusive se ha observado un mayor nivel de plomo en el organismo de quienes viven cerca

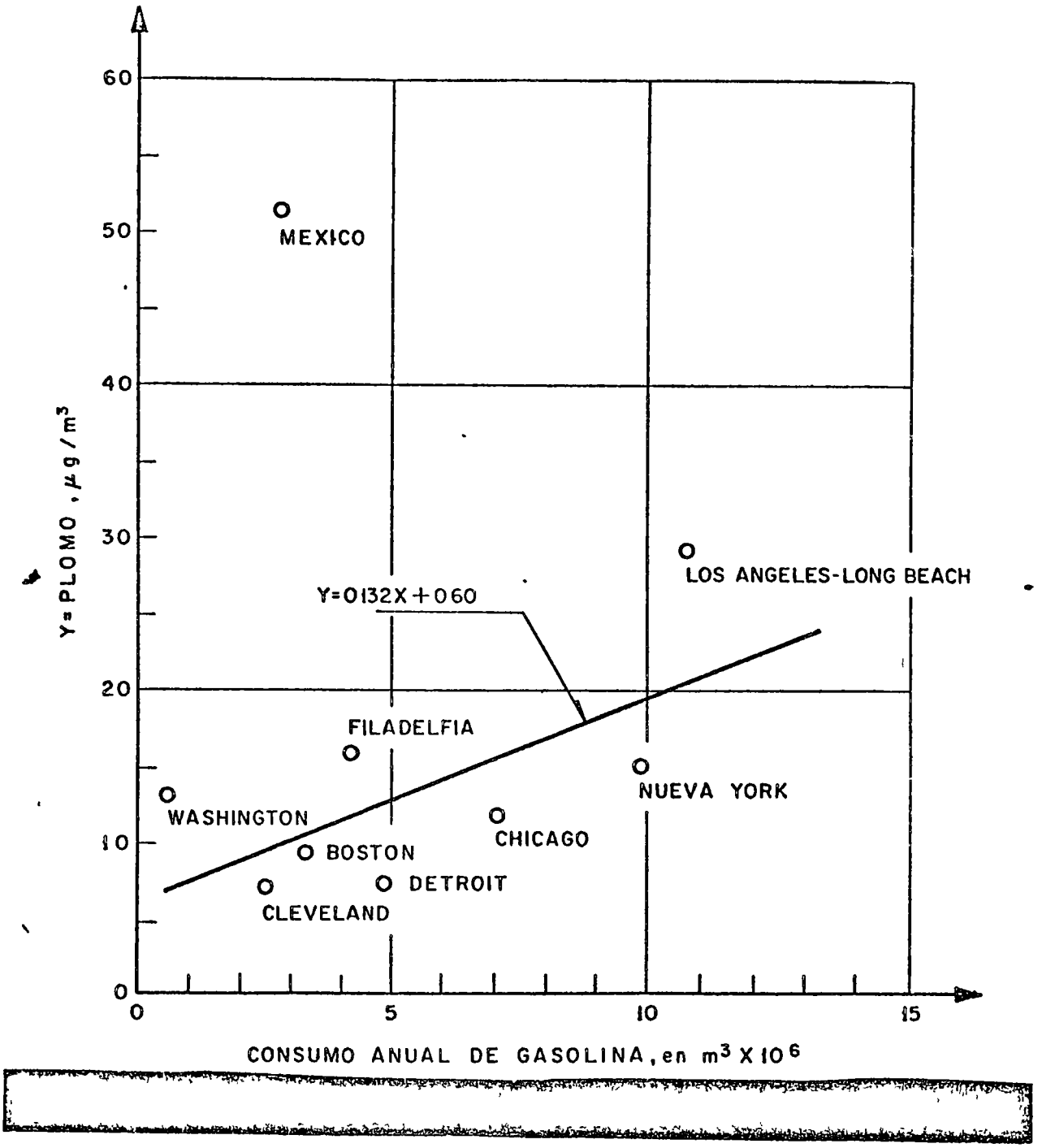

Fig 1 Relacion entre plomo ambiental y consumo de gasolina en diversas ciudades.

de una carretera en comparacion con quienes viven en puntos alejados (ref 4) En un estudio hecho en Mexico se demuestra (ref 7) la existencia de una bien definida correlacion entre el nivel de plomo en la atmósfera y el flujo de vehiculos En ese mismo estudio se hace la siguiente observación

" es notable el promedio obtenido para el plomo en la ciudad de Mexico con respecto a las ciudades americanas, ya que es 3 5 veces la concentracion de plomo anual para Cincinnati"

La comparación del nivel de plomo en la ciudad de México con el de las ciudades estadounidenses resulta aun más dramática si se examina la fig 1 En ella se exhibe la relacion entre el consumo anual de gasolina y el nivel de plomo en la atmosfera para varias ciudades La gráfica se tomó de la ref 4 haciéndole las siguientes modificaciones se extendio la escala vertical al doble para poder situar a la ciudad de Mexico, y se eliminaron las ciudades de menor importancia de Estados Unidos El coeficiente de correlacion en la grafica original es 0 71, y la relacion linealizada entre las variables es la siguiente

$$y = 0\,132\,x + 0\,6$$

De acuerdo con esta relación, y considerando que el consumo anual de gasolina en el Valle de Mexico, segun datos proporcionados por Pemex para el primer semestre de 1970, es 2 8 millones de m^3, se esperaria tener una concentracion de plomo de 0 97 $\mu g/m^3$ Sin embargo, las mediciones efectuadas durante los meses de octubre, noviembre y diciembre de 1968 (ref ') arrojaron un promedio de 5 11 $\mu g/m^3$

Esta alarmante situacion está totalmente injustificada segun se demostrara a continuación

Algunas platicas que en forma casual sostuvieron los autores con diversas personas, revelaron una ignorancia generalizada sobre las caracteristicas de las gasolinas que se expenden Aun mas, se encontro el prejuicio firmemente establecido de que el rendimiento de la gasolina aumenta y los depositos que deja en el motor disminuyen mientras mas cara sea esta Esta desorientacion motivo que se iniciara una encuesta consistente en relacionar los automoviles típicos del mercado nacional con el combustible que consumen, comparándolo con el que deberían usar

La tendencia observada es la de consumir gasolina de mayor octanaje y, por consiguiente, con mayor contenido de plomo y de mas alto costo que lo que se necesita, perjudicando simultáneamente el ambiente y el bolsillo del consumidor Esta tendencia se ha observado tambien en Estados Unidos (ref 9), a pesar de las campañas de orientacion que se han efectuado en ese pais La situacion es particularmente injustificada en el Valle de Mexico, ya que el octanaje requerido por un motor disminuye con la altura sobre el nivel del mar Esto obedece al hecho de que el octanaje requerido varía proporcionalmente con la presion media indicada (ref 3, pág 130) y esta ultima aumenta con la presión atmosférica para una velocidad dada del motor y una posición del control de aceleracion Si se supone que la presión media indicada es proporcional al flujo de combustible, que a su vez varía con la raíz cuadrada de la presion atmosferica, se obtendra que el octanaje requerido en la ciudad de Mexico es como 0 88 del que se requiere a nivel del mar Esto se traduce aproximadamente a un cambio de Pemex 100 a Gasolmex, o bien de Gasolmex a Supermexolina al pasar del nivel del mar a la ciudad de Mexico

Existe otra anomalía con efectos adversos La mexolina, que es la gasolina con menor contenido de plomo, no se expende publico en general, sino solamente para los automoviles de alquiler y camiones de carga, y agrava aun más la situacion el hecho de que la gasolina mexicana llega a contener hasta 4 g de plomo por galón de gasolina, siendo el limite legal en Estados Unidos de 3 g/gal Este limite se reducirá drásticamente en dicho pais para 1975 (ref 10)

Segun la ref 11, entre las gasolinas para uso automotriz, Pémex 100 supera en contenido de plomo a todas las del mundo, excepto las que se expenden en Jordania y las Islas Falkland Algunos ejemplos extraidos de la misma referencia de contenido máximo de plomo (en g/gal) en gasolina de 100 octanos son Francia—2 30, Alemania Occidental—2 38, Italia—2 38, Canada—2 66

Ademas del efecto toxico del plomo, se ha demostrado que este ingrediente de la gasolina tiene un efecto adverso sobre la combustión, incrementando la emision de HC y disminuyendo la vida util de los convertidores catalíticos

Con relación a los motores dísel, el combustible que usan no contiene plomo por no haber problemas de detonación

6 SINTESIS DEL PROBLEMA EN MEXICO Y RECOMENDACIONES

De la exposicion anterior se concluye que urge tomar medidas para reducir la emision de HC, CO y plomo provenientes de fuentes vehiculares Algunas de esas medidas pueden ser las siguientes reglamentaciones

a) Supresión de emisiones del cárter

Aplicable a los automóviles y camiones de gasolina nuevos y, de ser posible, a los de modelo posterior a 1965

b) Limitacion de emisiones de HC y CO por el escape

Para establecer una reglamentación al respecto es necesaria una investigacion para determinar los niveles maximos factibles de imponer, asi como el procedimiento a seguir y el equipo que se debe usar en las pruebas para determinar dichos niveles Ya que esto no es facil de lograr en un plazo corto, es imperativo que el reglamento existente sobre las condiciones mínimas de funcionamiento sea actualizado cientificamente y puesto en vigor Un motor con bujias en mal estado, fuera de tiempo, valvulas mal asentadas, carburador desajustado, anillos que no sellan bien, o filtro de aire tapado, produce mayor contaminacion que otro en buenas condiciones

El reglamento que se prepare debe incluir normas para motocicletas que, aun teniendo motores de bajo desplazamiento, frecuentemente contaminan el ambiente en forma desproporcionada

c) Supresion de emisiones por evaporacion

Aplicable a los automoviles y camiones de gasolina nuevos, que requerirá el control tanto de la evaporacion del tanque de gasolina como del carburador

d) Control de octanaje en vehículos

Cada automovil o camión de gasolina llevaría una certificación por medio de una calcomanía en el parabrisa, autorizando el tipo de gasolina correspondiente al máximo octanaje permitido en el Valle de Mexico

e) Limitación de potencia en los motores

Considerando que mayor potencia implica mayor flujo de gas de escape y, por tanto, mayor contaminacion, debe existir una reglamentacion que señale el caballaje máximo permitido en función del tipo de vehículo Esto constituiría una legislacion mas avanzada que la existente en Francia, la cual tiene como base fundamental el llamado "caballaje fiscal" en relacion al cual se determina el impuesto con que se ha de gravar un vehículo

Como ya se expuso, la altitud incrementa las emisiones de HC y CO, por lo cual es preciso desarrollar y perfeccionar correctores altimetricos para el carburador, por la circunstancia, unica en el mundo, de tener en Mexico concentrados más de medio millon de vehículos a mas de 2 000 metros sobre el nivel del mar

No se han mencionado otros contaminantes tales como los oxidos de azufre y las partículas, puesto que los vehículos contribuyen aproximadamente con solo el 4 0 y 8 3 por ciento, respectivamente, de la producción total de estos contaminantes (ref 1)

El ruido es, a veces, considerado como un contaminante Los vehículos son una de las principales fuentes del mismo, y su abatimiento a niveles mucho más bajos que los que soportamos en la ciudad de Mexico no presenta ningun problema tecnico Bastaría con que se pusiera en vigor un reglamento existente que prohíbe, por ejemplo, escapes directos y uso indebido del claxon Si esto, tan facil de lograr, no se ha hecho, ¿que probabilidades hay de que se observe un futuro reglamento sobre contaminacion atmosferica, que tendrá muchas más complicaciones tecnicas?

Las medidas que se han propuesto ayudarian a resolver el problema del deterioro de la atmosfera, y su aplicación inmediata constituye una urgente necesidad Sin embargo, se requiere una acción coordinada y sostenida que ataque global y previsoramente el problema en todos sus aspectos Esto significa que, ademas de las medidas ligadas en forma más directa a las emisiones de los vehículos que han sido tratadas en el presente artículo, es preciso enfocar la situación desde un punto de vista de ingenieria de sistemas, de tal manera que se consideren en conjunto factores tales como numero y distribución de estacionamientos, necesidades de vias rápidas, mantenimiento y ajuste de tiempo en los semáforos, densidad de población, y necesidades de transportes colectivos

Estamos muy lejos de la solucion del problema de las emisiones vehiculares, pero es muy importante que Mexico se una a las naciones tecnológicamente desarrolladas en el empeño por mejorar los actuales sistemas de propulsion y el desarrollo de otros radicalmente nuevos, por ejemplo, la turbina de gas o vapor, sistemas electricos, sistemas híbridos, propulsión de volante inercial y sistema de ciclo *Stirling* Esto se puede lograr con el apoyo del gobierno como patrocinador de dichas investigaciones Un beneficio adicional de tal esfuerzo, sería el impulso al desarrollo científico y tecnológico del país

Finalmente, conviene citar al Dr Haagen Smit, quien propuso la teoría de la reaccion fotoquimica como causa del "smog", y observa, con relación a las medidas tomadas en Estados Unidos para abatir la contaminacion atmosférica (ref 12)

"En el pasado, los esfuerzos para controlar (la contaminacion) se han caracterizado por una subestimacion de la gravedad y magnitud del problema, un error de juicio del potencial de las tecnicas de control disponibles, y un gran optimismo respecto al grado de cooperación de la industria y de la comunidad Hoy reconocemos que hemos sido siempre muy tímidos al determinar nuestras metas Esta política ha conducido a un desperdicio de esfuerzo y dinero para soluciones y remedios temporales, cuando en realidad se requieren medidas más drásticas "

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AIR POLLUTANT RESUME

Type of Pollutant	Effect	Source	Possible Control Measures	Air Pollution Sampling Method
Fallout Particulate Matter	Soiling of property, nuisance	Industry, combustion processes, road mix plants, incinerators, etc	Cyclones, bag filters, electrostatic precipitators, washers, etc.	Dustfall sampling Use of glass slides
Suspended Particulate Matter, Smoke	Soiling of property, visibility reduction, nuisance, health effects	Industry, combustion processes, road mix plants, incinerators, etc.	Bag filters, electrostatic precipitators, good combustion practices	1 High Volume Filter Sampler 2 AISI Smoke Sampler 3. Visibility Determinations
Hydrocarbons	Primary contributors to Los Angeles type smog (eye irritation, rubber cracking, visibility reduction, oxidant formation, plant damage)	Automotive vehicles, oil refineries, fuel handling, solvent handling	Automotive exhaust control devices and blowby devices, floating roof covers, vapor recovery systems	Flame ionization
Oxides of Nitrogen		Automotive vehicles, combustion processes, industry	Automotive emission control devices, controlled combustion	Saltzman method
Oxidant (a measure of Los Angeles smog)	Eye irritation Rubber cracking Plant damage	Photochemical reactions in the atmosphere	Controls for hydrocarbons and oxides of nitrogen	Potassium iodide method
Carbon Monoxide	Toxic pollutant Reduces visual and mental acuity	Automotive vehicles Incomplete combustion	Automotive exhaust devices (under development) Good combustion practices	A modification of the NBS colorimetric detector tube technique
Sulfur Dioxide	Corrosive, odorous, plant damage, health effects	Combustion processes, industry, etc	Absorption towers, control of sulfur content in fuel	West-Gaeke method
Pollen	Allergy, hay fever	Natural—trees, grasses, weeds, etc	Farming methods, weed control	Collection on slides
Odors	Nuisance	Industry, sewage and water treatment, open burning, etc.	Good housekeeping, chemical control, masking counteractant, afterburners, etc.	Trained observers Panel of observers Volunteer observers

DEFINITIONS

From American Standards Association:

Dusts: Solid particles generated by handling, crushing, grinding, rapid impact, detonation and decrepitation of organic or inorganic materials such as rock, ore, metal, coal, wood, grain, etc. Dusts do not tend to flocculate except under the influence of gravity.

Fumes: Solid particles generated by condensation from the gaseous state, generally after volatilization from molten metals, etc., and often accompanied by a chemical reaction such as oxidation. Fumes flocculate and sometimes coalesce.

Mists: Suspended liquid droplets generated by condensation from the gaseous to the liquid state or by breaking up a liquid into a dispersed state, such as by splashing, foaming, and atomizing.

Gases: Normally formless fluids which occupy the space of enclosure and which can be changed to the liquid or solid state only by the combined effect of increased pressure and decreased temperature. Gases diffuse.

Vapors: The gaseous form of substances which are normally in the solid or liquid state and which can be changed to these states either by increasing the pressure or decreasing the temperature alone. Vapors diffuse.

Other Terminology

Smoke: Carbon or soot particles less than 0.1 micron in size which result from the incomplete combustion of carbonaceous materials such as coal, oil, tar, and tobacco.

Fly Ash: Particles of ash which become entrained in the combustion gases and are carried into the air.

Aerosol: An air or gas suspension of particles (usually less than 50 u).

Fog: An aerosol of liquid droplets near the ground as distinct from clouds.

Smog: Mixture of smoke and fog as coined in England. Presently used also to describe photochemical aerosols such as those in Los Angeles.

Haze: Suspension of small (fractional micron) particles in the air which makes distant, large objects indistinct (most often in hot air).

Smaze: Mixture of smoke and haze. Suggested for photochemical smog but is not widely used.

Radioactivity: The nuclear disintegrations which atoms undergo in giving off ionizing radiations.

Radiation: Electromagnetic radiations plus those corpuscular emission which are classed as "rays."

Noise: Unwanted sound. Sound is the effect which rapid, local fluctuations of the atmospheric pressure have on the ear.

GAS LAWS

1. Boyle's Law. The volume of a gas varies inversely with its pressure at constant temperature. This law is so simple and usually so well understood that further elaboration seems unnecessary. Its principal application is in reducing observations of gas volumes from field conditions to some standard condition.

2. Charles's Law. The volume of a gas at constant pressure varies in direct proportion to the absolute temperature. Interpretation of this law poses no problems provided that the absolute temperature scale is used. Charles's law finds its greatest use in the calculation of pressures in fixed-volume containers with variable temperature.

3. Dalton's Law of Partial Pressures. In a mixture of gases, such as air, each gas exerts pressure independently of the others. The partial pressure of each gas is proportional to the amount (per cent by volume) of that gas in the mixture. The basic concept of this law, in combination with Henry's law, serves in many engineering considerations and calculations.

4. Henry's Law. Henry's law states: The weight of any gas that dissolves in a given volume of a liquid, at constant temperature, is directly proportional to the pressure that the gas exerts above the liquid.

5 Graham's Law. Graham's law is concerned with the diffusion of gases, and it states: The rates of diffusion of gases are inversely proportional to the square roots of their densities. This law can be illustrated by a comparison of the rates of diffusion of hydrogen, oxygen, chlorine, and bromine, which have atomic weights of approximately 1, 16, 36, and 80, respectively. On the basis of Graham's law, oxygen diffuses about one-fourth, chlorine about one-sixth, and bromine about one-ninth as fast as hydrogen. This law finds its greatest application in the field of industrial hygiene and air pollution control.

6. The Ideal Gas Law. The perfect gas law may be used to define the volume of gas present in terms of mass, temperature and pressure.

$$PV = nRT$$

P = pressure
V = volume
n = number of moles of gas
R = "universal gas constant"
T = absolute temperature

Handout 5

Notes on Stack Sampling: Please see example and refferences.

I. Need for stack Sampling:

Emission Inventory
Enforcing codes
Research
Certifying oppertion to meet standard

II. Basic Equipment Needed:

1. Pitot tubes: (Usually used with inclined manometer guage.)

Regular
Type S for wet effluents
Orfice disk for small pipes
Anemometer for low velocities

2. Pumps, Gas meters, Clean tubing, Glass filter holders, Glass fiber filter paper(without binder, usually type A), Impingers (4-6), ice bath, Thermometers (3)(1 high temperature), Water manometer, mercury manometer, and gas control valves. Asbestos cloth, heating wire and reostat, thermocouples and indicators (usually on Pitot assembly).

3. Probes:

Simple heated
Null probe (contains pitot tubes for automatic isokinetic sampling). Also Heated.

4. Lab Equipment:

Dessicator Jars
Low temperature oven
Microbalance for pre and post weighing of filter papers.
Low temperature evaporation dishes.

III. Method , (Simplified)

1. Make velocity Travers, make Temperature travers if necessary (usuallly not)

Use equal areas if possible
Number of test points (Suggested only)

Area	No. of Points
<2 ft^2	4
2 to 25 ft^2	12
>25 ft^2	20

2. Sampling. Consider:

Heating of probe to gas temperature , also filter holder
Isokinetic flow at probe mouth
handling of preweighed filter papers.
proper cooling of impingers
One test at each sampling point for equal time isa sample.

3. Where to sample:

IN NON TURBULENT FLOW REGIONS
If pitot pressure difference is irractic flow is turbulent.

A. Usually ducting following process before the control equipment, or before stack, or both if efficiencies are needed.
B. Before entering stack, or
C. Near base of stack in laminar region, and rarely at the top of the stack

Stack analisis (Coont.)

IV. Sample Handling

A. Leave in holders if possible

B. Dehydrate filters by heating followed by dessication for 24 hours. dessicate for an additional 24 hours and weigh again.

C. Wash out probe and tubing to filter holder with solevent (no residue) after each test and put into preweighed evaporation dish. Include weight in filter weight. THIS IS IMPORTANT.

D. Wash out Impingers and evaporate in preweighed evaporation dishes . These are your "Condensables".

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PRICE LIST FOR HIGH VOLUME AIR SAMPLER

Model GMWL 2000

Effective July 1, 1967

Prices Subject To Change Without Notice

High Volume Air Sampler Model GMWL 2000 Less Filter Holder	$75.00
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Parts For Model GMWL 2000 Air Sampler

2001	1/8" Neoprene Gasket	$ .90
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