SAMPLING THE ATMOSPHERE

by

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Several groups at Brookhaven have devoted much attention to problems associated with air cleaning and air sampling. The activities conducted by the Health Physics Division in relation to air cleaning have been summarized in an earlier presentation by Gemmel. My purpose is to review briefly a few aspects of the Meteorology Group atmospheric sampling program. Atmospheric sampling separates into three rather distinct studies denoted by the terms sampling methods, periods and locations. The last of these has been given full consideration, but there are several developments within the first two categories that may be of interest to this assemblage.

Early efforts toward obtaining accurate oil-fog sampling techniques were largely directed toward light-scattering instruments similar to those of Gucker [1] . These developments led to a photometric densitometer that is completely suitable for its specific field use. The device utilizes the 90° scattering of visible light by small particles as the basic operating principle. It differs from other instruments of this general type largely in the refinement of the equipment to give a high degree of stability in field operations. Noteworthy are the use of nickel-cadmium batteries operated in conjunction with a 6-volt charger to provide a constant wattage at the light source, and a completely sealed, dehumidified chamber enclosing both the range switch and its associated resistors. The units are shielded from shock and vibration by rubber mountings. A uniformly clean,

background atmosphere for "zeroing" in the field is provided by helium gas. The instruments in their present form can detect .003 mg/m^3 of oil-fog even while in motion.

Although these units provide [illegible] each requires a vehicle and a complex assortment of auxiliary equipment. As such they are not likely to be used in large numbers, for the cost in dollars and manpower would be excessive. To obtain a large number of simultaneous samples, a filter-type sampler has been developed. This instrument is essentially similar to many other battery-operated units, but it is considerably cheaper, more accurate and draws a larger volume of air than most. The heart of the sampler is a Trico EV-105 pump operated by a standard automobile storage battery. This pump, available in quantity at a unit price of approximately $14.00, will draw 0.75 cfm through a 1-inch Millipore filter for more than 2 hours with a decrease of only 10% in flow rate. The unit currently used at Brookhaven employs the 6-volt model, but the 12-volt assembly would probably operate at lower temperature with longer life. A high order of accuracy is achieved by determining the pressure-drop flow rate curve for each individual filter and head, and subsequently measuring the pressure-drop during field operations by a mercury manometer mounted on the case. The manometer was chosen because of the difficulty experienced with several types of small flowrators.

The Millipore filter is of course not a necessary component of the assembly for all purposes. It is used for the oil-fog testing because it has proven highly reliable in both the collection and the subsequent fluorometric analysis. Measurements of .008 mg of oil are possible with the technique in its present form, and as many as 100 samples can be pro-

cessed during a normal working day.

The most recent development is the conversion of the filter system for airborne operation. Based on considerable unfortunate experience with airborne sampling techniques, it was decided at the outset that any sampler involving excessive weight, complicated electronics, wires or control lines might as well be discarded without test. A simple device, preferably inexpensive since the chance of loss is great, was the objective. A very suitable solution was found in the Fox 35 model aircraft motor. This semi-diesel, "glow plug" motor is used with the Millipore filter head in two ways. In the first, a portion of the intake vacuum draws air through the filter. The volume is necessarily small (0.05 cfm), but the flow rate is reasonably steady and successful runs of 30 minutes or more are common. The second model makes use of a cut-down Trico pump coupled to the motor to provide a flow rate of 0.5 cfm, comparable to that of the ground sampler. The weights of the two assemblies including filters, tubing etc. are 1.5 and 3.5 lbs. respectively. Since the J-1400 Kytoon has a static free lift of 2.2 lbs., they can also be described as 1-Kytoon and 2-Kytoon models. Oil-fog concentration measurements during temperature inversions have already been obtained, and test runs extending to 1000 feet above ground have been shown to be practicable. Two men are required for launching, and one can manage the instrument afterward.

The use of the filter samplers focuses attention directly on the problem of sampling time. The dependence of sampling accuracy on the time scale of concentration fluctuations was described at the recent Symposium at Pasadena by Smith and Singer [2] . Further efforts along this line have resulted in the preparation of a UNIVAC program for the processing of both wind and

concentration power spectra. Enough data have been studied by this means to show conclusively that in typical daytime conditions, eddies having periods of 6-10 minutes dominate the dispersion from the 355 foot test stack at Brookhaven. If additional studies give results in agreement with these initial data, it will be necessary to consider rather far-reaching revisions in much of our instrumentation as well as our sampling techniques. After all the emphasis on fast response equipment, it would be ironic to find that heavily-damped instruments were really the most suitable for typical pollution problems.

REFERENCES

1. Gucker, Picard and O'Konski, 1947: A Photoelectric Instrument for Comparing Concentrations of Very Dilute Aerosols and Measuring Low Light Intensities, J. Am. Chem. Soc., 69, 429.

2. Smith and Singer, 1955: Sampling Periods in Air Pollution Evaluations, Proc. 3rd Nat. Air Poll. Symp., Pasadena, Cal., pp. 80-85.

SOME OBSERVATIONS OF PARTICLE DISTRIBUTION WITH HEIGHT IN THE LOWER ATMOSPHERE

by

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ABSTRACT

Quantitative observations of dust particle concentrations and particle size-frequency distributions at various heights up to 400 feet above the ground surface are presented. It is observed that particle concentrations decrease rapidly with height near the ground and less rapidly at higher elevations. The decrease in concentration of large particles with height is much more rapid than for small particles.

SOME OBSERVATIONS OF PARTICLE DISTRIBUTION WITH HEIGHT IN THE LOWER ATMOSPHERE

I. INTRODUCTION

The particle load carried by the free atmosphere is of direct interest in at least two general problems of air cleaning. The amount of particulate material and the size of the particles carried by the atmosphere to the air intakes of an industrial plant is of practical interest since these quantities determine the amount and type of air purification required to meet the plant requirements for particle-free air. Similarly, the particle loading of the air leaving the plant has direct consequences in the problems of deposition and deleterious effects of the particles on the surrounding area.

The present paper is directed to the first of these problems. In particular, observations of dust particle loading of the lower atmosphere due to the erosive action of the wind upon the ground surface are presented to show, 1) the relative decrease in concentration of particles of various size with height, and 2) how the mass of particulate material per unit volume of air decreases with height above the ground surface. Prediction of the total dust loading of the atmosphere at any particular locality and under a given set of surface and meteorological conditions must be done on a largely empirical basis at the present time. Work on the specification of the necessary and sufficient parameters for the prediction of surface erosion, and subsequent airborne concentrations,

has gone forward during the past few years but no adequate quantitative treatment of this problem has yet emerged.

II. PARTICLE DISTRIBUTION WITH HEIGHT

Under natural conditions the energy necessary to remove particles from the surface and lift them to some height must be derived from the kinetic energy of the air motions. In the case of particle removal from the surface this momentum transfer is accomplished in two ways, 1) by direct drag of the air on the particles, and 2) by the impingement of previously airborne particles on the surface, the impinging particles having been accelerated by the air motions during their time of flight. Since the work done in moving a particle upward is directly proportional to the mass of the particle, heavy, or large, particles are more difficult to remove from the surface and these large particles are not carried to as great heights as the small particles by this initial impulse.

Once the particles are airborne they are dispersed by the turbulent motions of the wind. But the large particles have fall velocities which are generally large with respect to these turbulent motions and the large particles tend to return to the surface rather quickly. The small particles are more at the mercy of the air motions and may be dispersed to appreciable altitudes.

The net effect of the differential removal and dispersion of particles according to the size or mass of the particles is two-fold: 1) the concentration of particles decreases with increasing particle

size at all levels, and 2) the concentration of large particles decreases more rapidly with height than does the concentration of smaller particles. [illegible] substantiate this picture quite well and indicate the magnitude of these concentrations and vertical concentration gradients at Hanford.

We may specify more exactly what is meant by "large" and "small" particles from work done by W. S. Chepil[1]. From wind tunnel experiments and some observations made under field conditions, Chepil has classified the relative erodibility of various particle* sizes as follows:

Particle Diameter	Relative Erodibility
$d < 20\mu$	Non-erodible except under excessive wind speeds (> 50 mph at 6 in.)
$20 \leq d < 50$	Difficultly erodible.
$50 \leq d < 500$	Highly erodible.
$500 \leq d < 1000$	Difficultly erodible.
$d \geq 1000$	Non-erodible except under excessive wind speeds (>50 mph at 6 in.)

Chepil[2] also points out that wind erosion of soils is more nearly controlled by the fraction of each of these particle sizes present on the surface so that particles less than 50μ in diameter are easily erodible in the presence the highly erodible particles 50-500μ in diameter.

According to the above classification we should not expect to find airborne particles greater than 1000μ in diameter simply because

*Natural dust particles, density assumed to be 2.65 gm/cm^3.

they are seldom removed from the surface. Hence, a particle 500-1000 μ in diameter could be considered to be a large particle. On the other end, the smallest airborne particle size is probably dictated by the smallest particles present in the surface soil.

III. PARTICLE CONCENTRATION MEASUREMENTS

All of the particle concentration measurements reported here were made with cascade impactors of the type shown in Figure 1. The impactor is on the left and temperature, wind speed, and wind direction sensors are shown to the right. The particle size-frequency distributions were obtained by visual sizing and counting of the particles impacted upon the four slides or stages used in this instrument. In order to obtain vertical distributions of particle concentrations three or more impactors were operated simultaneously at various heights above the ground. The 400-foot Meteorology Tower and the 42-foot Portable Mast were used as platforms for these observations.

The particle size-frequency distribution for one of these observations is shown in Figure 2. The five class intervals chosen for grouping of particles according to size are shown at the bottom of this figure. These class intervals of diameter correspond to Chepil's classification according to relative erodibility.

The average particle diameter and the mass mean diameter for this particular size-frequency distribution of particles are also

shown in Figure 2. The average diameter is simply the arithmetic mean while the mass mean diameter is defined as the particle diameter which would be observed if all the particles were of a uniform diameter and density. (The particles are assumed to be spherical and of a uniform density, 2.6 gm/cm^3, for all mass calculations.) Since the particle concentration decreases through no less than four orders of magnitude, the mass mean diameter gives a somewhat more representative measure of the size-frequency distribution, although it cannot supplant the size-frequency distribution.

The average concentration of particles in each of four class intervals of size and at various levels up to 400 feet above the surface on August 1, 1955, are shown in Figure 3. The decrease of particle concentration with increasing particle size and the relatively rapid decrease of concentration of large particles with height are clearly evident. The ratios of both of these quantities for the class intervals of size used here may be measured in terms of orders of magnitude.

The average mass concentration of dust particles and the mass mean diameter of these particles for the August 1 observations are shown in Figure 4. The mass concentration decreases ten-fold in the first 100 feet above the ground and is nearly constant above that level. The mass mean diameter also decreases with height, indicating the relative abundance of large particles in the lower levels.

The remaining observations of particle concentrations were made with the Portable Mast and are therefore limited to the first 41 feet above the surface. Only the average mass of dust particles and the mass mean diameters are shown in the figures; a more complete tabulation of particle size-frequency and average wind speeds are given in Table 1.

An observation of dust loading of the atmosphere when the Portable Mast was downwind from traffic over a dusty road is shown in Figure 5. This is not natural wind erosion, of course, but it is interesting to note that the dust kicked up by traffic did not rise to the 15-foot level even though abnormally high concentrations of dust were present at the 0.9-foot level.

A pair of observations of dust concentrations, one made in the morning and the other in mid-afternoon of the same day, are shown in Figure 6. These observations were made under natural conditions and the average wind speed was 3-5 mph during both periods. The dust concentration at each level was practically invariant between the observation periods. Again we note a rapid decrease in dust load in the lowest layers of the atmosphere.

A similar pair of observations, made during the morning and afternoon of May 27, 1955, are shown in Figure 7. Light rain had fallen during the afternoon and evening of the previous day so that the ground surface was damp during the morning of the 27th but dried out during the day. Particle concentrations were low during the

morning and there was practically no vertical gradient of dust mass. With increased erosion during the afternoon particle concentrations increased in the lower levels and the usual gradient of mass concentration was reestablished.

The observations shown in Figure 8 were made during a windy period on October 5, 1955, when the ground surface was dry. Again we observe a rapid decrease of dust concentration with height in the lower layers and essentially uniform concentrations above 15 feet.

IV. CONCLUSIONS

The implications of these observations of dust concentrations at various heights above the surface are obvious so far as the position of air intakes is concerned. A reduction of dust concentrations by a factor of one-fifth or one-tenth can be achieved by placing the air intakes at ten to fifteen feet above the surface. These observations are not strictly applicable in the vicinity of a large building since the building itself introduces turbulent motions which may mix particles to greater heights. But there appears to be little doubt that airborne dust concentrations, produced by erosion of the soil, decrease rapidly with height in the vicinity of the ground surface.

Similar observations have been reported by Chepil and Milne[3]. They found that approximately 93% of the total dust load transported

by the atmosphere over an open field in Canada was transported in the layer between the surface and a height of one foot.

V. REFERENCES

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(2) Chepil, W.S., 1945 Dynamics of wind erosion: I. Nature of movement of soil by wind. Soil Science, 60: 305-320.

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Table 1

Measurements of dust particle size-frequency distributions in the lower atmosphere at HAPO. 1955.

Tower	Date	Time	Height	Particle Size Range* A	B	C	D	E	Ave. Mass Conc.	Average Particle Diameter	Mass Mean Diam.	Average Wind Speed
			ft	No. per ft^3	No. per ft^3	No. per ft^3	No. per ft^3	No. / ft^3	x 10^{-5} gm/ft^3	μ	μ	mph
400 ft	Aug. 11	1600 to 1700 PST	1¼	6381	2585	747	71		73.7	12	39	14
			50	5181	1557	275	9		12.5	9	24	24
			100	3377	1138	185	3		5.8	9	24	26
			200	3821	1159	148	1		3.6	8	17	27
			400	2254	819	88	2		3.4	9	19	31
42 ft Portable Meteorology Mast	Apr. 8	0830-1530 PST	0.9	920	330	80	56	16	142	21	92	2-10**
			14.7	3500	800	84	4		5.1	7	21	2-12**
			41.3	2500	480	36	1		1.6	7	16	2-14**
	May 4	0900-1100 PST	0.9	2200	350	37	2		2.4	6	19	3
			14.7	1500	190	6	0.3		0.4	6	12	4
			41.3	1600	180	8	0.9		0.2	6	10	4
		1300-1600 PST	0.9	2200	590	56	1.4		2.3	7	18	3
			14.7	1800	180	8	0.3		0.5	5	12	4
			41.3	1600	180	9	0.6		0.8	6	15	5
	May 27	0830-1230 PST	0.9	870	150	19	1		1.2	7	20	6
			14.7	580	110	9	1		1.1	7	23	8
			41.3	720	110	13	1		1.1	7	22	10
		1300-1530 PST	0.9	1600	670	77	2		3.2	9	22	5
			14.7	1400	320	24	2		2.2	7	21	7
			41.3	1200	270	13	1		1.2	7	18	8
	Oct. 5	1215-1315 PST	0.9	5000	750	83	8		8.6	7	22	6
			14.7	3500	243	35	2		2.4	5	17	13
			41.3	5000	230	30	2		2.3	5	15	18

* A: 0.9 to 5 μ ; B: 5 to 20 μ ; C: 20 to 60 μ ; D: 60 to 240 μ ; E: 240 to 500 μ .

** Range of hourly average wind speeds observed during this period.

FIGURE-1

CASCADE IMPACTOR AND METEOROLOGICAL INSTRUMENTS

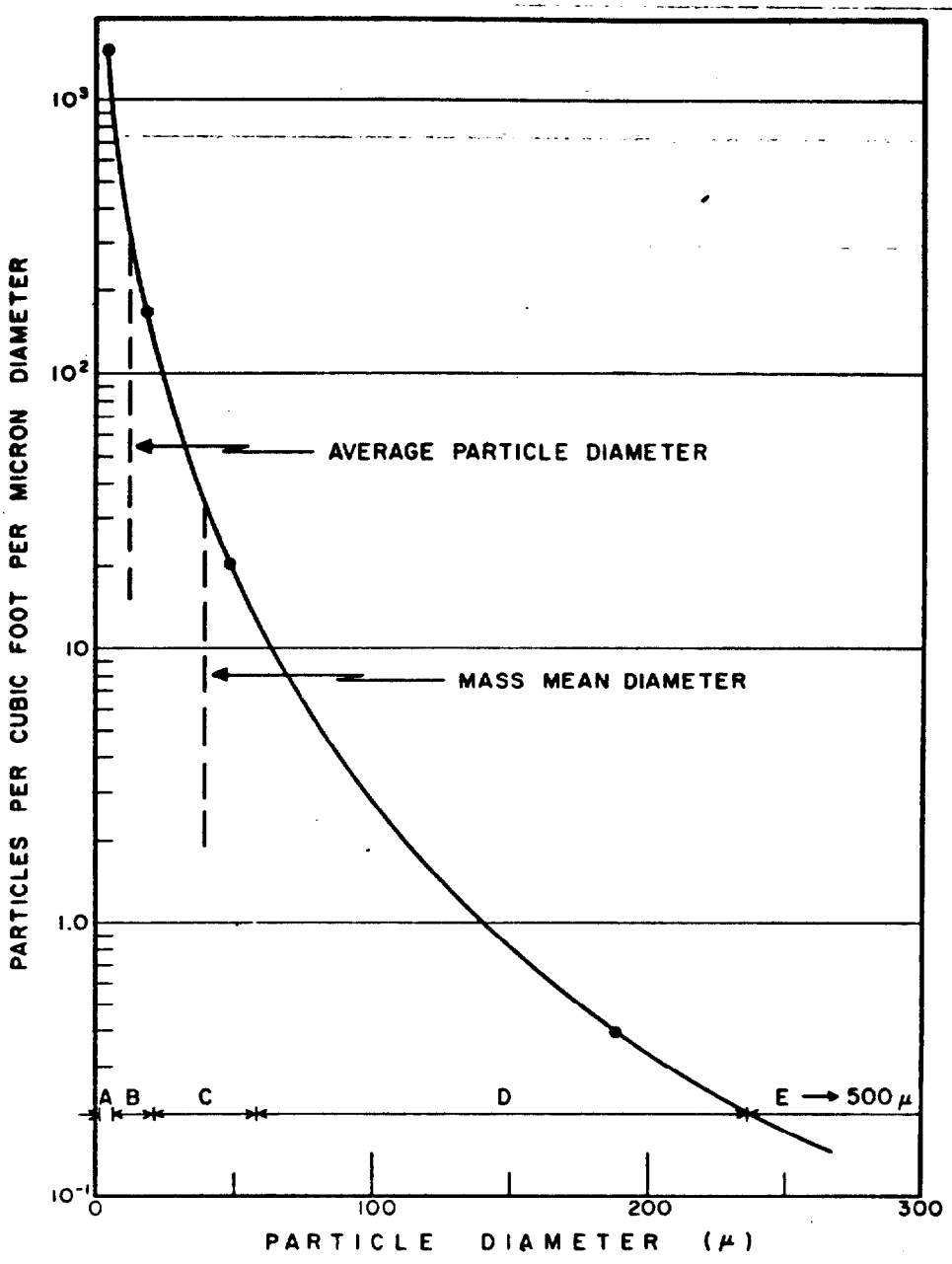

FIGURE – 2
PARTICLE SIZE-FREQUENCY DISTRIBUTION
15 INCHES ABOVE GROUND LEVEL.
METEOROLOGY TOWER, HAPO. AUGUST 1, 1955

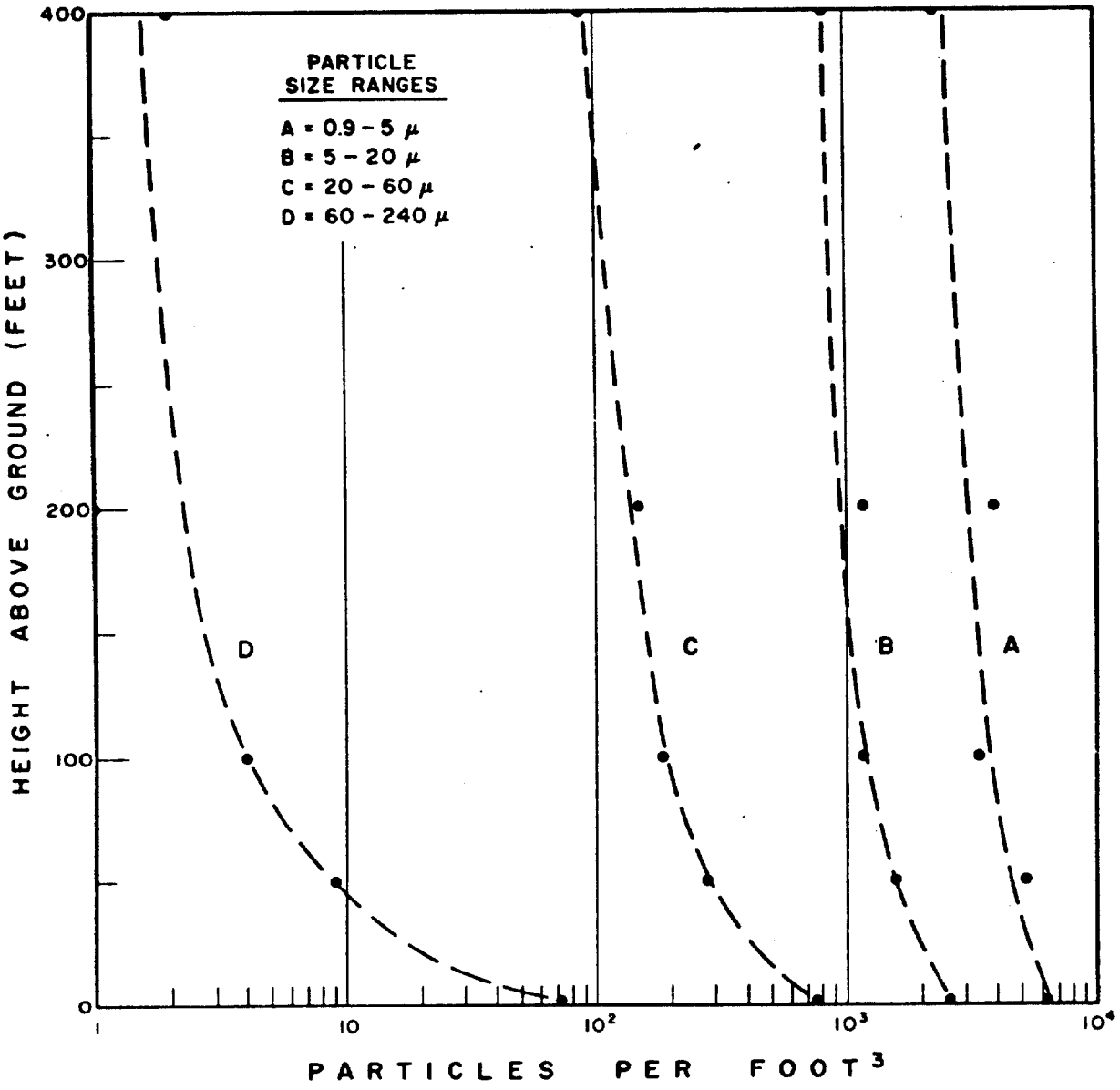

FIGURE - 3
AVERAGE CONCENTRATION OF DUST PARTICLES IN VARIOUS SIZE RANGES UP TO 400 FEET ABOVE GROUND LEVEL. METEOROLOGY TOWER, HAPO. AUGUST 1, 1955

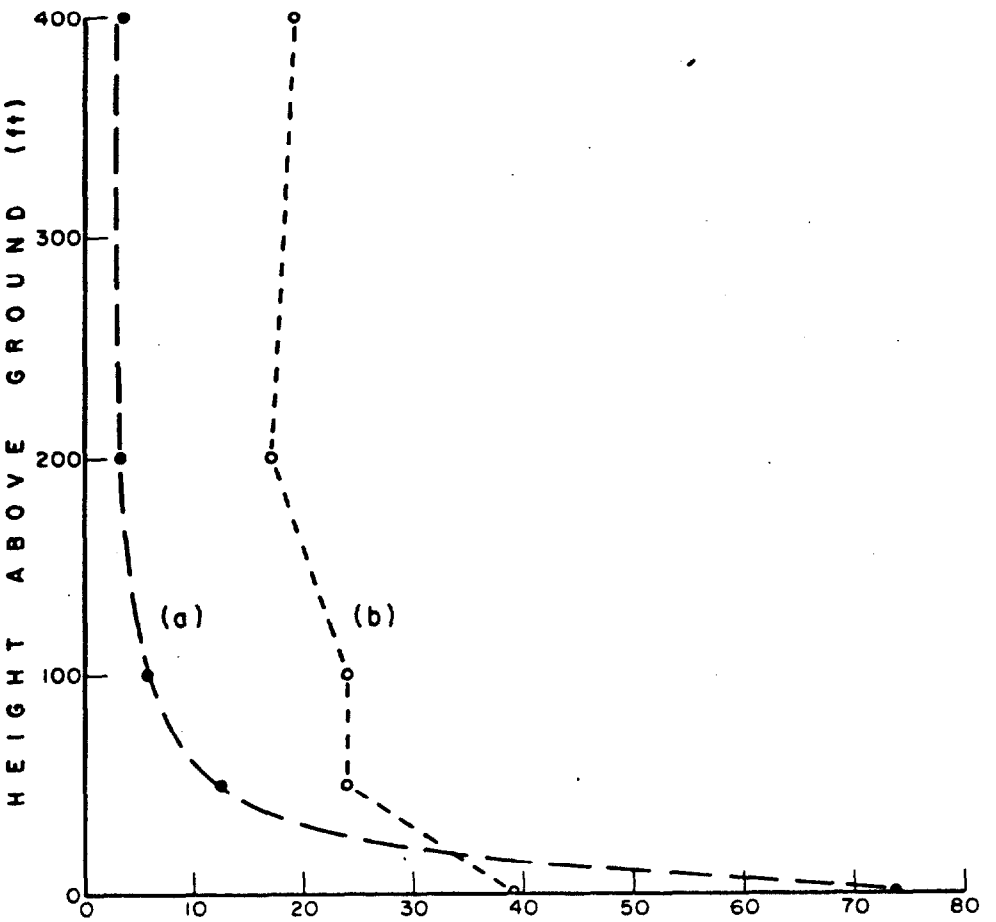

FIGURE – 4
(a) AVERAGE MASS OF DUST PER FOOT^3, AND
(b) MASS MEAN DIAMETER OF DUST PARTICLES.
METEOROLOGY TOWER, HAPO. AUGUST 1, 1955

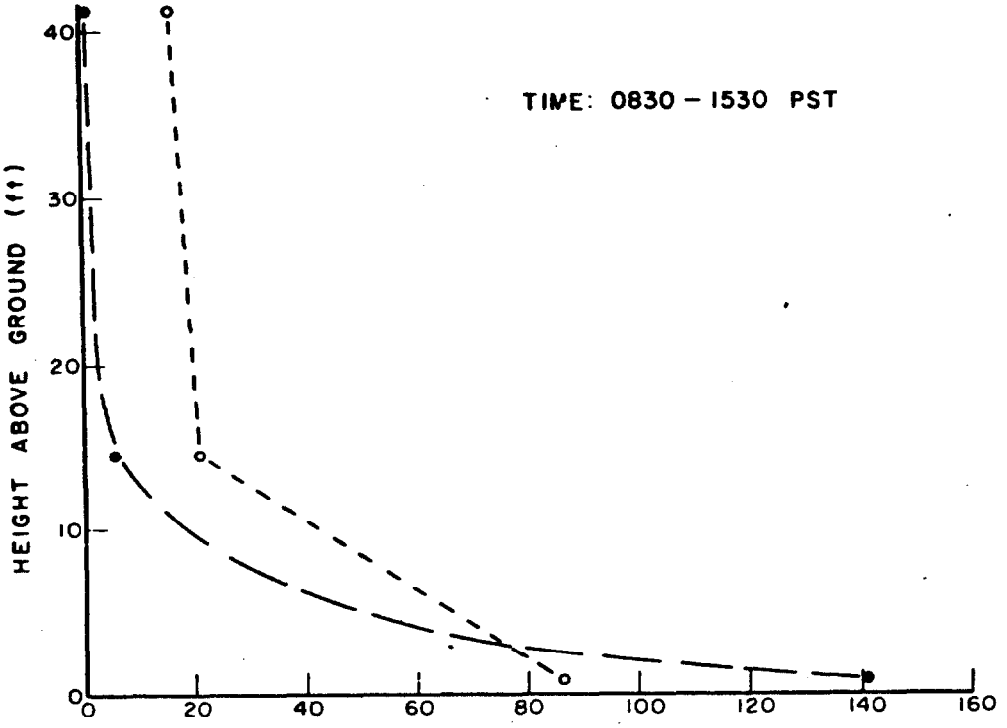

FIGURE – 5
(a) AVERAGE MASS OF DUST PER FOOT^3, AND
(b) MASS MEAN DIAMETER OF DUST PARTICLES.
PORTABLE MAST, HAPO. APRIL 8, 1955

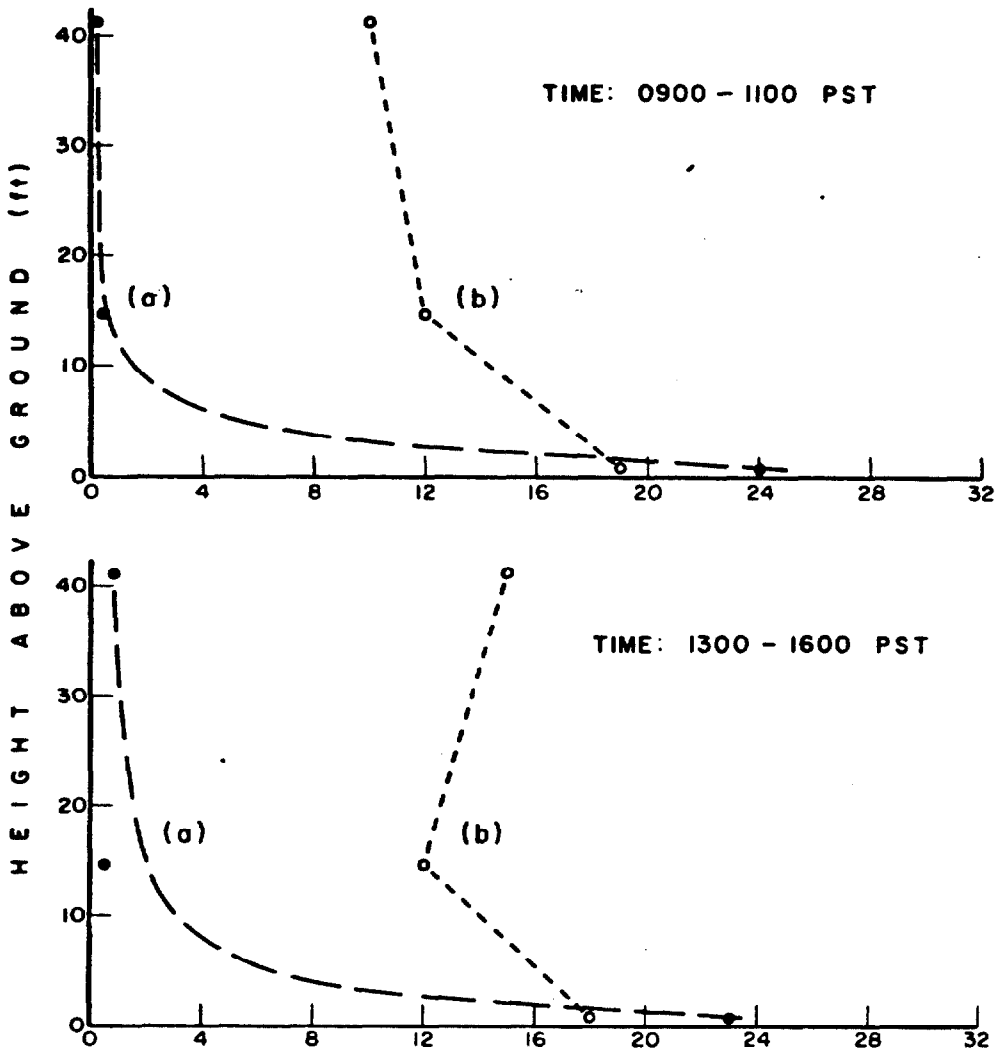

FIGURE – 6
(a) AVERAGE MASS OF DUST PER FOOT^3, AND
(b) MASS MEAN DIAMETER OF DUST PARTICLES.
PORTABLE MAST, HAPO. MAY 4, 1955

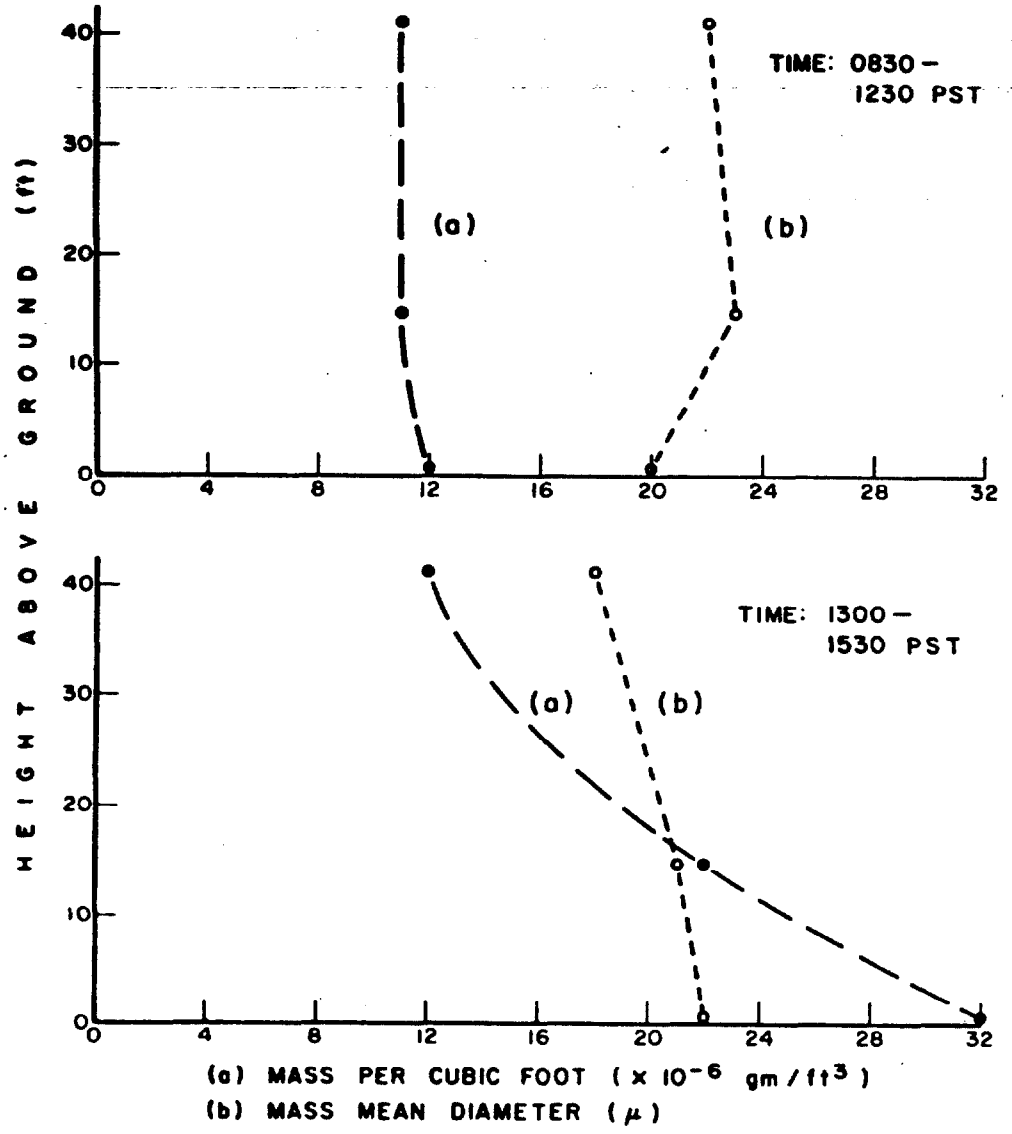

FIGURE – 7
(a) AVERAGE MASS OF DUST PER FOOT^3, AND
(b) MASS MEAN DIAMETER OF DUST PARTICLES.
PORTABLE MAST, HAPO. MAY 27, 1955

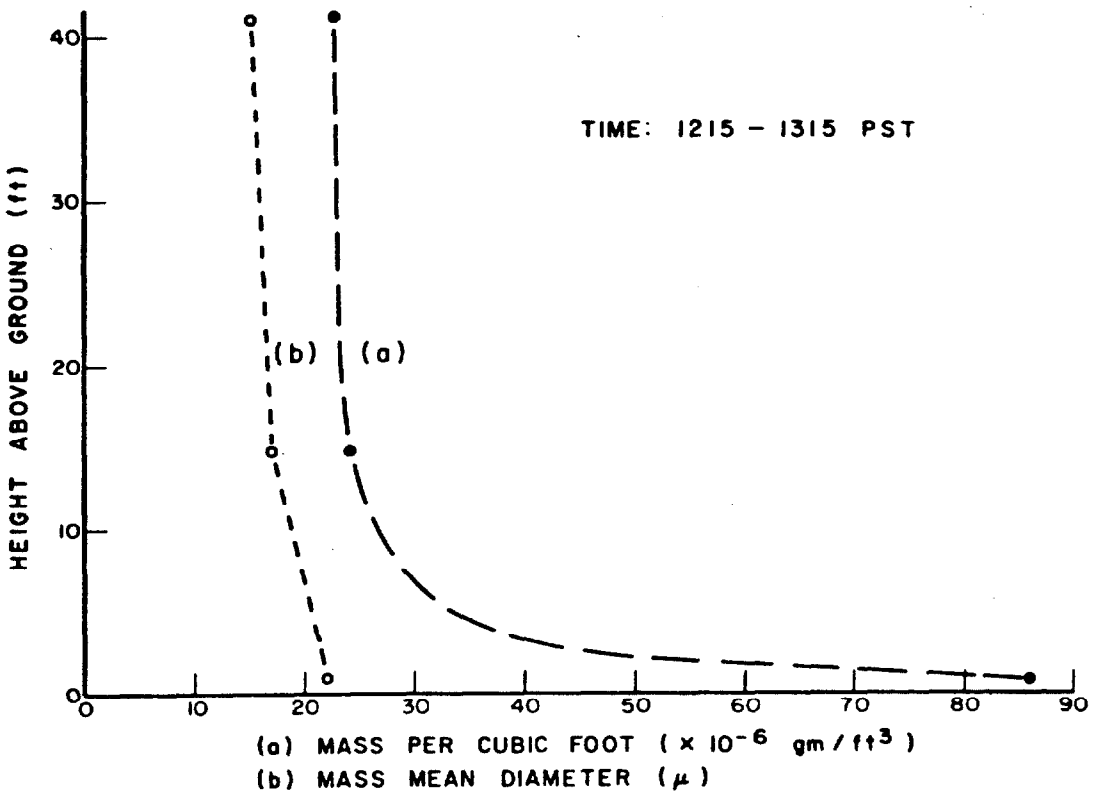

FIGURE – 8
(a) AVERAGE MASS OF DUST PER FOOT^3, AND
(b) MASS MEAN DIAMETER OF DUST PARTICLES.
PORTABLE MAST, HAPO. OCTOBER 5, 1955

ATMOSPHERIC DIFFUSION STUDIES USING FREON 12 AS A TRACER*

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I. Introduction

The problem of determining the concentrations of an effluent downwind from a building stack or some other source frequently confronts the industrial meteorologist or engineer. This problem becomes especially important when the material involved is toxic. To provide an estimate of the concentrations to be expected, one of the currently fashionable diffusion formulas is applied. Numbers are thus obtained describing the concentrations. All too rarely are valid checks or verifications of the estimates obtainable unless damage has occurred to property or mammals.

The biggest difficulty in applying the diffusion equations is in knowing what values to assign to the diffusion parameters; C_z, C_y and n in the Sutton[1] equations or "p" and "q" in the Bosanquet and Pearson[2] equations. Values have been suggested by Sutton, Bosanquet and Pearson and others[3] but usually the conditions of the problem to be solved are sufficiently different from those upon which the equations are based that there is some doubt concerning the validity of the estimates. In most cases the meteorologist or engineer is forced to use the suggested values of the diffusion parameters for want of something better. In this paper three cases are presented where actual measurements of concentrations are compared with predictions from Sutton's formula.

A. Experimental Technique

Freon 12 was used as a tracer in these experiments. This substance is especially desirable since it is inexpensive, readily available and non-toxic. It is also colorless, odorless and tasteless in gaseous form.

For these experiments freon 12 was released from three different locations: (1) thirty inches above the ground, (2) the 37.5-foot level of the Meteorology Tower, and (3) the stack on Building 310, 53-feet above the ground. Either 10 or 25-pound tanks of freon 12 were used. The freon from the tanks passed through a measuring apparatus which consisted of a reduction valve, pressure gauge, Fischer-Porter Flowrator, heat-exchanger and nozzle before it was released to the atmosphere. For the experiments on Building 310 the freon was injected into the ventilation ductwork just ahead of the last bank of filters.

A special sampling bottle for use in these experiments was designed at the Argonne National Laboratory by Dr. Harvey A. Schultz and Mr. Jack Dodd. This bottle shown in Figure 1

* Performed under the auspices of the Atomic Energy Commission.

consists of a round-bottom 1-liter flask, a two-hole neoprene stopper, a balloon, a stopcock, and glass tubing. The balloon is fastened to a piece of glass tubing which is inserted into one of the stopper holes. Another piece of glass tubing joined to the stopcock passes through the other hole. The stopper is securely fastened to the bottle in the manner shown with the balloon inside the flask.

Prior to taking an air sample the balloon is inflated while the stopcock is open so that most of the air in the flask is displaced. The stopcock is then closed. The balloon cannot deflate because of the pressure balance between the air inside the balloon and the air outside the balloon but within the bottle. To take an air sample the stopcock is opened and the balloon is allowed to deflate. This causes air to flow into the space between the outside of the balloon and the inner walls of the flask. The stopcock is then closed to retain the sample. The air sample is released when the stopcock is opened and the balloon is reinflated.

About 20–30 sampling bottles were set up in a grid downwind during each experiment. The bottles were mounted on ½-inch metal rods either driven into the ground or fastened to ring-stands. Jaw clamps attached to the rods held the bottles at about 30 inches above the ground.

Prior to the experiment the balloons were inflated. About a minute after the freon release began, a signal was given to a group standing by to open the sampling bottle stopcocks. Each man opened about 4 or 5 bottles on his assigned route. Calibrated glass capillaries were attached to the intakes of the bottles so that the sampling time was held to a predetermined period. This was three minutes in most cases. At the end of the period the men were signalled to close the stopcocks. The sampling bottles were then taken to the laboratory for analysis.

Analyses were performed under the direction of Dr. Harvey A. Schultz by means of a General Electric Halide Detector modified at Argonne. The sensitive element of this instrument consisted of two concentric thin-walled platinum cylinders. The outer one was 40 mm long and 7 mm in diameter and the inner one was 30 mm long and 5 mm in diameter so that the annular space between them was 1 mm. A potential of 200 volts was applied between the two cylinders with the inner one positive. Also, the latter was heated to a temperature exceeding 1000°C. When air containing small concentrations of freon 12 was passed through the annular space, the current developed was proportional to the concentration.

As used at Argonne, the output of the halide detector was fed into a specially designed amplifier and the data were recorded on an Esterline-Angus recorder. Other modifications consisted of more accurate temperature control of the inner cylinder and accurate flow control of the freon-containing air sample. Dr. Schultz found that the relative humidity of the sample affected the readings. A cold trap was therefore used to cool it to −15°C in order to remove a large fraction of the water vapor. Also a trace of hydrogen was injected into the sample to stabilize the operation of the equipment.

Two methods were used to determine the emission rate of the freon. The first method consisted of weighing the freon tanks before and after the experiment. Since the emission rate was held constant and the period of emission was known, it was possible to calculate the emission rate. In the second method the source strength was calculated from readings of a Fischer-Porter Flowrator. The two methods gave values which agreed to within about ten percent.

Ground Source Data

At the time of this run, 1346:40–1350:40 CST August 16, 1951, a high thin overcast with lower broken clouds was present. The wind at 6.5 feet was light ranging from 4 to 8 miles per hour from a direction of 20°. No stability measurements were available during this run. Freon 12 was released in the vicinity of the Meteorology Tower from a level of 30 inches above the ground at the rate of 3.2 grams per second. The concentration isopleths measured are shown in Figure 2. As often happens during experiments of this type there was a shift of wind direction after the sampling grid was set up. As a result only slightly more than one-half of the plume passed over the grid. However, measurements on either side of the maximum concentration line were obtained.

Theoretical isopleths using Sutton's equation have been calculated and are superimposed in red on the measured isopleths. These are shown in Figure 3. The diffusion parameters of n = .25 and $C_z = C_y = .20$ were chosen. The value for n was determined from the ratio of the wind speeds at the 6.5 and 150-foot levels. The agreement between the theoretical and measured isopleths is quite good although the measurements indicate somewhat higher concentrations on the 50-foot arc at 20–25° from the center line.

Elevated Tower Source Data

These data were obtained during the period 1457:30–1501:00 CST on September 13, 1951. During this time there were scattered clouds at 3000 feet and the wind at 37.5 feet was from 260° at 14 miles per hour. The temperature difference between 144 and 5.5 feet was 0°C. Freon 12 was released from the platform on the Meteorology Tower, 37.5 feet above the ground at a rate of 17.2 grams per second.

Figure 4 shows the concentration isopleths measured during the test. Three sets of theoretical isopleths were calculated for this run. In the first set, Figure 5, n was taken as .25, C_y as .21, and C_z as .12. The value for n was obtained from wind speed ratio measurements from anemometers on the tower. Values for C_y and C_z were values recommended by Sutton for neutral conditions. These isopleths indicate that the theoretical concentration occurs farther from the stack. Also the plume is more confined.

The second set of theoretical isopleths shown in Figure 6 were obtained by taking n = .25, $C_y = .15$ and $C_z = .19$. These values of C_y and C_z were determined from the measured isopleths in the following manner: Since the distance at which the maximum concentration occurred can be determined from the measurements and the source height is known and n has been measured, C_z can be calculated from the expression:

$$x_m = \left(\frac{h^2}{C_z^2}\right)\frac{1}{2-n} \tag{1}$$

Where x_m = distance in meters to point of maximum concentration from source measured along the horizontal
h = source height in meters

C_z was thus found to be .19.

Assuming the measured value for the maximum concentration to be correct, C_y can be calculated from the expression:

$$\chi_{max} = \frac{2Q}{e\pi uh^2}\left(\frac{C_z}{C_y}\right) \text{ or } C_y = \frac{2Q\,C_z}{\chi_{max} e\pi uh^2} \tag{2}$$

Where Q = the emission rate in grams per second,
χ_{max} = the maximum concentration in grams per cubic meter,
u = the wind speed in meters per second,
and h = the source height in meters.

Substituting the value for C_z obtained from equation 1, equation 2 yields a value of .15 for C_y.

From Figure 6 it is evident that the actual dispersion was much more pronounced than the theoretical values. Note the value of .19 ppm on the 220° radius and the distance of the .10 ppm line from the center line. Another point of interest is the higher concentrations on the 100-foot arc. These may well be due to the eddies around the tower.

The third set of isopleths shown in Figure 7 compare actual and theoretical values where n was taken as .25 and $C_y = C_z = .50$. In this case the fit is very poor. Although the dispersion

is greater because of the larger magnitude of C_z and C_y the measured and theoretical concentration values agree poorly. Also the magnitude and location of the concentration maximum differ in the two sets of curves.

Building Stack Source

This run was made during the period 1427:00–1431:00 CST on September 27, 1951. Lower scattered clouds at 4000 feet were present and the wind was from 277°, 22 miles per hour at 37.5 feet. The temperature difference between 144 and 5.5 feet was 0.1°C, the upper level being colder. Freon 12 was injected into the ventilation ductwork of Building 310 prior to the last bank of filters at a rate of 24.5 grams per second. The air flow through the ductwork was about 300 cubic feet per minute and its temperature varied from 92 to 102°F.

Figure 8 shows the measured concentration isopleths. The wide dispersion of relatively high concentrations is evident from this figure. An attempt was made to obtain values for the peak concentration in the vicinity of the building. The freon was traced by means of bubbles generated from a commercially available toy bubble compound. It was necessary to use bubbles instead of smoke because tests showed that the halide detector reacted to smoke but not to bubbles. The bubble generator was located on the roof of the building near the emitting stack. Observers followed the bubbles and took short-period samples in regions near the building where the bubble concentration was at a maximum. A peak concentration of 1.95 ppm was obtained.

Several sets of theoretical Sutton isopleths were calculated for this case also. The value of n was calculated from the meteorology tower anemometers and found to be .33. At first, a calculation was made allowing C_y to equal .21 and C_z to equal .12. The fit was very poor. The maximum concentration came out to be .25 ppm as against 1.32 ppm and the horizontal distance 1100 feet as compared with about 200 feet. Using the measured value of the maximum concentration and its distance from the stack and equations 1 and 2, C_z was found to be .52 and C_y equal to .17.

A new set of theoretical isopleths was calculated setting n = .33 and these values for C_y and C_z. These are shown in red in Figure 9. It is evident that the fit is still poor. The actual dispersion is markedly larger and the concentrations higher.

Of course, Sutton's equations were not designed to be used to determine concentrations around buildings. However, at times, they have been used as a guide for want of something better. This case is presented to indicate the magnitude of errors to be expected and emphasize the caution that must be applied even in using the theoretical expressions as a guide.

Acknowledgments

Thanks are due to Mrs. Harriet R. Newton for aid in planning and carrying out these measurements. She was in charge of the Meteorology Group at the time of the freon experiments. The assistance of Mr. Frank C. Kulhanek and other members of the Radiological Physics Division is gratefully acknowledged. Their help contributed substantially to the success of the experiments. The cooperation of Mr. Walton A. Rodger and Mr. Donald C. Hampson of the Chemical Engineering Division in connection with the measurements in the vicinity of Building 310 helped immeasurably. Their assistance is appreciated.

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2. C. H. Bosanquet and J. L. Pearson, The Spread of Smoke and Gases from Chimneys, Transactions of the Faraday Society, 32: 1249-1264 (1936).
3. L. L. Falk, et al., Savannah River Plant Stack Gas Dispersion and Microclimatic Survey, DP-19, E. I. du Pont de Nemours & Co., Inc. (1953).

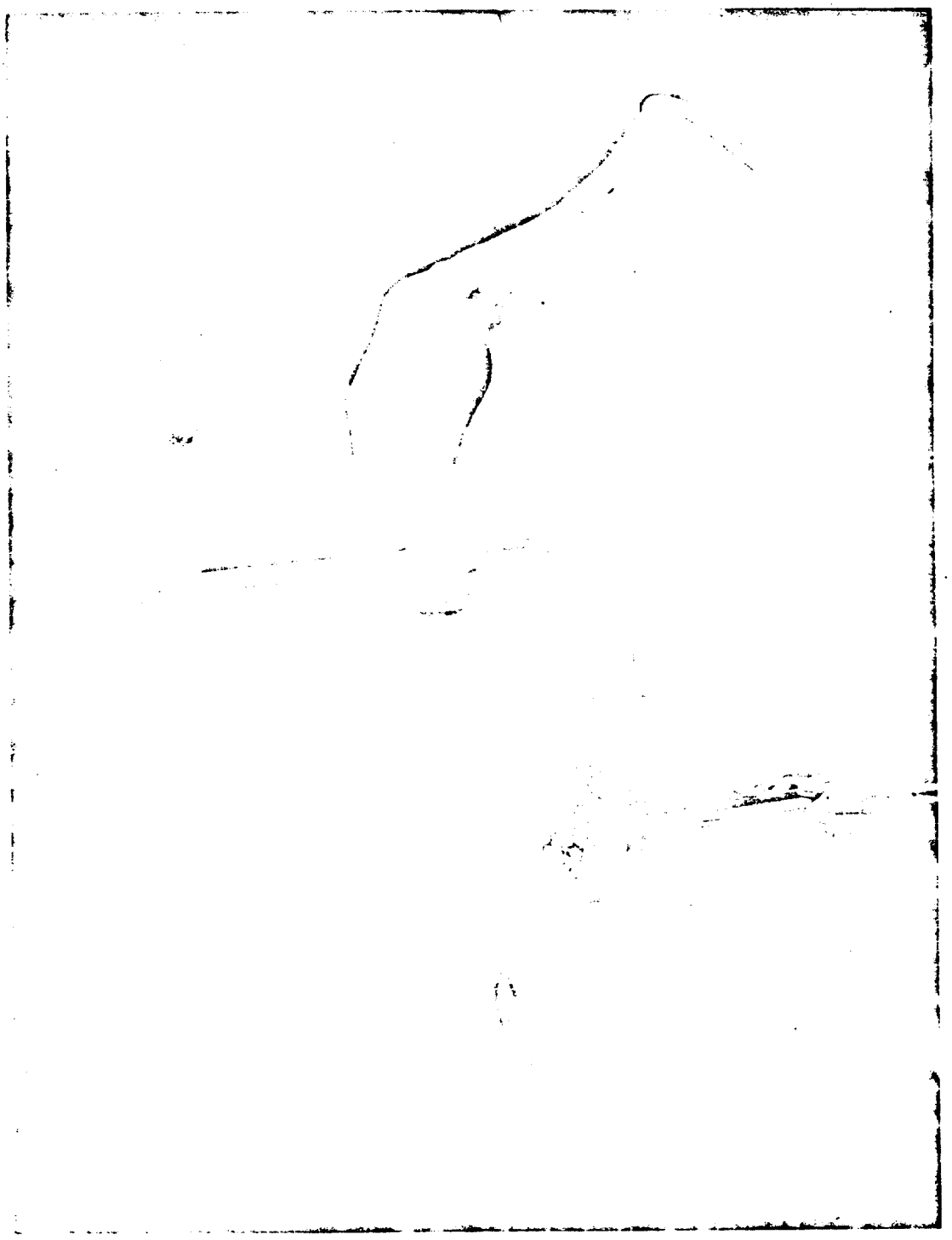


Figure 1

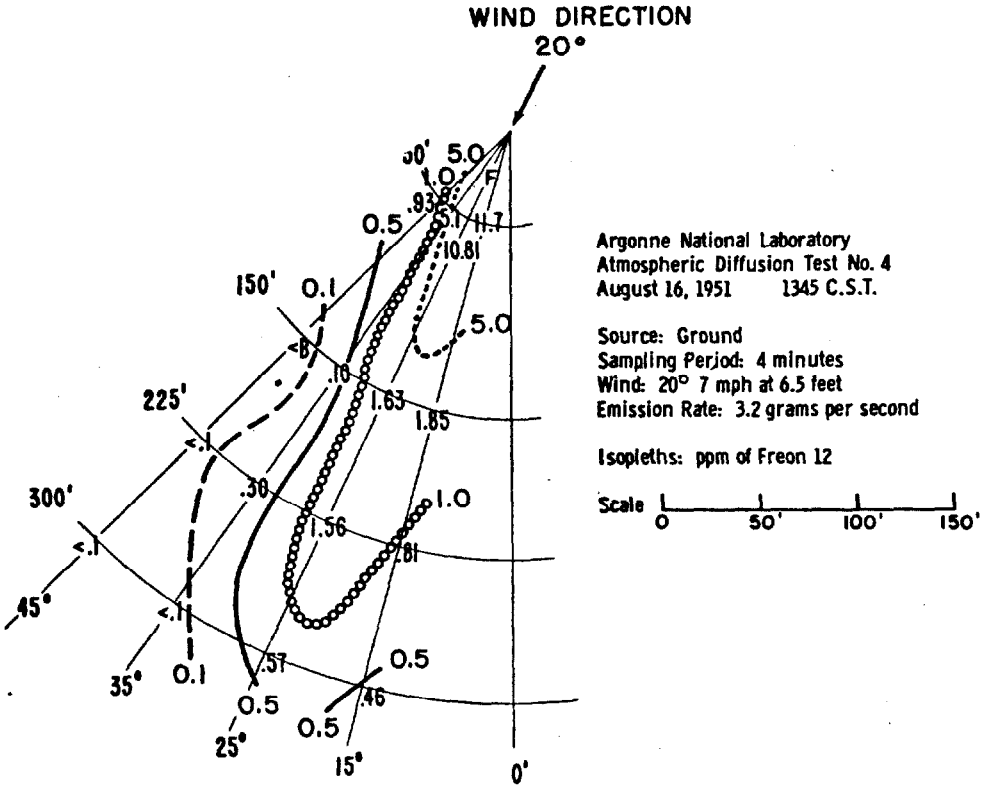


FIGURE 2

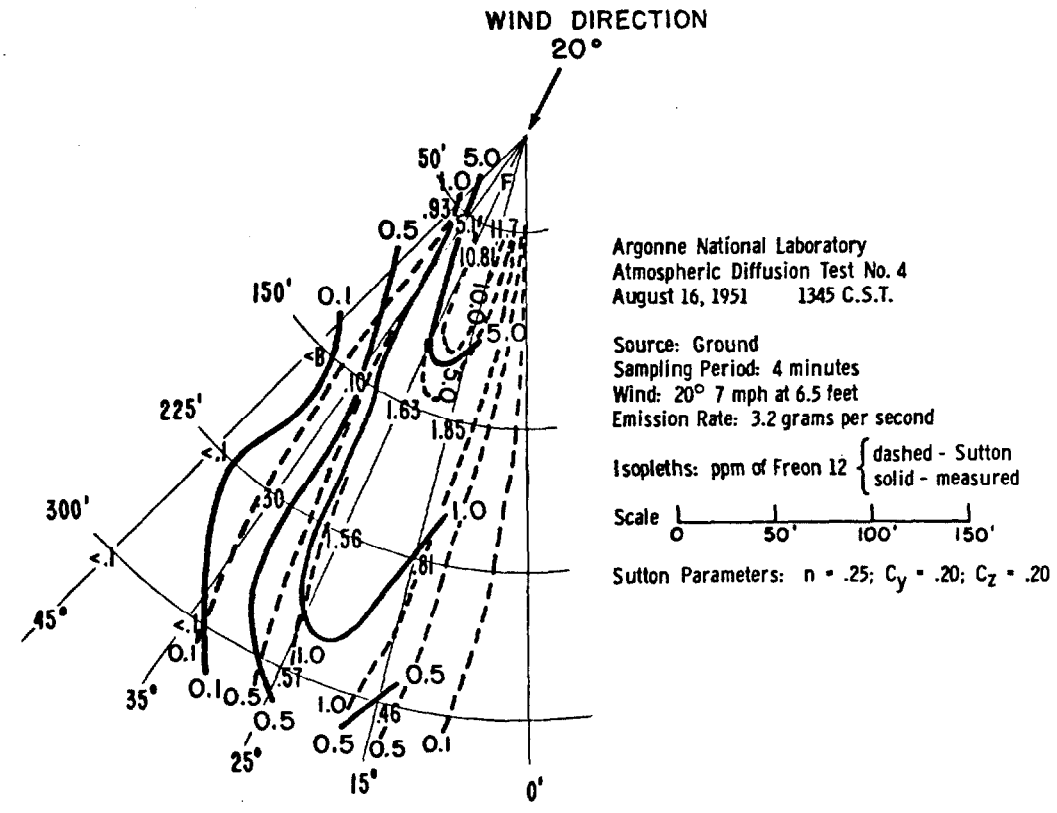


FIGURE 3

Argonne National Laboratory
Atmospheric Diffusion Test No. 7
September 13, 1951 1500 C.S.T.

Source: Meteorology Tower - 37.5-foot level
Sampling Period: 3 minutes
Wind: 264° 14 mph at 37.5 feet
Emission Rate: 17.2 grams per second of Freon 12

Isopleths: ppm of Freon 12

Scale: 0 100' 200' 300'

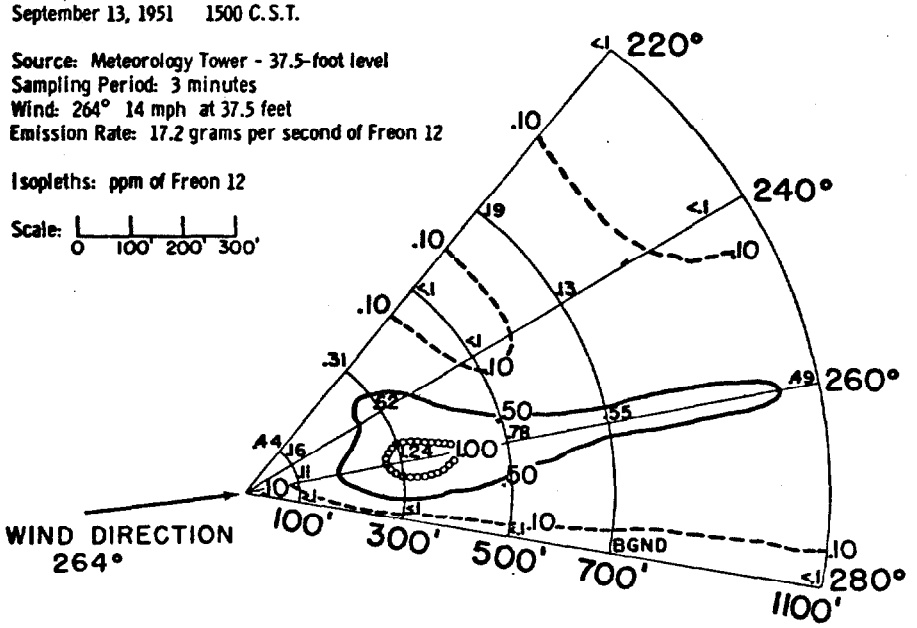


FIGURE 4

Argonne National Laboratory
Atmospheric Diffusion Test No. 7
September 13, 1951 1500 C.S.T.

Source: Meteorology Tower - 37.5-foot level
Sampling Period: 3 minutes
Wind: 264° 14 mph at 37.5 feet
Emission Rate: 17.2 grams per second of Freon 12

Isopleths: ppm of Freon 12 { dashed - Sutton; solid - measured }

Sutton Parameters: n = .25; C_y = .21; C_z = .12

Scale: 0 100' 200' 300'

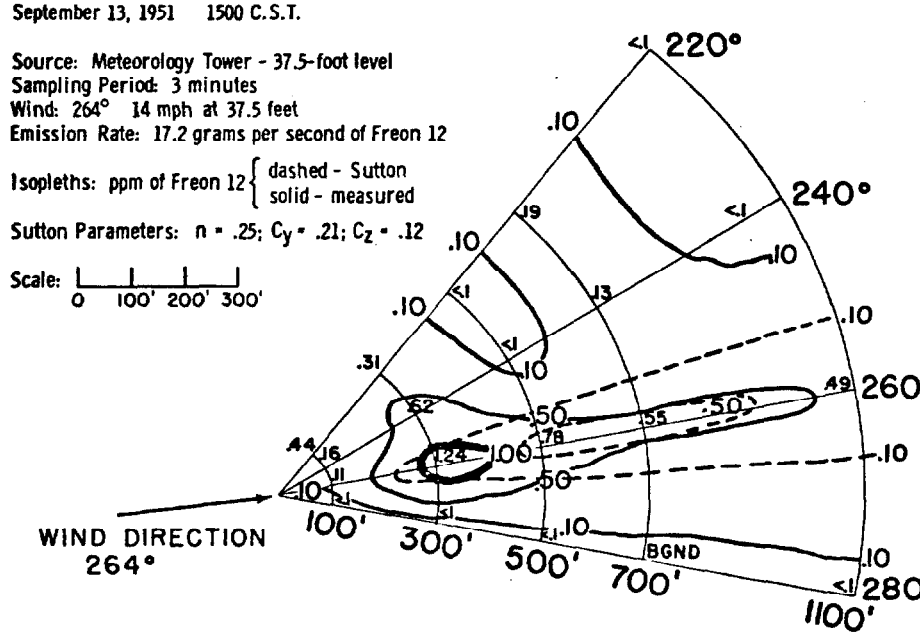


FIGURE 5

Argonne National Laboratory
Atmospheric Diffusion Test No. 7
September 13, 1951 1500 C.S.T.

Source: Meteorology Tower - 37.5-foot level
Sampling Period: 3 minutes
Wind: 264° 14 mph at 37.5 feet
Emission Rate: 17.2 grams per second of Freon 12
Isopleths: ppm of Freon 12 { dashed - Sutton / solid - measured
Scale: 0 100' 200' 300'
Sutton Parameters: n = .25; C_y = .15; C_z = .19

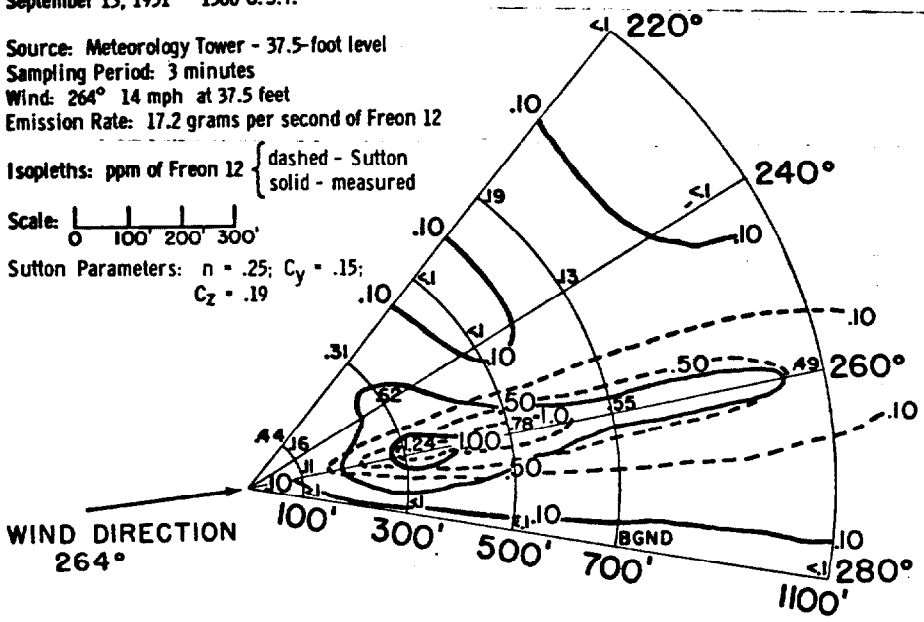


FIGURE 6

Argonne National Laboratory
Atmospheric Diffusion Test No. 7
September 13, 1951 1500 C.S.T.

Source: Meteorology Tower - 37.5-foot level
Sampling Period: 3 minutes
Wind: 264° 14 mph at 37.5 feet
Emission Rate: 17.2 grams per second of Freon 12
Isopleths: ppm of Freon 12 { dashed - Sutton / solid - measured
Sutton Parameters: n = .25; C_y = .50; C_z = .50
Scale: 0 100' 200' 300'

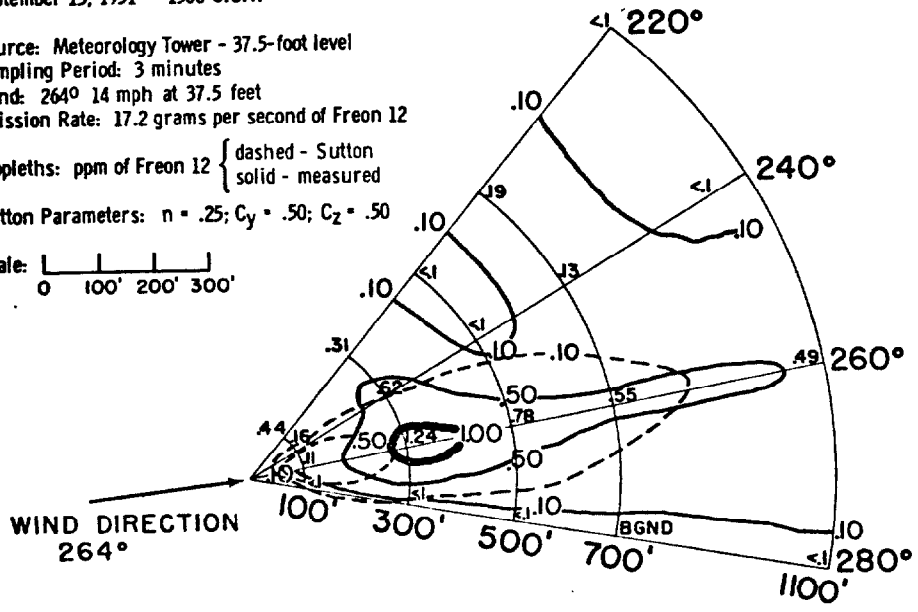
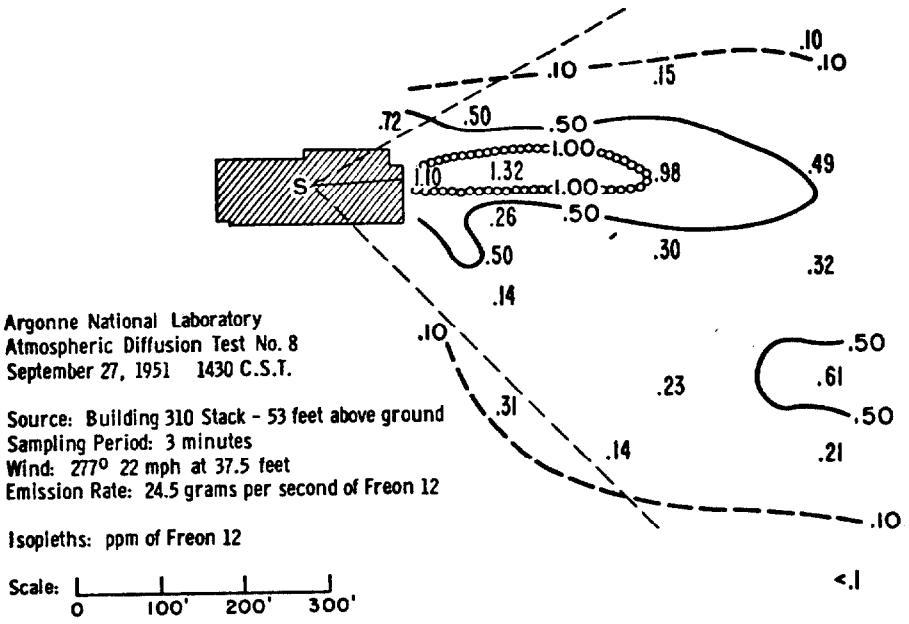


FIGURE 7



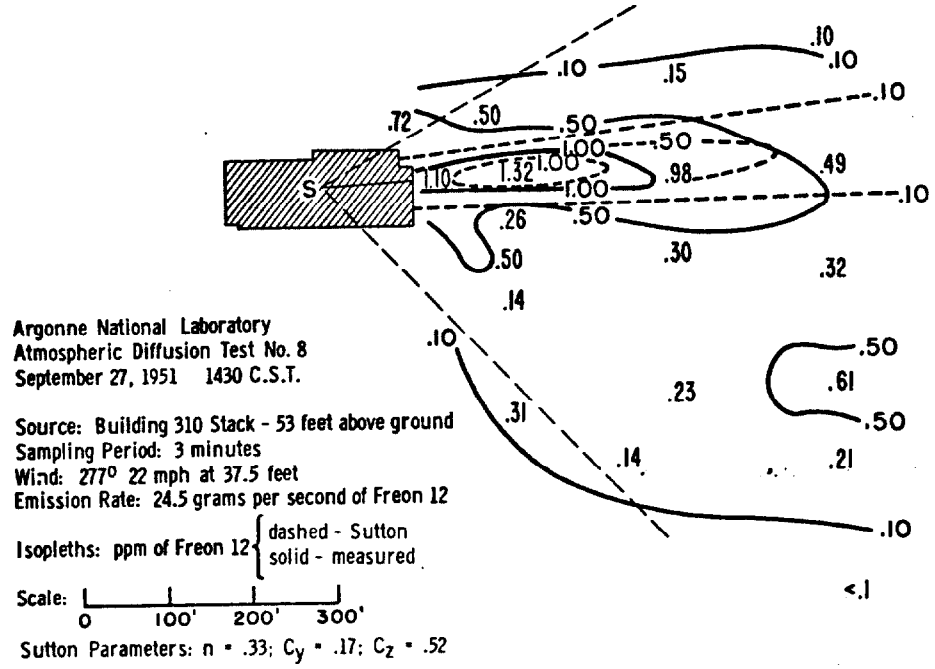
Argonne National Laboratory
Atmospheric Diffusion Test No. 8
September 27, 1951 1430 C.S.T.

Source: Building 310 Stack - 53 feet above ground
Sampling Period: 3 minutes
Wind: 277° 22 mph at 37.5 feet
Emission Rate: 24.5 grams per second of Freon 12

Isopleths: ppm of Freon 12

Scale: 0 100' 200' 300'

FIGURE 8



Argonne National Laboratory
Atmospheric Diffusion Test No. 8
September 27, 1951 1430 C.S.T.

Source: Building 310 Stack - 53 feet above ground
Sampling Period: 3 minutes
Wind: 277° 22 mph at 37.5 feet
Emission Rate: 24.5 grams per second of Freon 12

Isopleths: ppm of Freon 12 { dashed - Sutton
solid - measured

Scale: 0 100' 200' 300'

Sutton Parameters: n = .33; C_y = .17; C_z = .52

FIGURE 9

PHOTOGRAPHIC TECHNIQUES FOR MEASURING DIFFUSION PARAMETERS

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Argonne National Laboratory

Meteorological interest in air pollution is primarily concerned with the capacity of the atmosphere to dispose of contaminants. In line with this the meteorological group at Argonne has a dual program. One part of this program deals with climatological aspects of air pollution and the other part deals ultimately with the prediction of concentrations of contaminants. Our research efforts are directed towards a rational solution to this latter problem. In this respect we hope to accomplish several things. One of these is to test already existing hypotheses concerning diffusion for their validity and for the magnitude of certain parameters, or to formulate improvedhypotheses. Another goal is to make quantitative measurements of the entrainment of environmental air into smoke plumes and clouds. Since the Sutton hypothesis of diffusion is widely known and used, we are proceeding to test this first. At the same time, we hope to obtain usable values of the diffusion coefficients of his equations for interim use.

To accomplish these ends new photogrammetric techniques are used whereby oil fog which is generated into a 110-foot stack by an Army M-2 smoke generator is photographed. In one of these techniques, use is made of K-24 (Air Force) aerial survey cameras to take pairs of pictures at approximately 3.5 second intervals (Fig. 1). These cameras are located at opposite ends of a 400-foot baseline that is tangent to a circle of 80 feet radius, centered at the stack. The point of tangency, midway between the two cameras, is ideally directly under the smoke plume. The axes of the cameras are elevated so that the image of the top of the stack coincides

with a reference line ruled on glass in the focal plane. This horizontal line represents the vertical distance of 110 feet above the base of the stack. The two cameras are triggered simultaneously through an electrical circuit that is keyed by the controller at the base of the stack. Usually a series of twelve to fifteen exposures is made during given stack conditions, then the stack velocity is changed.

From these pairs of photographs measurements are made of the vertical dimensions of the smoke plume, of the height of rise and of the path of the center line. To make these measurements accurately, the meteorological group and personnel of Central Shops have jointly designed and constructed a three dimensional projector-plotter. Essentially, this machine reproduces to scale the photographic setup used in the field (Fig. 2). Two projectors are located at opposite ends of an 80-inch baseline. Between the projectors and normal to the line joining them is a translucent tracing paper screen mounted on a carriage so that the screen can be moved normal to its plane. The projectors are elevated at the same angles as the respective cameras, thereby eliminating the distortions due to the tilt of the cameras. Since the smoke plume ordinarily does not remain exactly halfway between the two cameras, the two images of a particular point on the plume will be coincident only when the plane of the screen is in a position relative to the two projectors similar to the location of the smoke plume relative to the two cameras. Thus, if horizontal distances parallel to the plane of the screen are x-distances, and vertical distances are z-distances, the position of the screen to the right or left of the midpoint of the projector baseline gives the y-distance, to scale, of the portion of the smoke plume that has the two images coincident. As the screen is moved over a horizontal table, the x y coordinates of any

position may, at will, be punched on a piece of tracing paper stretched over the table. The x z coordinates of any point are punched directly on the vertical translucent screen. Punching of coordinates is done by means of two needles that are actuated by solenoids. A cross-hair, through the intersection of which the x z needle operates, can be moved over the surface of the screen. All motions are made by means of reversible DC motors that are controlled from a common control point. Ordinarily all of the pairs corresponding to one set of stack conditions may be punched on the same pair of papers with individual frame images identified by colored pencil. Thus, with this photogrammetric technique, relatively precise entrainment measurements and diffusion measurements may be made. At the present time, one complete run of pictures has been punched onto tracing paper and some analysis has been made as a test of the projector-plotter. The system works quite well with certain limitations. One of which is that differences in density of the two films makes it difficult to determine exactly when the two images are coincident. As long as this difference in density can be compensated for by adjustments of the stop openings of the projector lenses, or lamp intensity, this limitation is negligible. However, it emphasizes the need for good control of the photographs during exposure and processing. In this respect, we have been well favored by the excellent work of Mr. G. A. Zerbe of the Meteorology Group and that of the photographic group of the Laboratory. Another limitation on this scheme is the angle between the smoke plume and the picture plane. As this angle approaches 45° the usable portion of the film diminishes.

Another limitation of this method when using black and white film is the poor contrast between white smoke and the clouds. A simple method of coloring the smoke output of the generator was developed by burning colored smoke grenades in the air-stream to the stack. Two red grenades will color the smoke a bright pink, which stands out quite clearly against white clouds when color film is used. Kodak Ektachrome Aerial film has a film speed high enough to permit taking color photographs under the adverse lighting conditions that occur beneath overcasts.

The second photographic technique used is that of making multiple exposures of the smoke plume (Fig. 1). Use is made of two cameras, the one directly under the stack is positioned so that the top section of the smokestack registers on the film; the second camera positioned crosswind from the smoke stack at a distance of about 1000 feet from the stack. The importance of having two simultaneous photographs of the smoke plume must be emphasized. With two pictures taken simultaneously from known positions, it is possible to make accurate measurements and one is not at the mercy of having made inadequate visual measurements at the time the picture was taken (Fig. 3). This multiple exposure technique was pioneered by Prof. Gordon H. Strom, with the meteorological wind tunnel at New York University. Strom worked with the Argonne meteorological group this past summer in developing this technique and the analytical methods of rectifying the measurements made on the films. Current practice is to make sixteen exposures at fifteen-second intervals with good success using Kodak Contrast Process Panchromatic film.

Current analysis of these multiple exposure films has been directed at testing the validity of the Sutton hypothesis. Sutton (QJRMS 73:p.267) gives an expression for the width of a cloud from a continuous point source and one that can be modified to give the vertical extent of a cloud from a continuous point source.

These equations are:

$$(1)\ \Delta y = 2\left(\ln \frac{100}{p}^{\frac{1}{2}}\right) C_y\ x^{(2-n)/2}$$

$$(2)\ \Delta z = 2\left(\ln \frac{100}{p}^{\frac{1}{2}}\right) C_z\ x^{(2-n)/2}$$

where:

Δy = width of cloud

Δz = thickness of cloud

p = percent of axial concentration

x = distance downwind from sources

C_y, C_z, n are diffusion coefficients.

The width or thickness versus the distance downwind plots as a straight line on log-log paper. The procedure follows:

1. Draw a smoothed outline of the smoke plume on the plan and profile films. Ideally, the outline obtained from the Sutton equations will be a smoothed outline.

2. Measure the vertical and horizontal extent of the plume outline as a function of distance downwind.

3. Rectify the above quantities to true space coordinates and plot on log-log paper. It will be seen that the points remote from the stack tend to fall on a straight line, while those near to the stack usually fall above the straight line. This appears to be due to two factors, (1) the source is not a true point source, and (2) the equations

do not allow for the apparent enhancement of the crosswind dimensions of the plume due to the rise of the plume above the top of the stack. This is particularly true of the profile dimensions. This non-linearity is corrected for by a trial determination of a constant distance, which when added to each of the observed x values, yields a straight line.

4. Determine the slope of the resulting line, and from it compute a value of n. In general, the profile line will yield one value of n and the plan line will yield another value of n. In some cases these values are quite close and in others there is a considerable disparity. Following the completed analysis of a sufficient number of these curves, it will be possible to determine whether or not the differences are statistically significant.

5. The intercept of the profile line determines a quantity from which the value of C_z can be computed. The plan line intercept gives a value from which the magnitude of C_y can be computed. To get numerical values for these parameters, it is necessary to assume that the visible outline of the plume corresponds to some constant fraction of the axial concentration. For convenience it is assumed that the outline of the visible plume has a concentration that is one-tenth of the axial concentration. Since the square root of the natural logarithm of the reciprocal of this number is the quantity which appears in the formulae choosing a value of one-hundredth would only decrease the magnitudes of the C's by a factor of 0.707 and making the outline concentration equal to the axial concentration would increase the quantities of 1.414 of the indicated values.

An important consideration in the foregoing method is the ability to accurately determine the outline of the plume, essentially a problem in the photographic quality. Experience based on the analysis of about

two dozen pairs of films demonstrates that in cases where the outline is well defined there is no difficulty in obtaining a straight line on log-log paper.

Prof. Strom and the writer have analyzed to date eighteen cases in which one could be confident of the outline of the smoke plume, thereby deriving a straight line on log-log paper by the addition of a constant to the downwind distances. From these lines, values of n_v, C_z, n_h and C_y have been obtained. Then from the laboratory's permanent meteorological instrumentation, simultaneous values of the wind speed ratio between 150 feet and 19 feet and the lapse rate between 6 feet and 144 feet were obtainable. Eighteen cases is too small a sample to give an adequate test of an hypothesis. However, a study of the correlations between certain of the parameters will help give some idea of what can be expected from this technique. To this end certain pairs of these data were plotted on scatter diagrams, thus computing the correlation coefficients for these pairs of parameters.

If the Sutton hypothesis is valid, one would expect the plan and the profile data to give the same values of the n's (Fig. 9). In this case, an ideal scatter-diagram would be simply a straight line of slope one passing through the origin. For the eighteen cases mentioned, which include both inversion and lapse conditions, the correlation coefficient between n_v and n_h is 0.94. This is statistically significant at the one percent level.

The magnitude of n is also supposed to be related to the lapse rate of temperature. In this connection, correlation coefficients were

computed for each of the above mentioned n's and the lapse rate between the 6 foot level and the 144 foot level (Fig. 7). For n_h this coefficient is 0.61 which is statistically significant at the one percent level. For n_v it is 0.42 and (Fig. 8) for the theoretical n it is 0.54; neither of these values is significant at the one percent level, but the value for the theoretical n is statistically significant at the five percent level.

Sutton has stated that the turbulence above 25 m is ordinarily isotropic. If this is generally true, the scatter-diagram of C_z versus C_y will give a straight line of slope one and passing through the origin. (Fig. 9). For these eighteen cases the correlation coefficient between the C's is 0.64 which is statistically significant at the one percent level. Neither set of C's had a statistically significant correlation coefficient when correlation with the lapse rate. The correlation coefficient for the C_z's was -0.01 and that for the C_y's was 0.45.

The analysis of these data to date is insufficient to warrant any conclusions as to the validity of any hypotheses. However, the results do indicate that is will be worthwhile to make a thorough analysis of all of the multiple exposure runs which are not available, the number being such that the results should be statistically significant. Sufficient data have been obtained to classify diffusion characteristics under stable and unstable conditions. Within these classes it may be possible to get meaningful subcategories based on wind speed and wind direction.

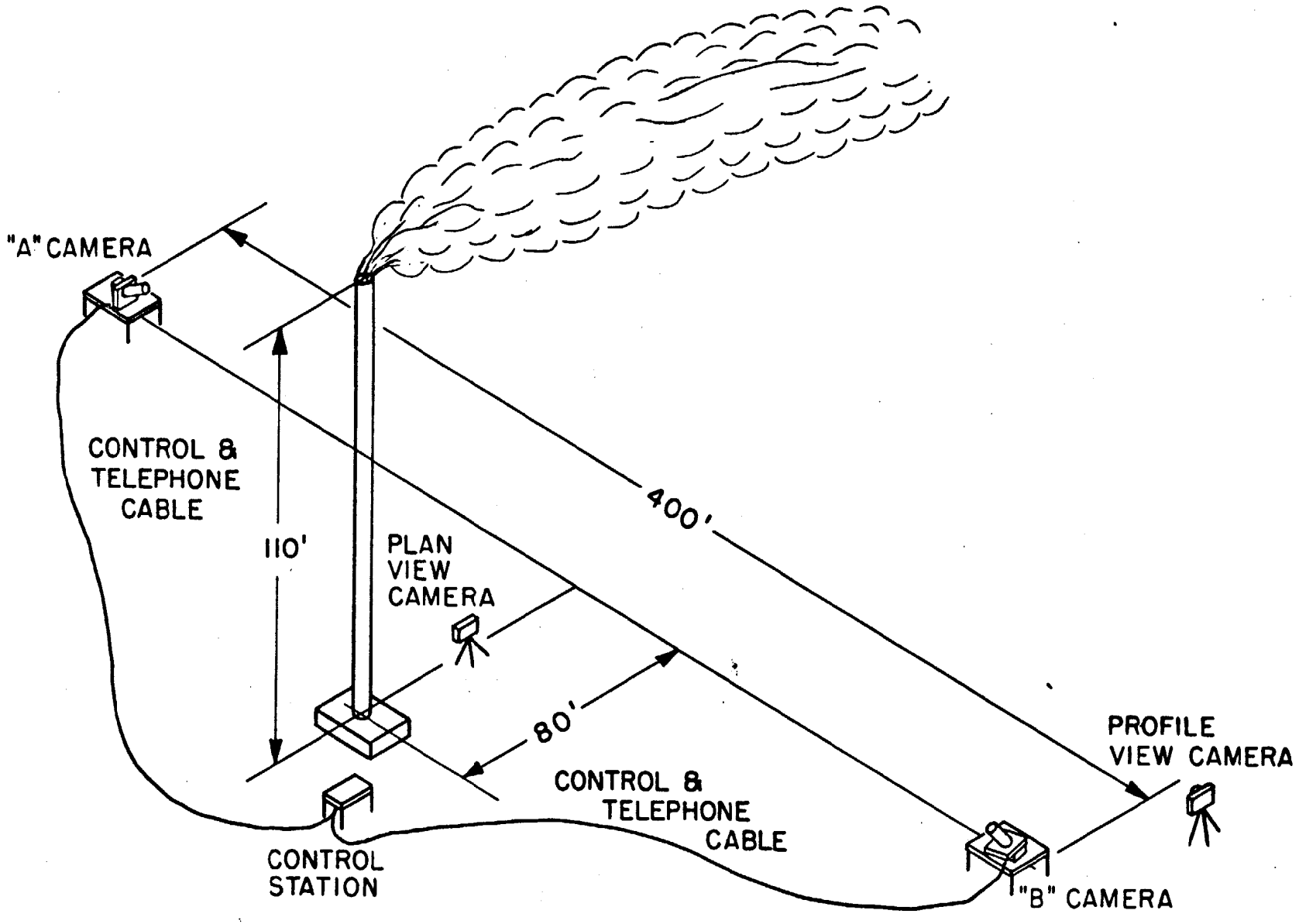

Fig. 1--Field Set-up for Use of K-24 Cameras.

Fig. 2--Photogrammetric Plotter.

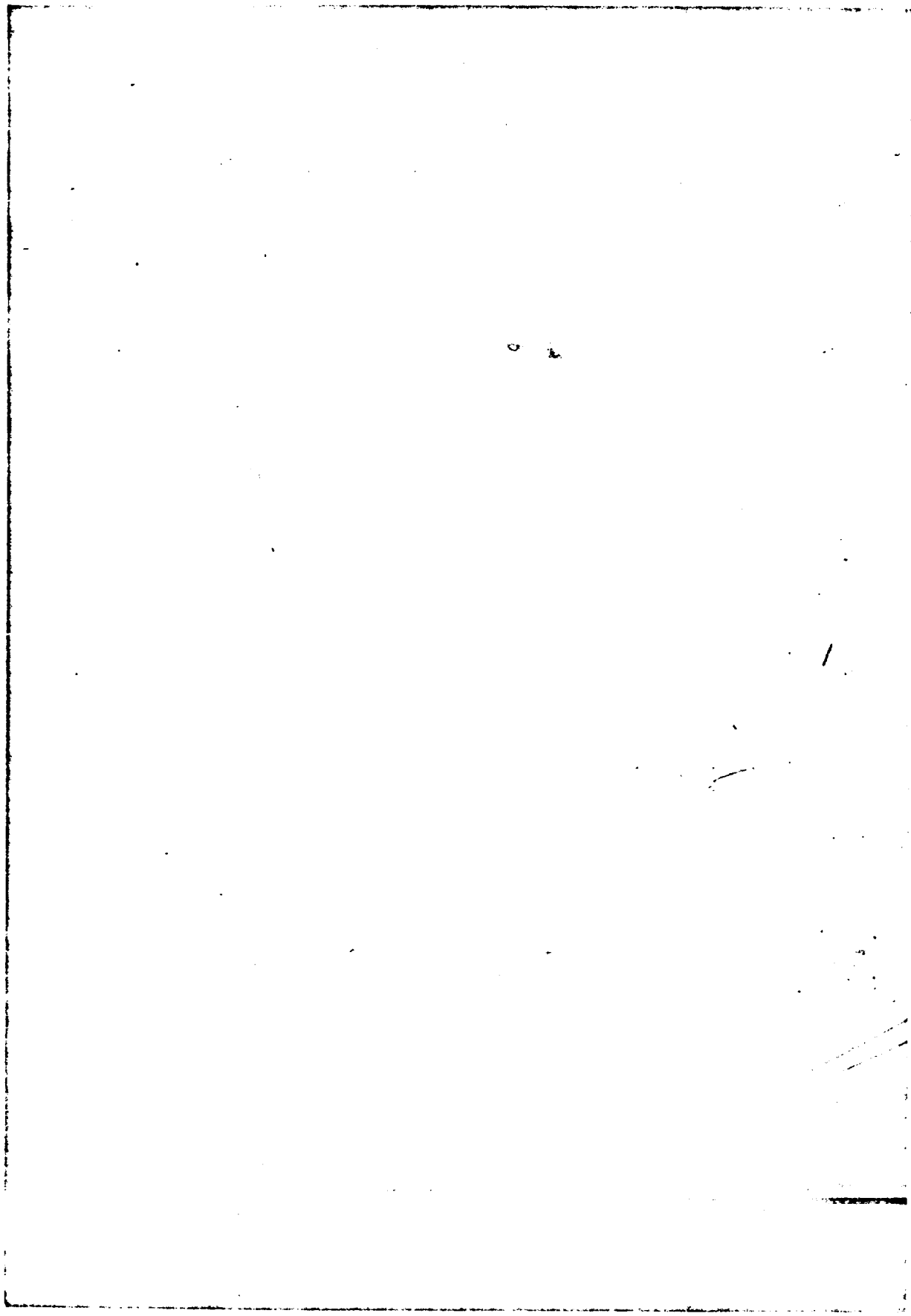

Fig. 3--Multiple Exposure Profile Picture.

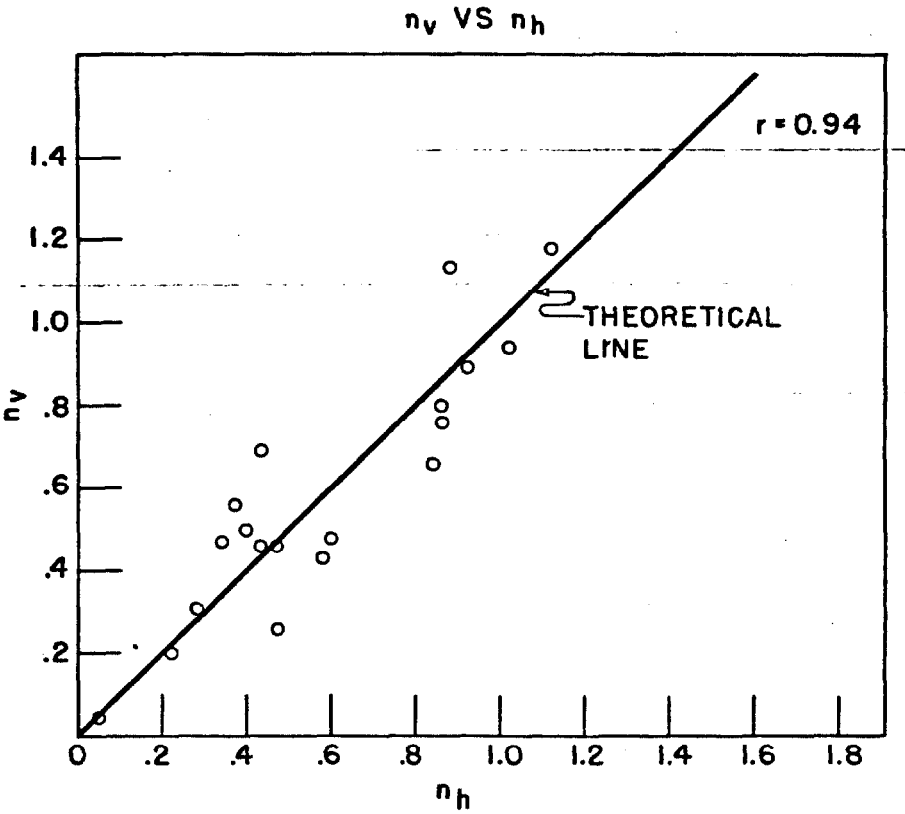

Fig. 4--n_v vs. n_h.

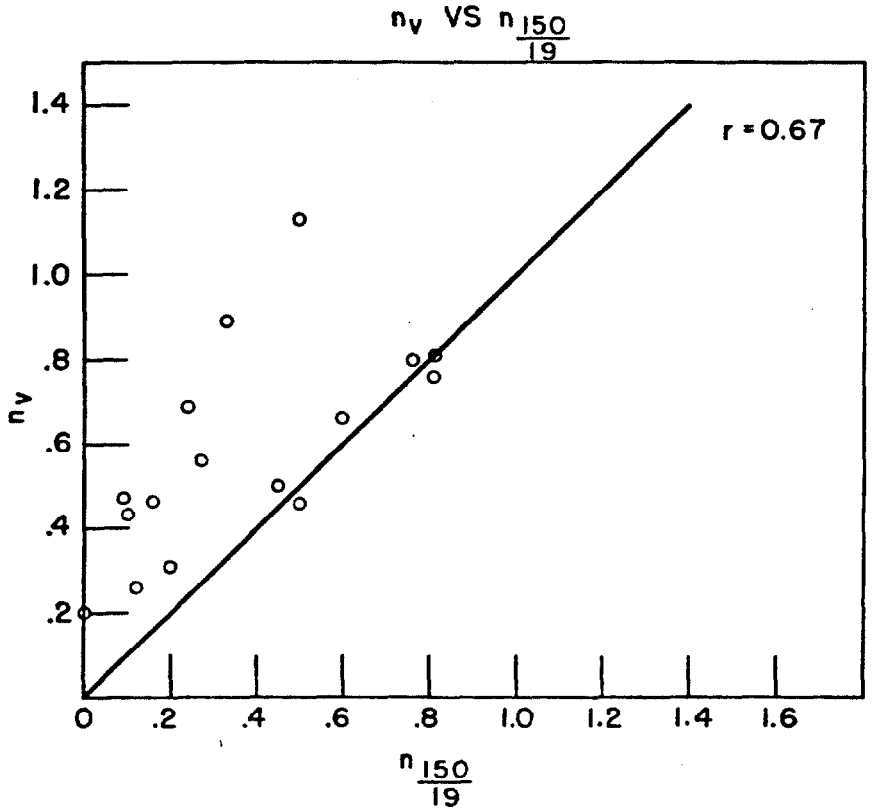

Fig. 5--Measured n_v vs. Theoretical n.

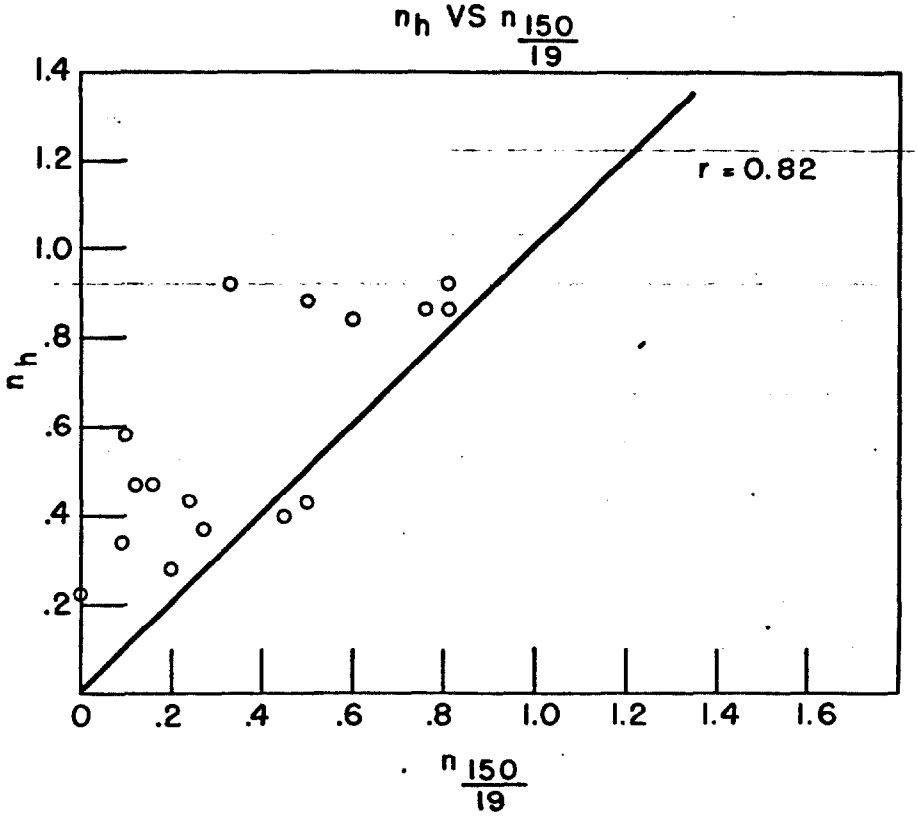

Fig. 6--Measured n_h vs. Theoretical n.

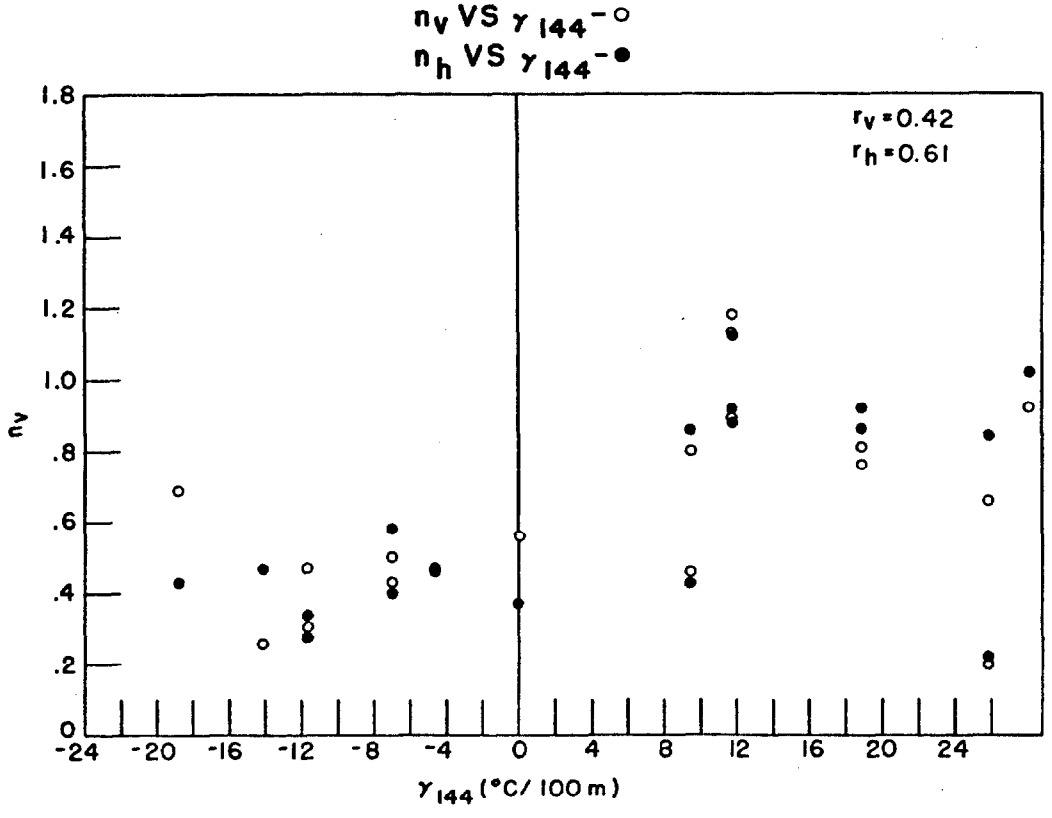

Fig. 7--Correlation of Measured n's with Lapse Rate.

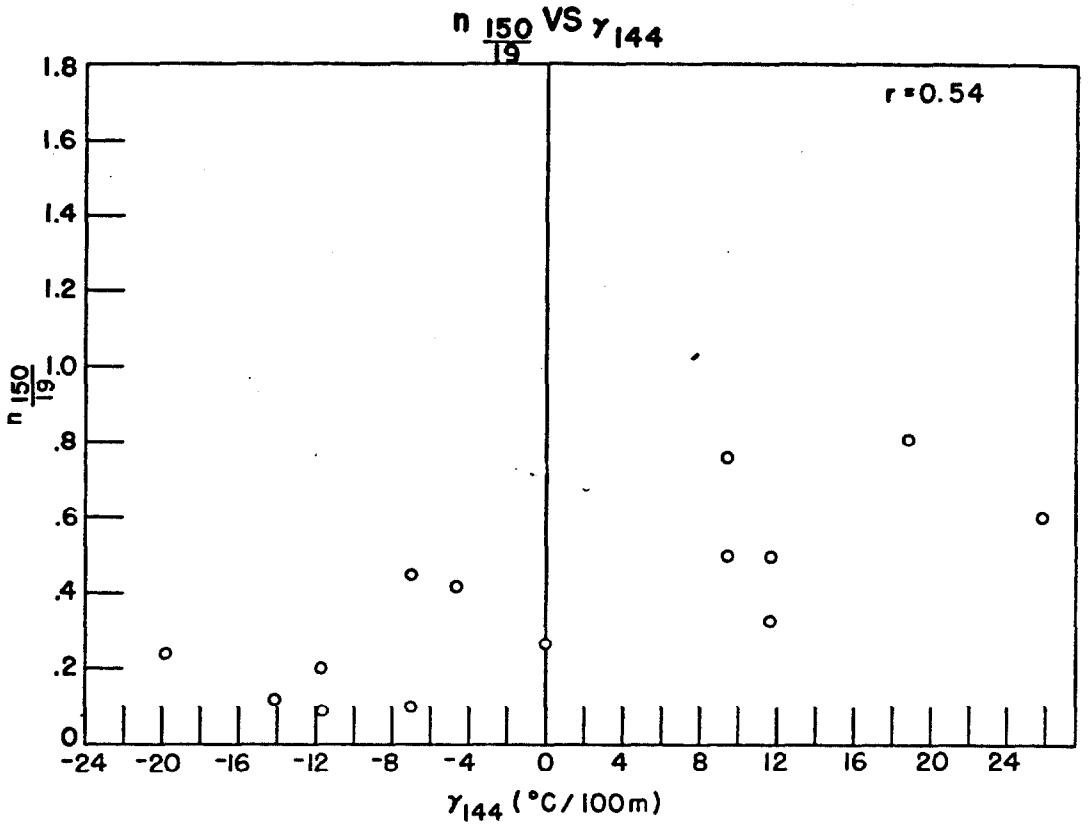

Fig. 8--Correlation of Theoretical n with Lapse Rate.

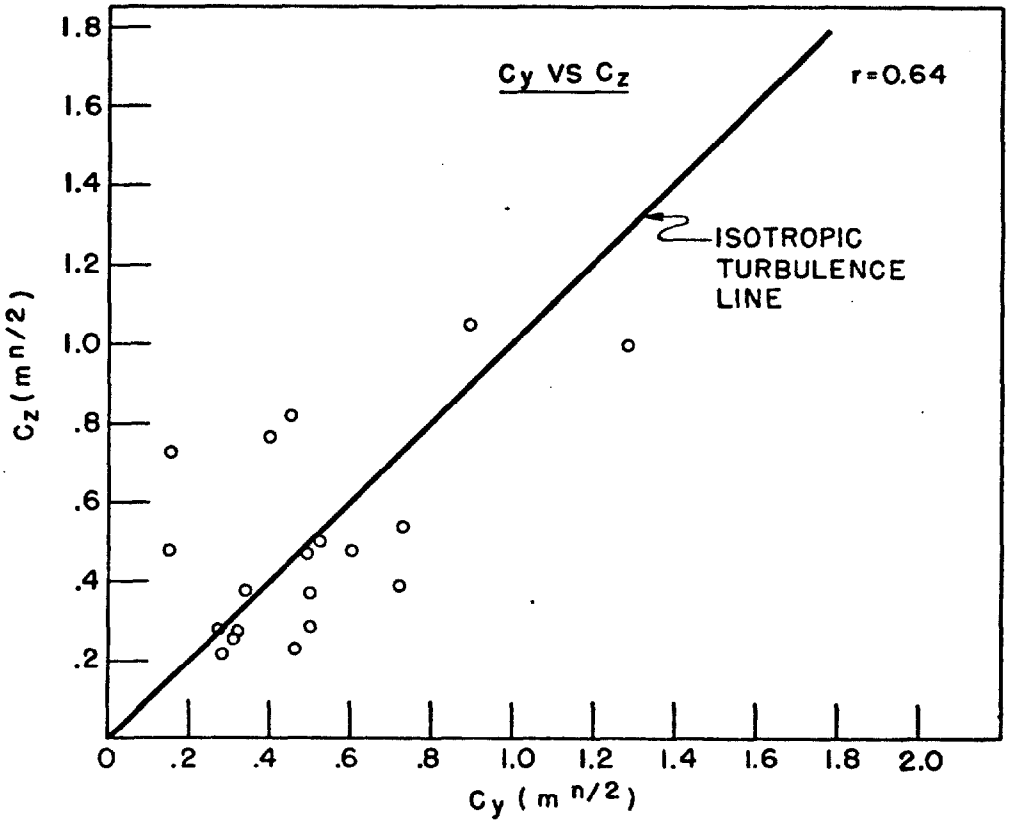

Fig. 9--Correlation of C_y and C_z.

RESEARCH AND DEVELOPMENT AT THE HARVARD AIR CLEANING LABORATORY

by

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In this brief introduction I will very briefly describe the activities of the Harvard Air Cleaning Laboratory since the Los Alamos seminar. As you know, our laboratory has five principal functions as listed below:

1. Research and development on air and gas cleaning problems
2. Evaluation of commercially developed equipment as requested by the Commission
3. Collection and collation of data on air and gas cleaning obtained by AEC facilities and contractors
4. Consultation services when requested by the Commission or its contractors
5. The training and professional education of AEC personnel.

The present Air Cleaning Seminars were an outgrowth of the last objective.

Of utmost importance to us has been research and development work and it continues to be of primary interest. During the time interval described above we have been studying the performance of high velocity filters for precleaning air, with regard to adhesive characteristics, and the effects of dust generation techniques upon their performance.

We have made rather extensive studies of the effect of electrostatic charge on fixed filter beds, some of which were reported at Los Alamos by Dr. Rossano and some of which will be reported here by Mr. Anderson. We recently published an article on the frictionally charged filter unit. This appears in the May issue of "Industrial and Engineering Chemistry" (1).

Our further studies on reverse-jet filters have been handicapped because the commercial equipment which was provided has not proved the optimum for evaluating the nature and characteristics of the deposited aerosol. It is this effect on performance we wish to delineate further.

We have also continued our investigations of isokinetic sampling probes and their influence on the measurement of aerosols as related to air cleaner performance.

We have also undertaken an investigation of the structural characteristics of filters under conditions of reverse air flow. In particular we wished to ascertain the effect of external sonic shock waves which might be imposed upon installed air cleaning equipment. Mr. Billings will present test results obtained on Dust-Stop and AEC type filters.

At AEC request we have been investigating the performance of the Bureau of Mines AEC incinerator in regard to the type of effluent produced and its effect on the proposed air and gas cleaning system.

We have also studied, in a pilot investigation, the performance of miniature cyclones with dimensions ranging from $\frac{1}{4}$ to 2 inches in diameter. We have evaluated, in a preliminary manner, the performance of a new type of electro-deposited screen known as Pyramid screen which may offer some promise as a roughing filter for precleaning of gases.

We have made preliminary studies of external voltage supplied electrified fiber filters, one type (Model K electrostatic - Western Precipitation Corporation) was described and has since appeared as an AEC document (2). Further studies have been made in the laboratory on two similar filters using electrified paper and glass fibers as made by another manufacturer. Results

of these will be issued in a report when studies are completed.

The performance of a new type of scrubbing device developed in France has been observed for the past few months at the request of the Commission. Mr. Edward Kristal will report on this later.

At the present time we have investigations continuing on a high-efficiency cyclone for possible use on fine particulates; on electrostatic filters; and on treated hair media (for high temperature resistance) which might have application as a roughing filter.

Our present fundamental studies, in addition to those given above, are directed towards ascertaining the forces which cause particles to adhere to fibers and surfaces. We are also conducting fundamental studies of electrostatic filters developed from fluidized beds. This provides a novel means of developing a collecting charge and simultaneously acting as a filter for aerosols.

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(2) Billings, Charles E., Dennis, Richard, and Silverman, Leslie: Performance of the Model K Electro-Polar Filter (Report of Laboratory Tests). USAEC NYO-1592, Harvard University, July 15, 1954.

A STUDY OF A NEW TYPE WET COLLECTOR

by

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SUMMARY

Performance tests were conducted on an experimental model of a new type wet collector known as the "Solivore". This unit (600 cfm capacity) consists of four, similar collection stages in series, each containing two spray generators, rated at 9 gpm and 7 psi, and a special Venturi tube. A special feature of this device is a spray generator which uses a rotating mechanical interrupter to disintegrate small liquid streams to produce a fine water spray.

Weight collection efficiencies were obtained with several aerosols for inlet dust loadings ranging from 0.02 to 2 grains per cubic foot, water rates of 6 to 12 gallons per minute per spray generator and for one, two and three stage operation. Efficiencies determined for a single stage varied from 99 per cent for fly ash to 22 per cent for iron oxide. Coarse and fine sulfuric acid mists were collected at efficiencies of 95 per cent and < 5 per cent, respectively. Collection efficiency for sulfur dioxide in low concentration (130 mg/m^3) was about 91 per cent with three stages.

Efficiency increased with multiple stages and with increasing water rate for a single stage.

Although the data obtained in this study may not apply exactly to larger scale equipment due to differences in design and operating conditions, they indicate performance characteristics comparable to several similar wet collectors. High efficiencies (above 99 per cent) are not obtained without high energy consumption.

Introduction

An experimental model of a new type wet dust collector, the "Solivore", is under study at the Harvard Air Cleaning Laboratory as part of the Atomic Energy Commission program of dust collecting equipment evaluation. The unit was developed by Ateliers Ventil, Lyon, France, and may be manufactured in this country by the Ventil Corporation, Harrisburg, Pennsylvania.

The "Solivore" wet collector consists of single or multiple series of stages, each containing a Venturi tube and two spray generators. Its principal collecting mechanism is the impingement of dust particles on water droplets which is enhanced by passing the saturated gas stream through a Venturi tube at high velocities (12,000 cfm throat velocity). This unit is not directly comparable to the Pease-Anthony Venturi scrubber since, in the latter device, water is atomized by the main gas stream at the Venturi throat. In the Solivore a water spray is introduced in a plenum prior to the Venturi. The pressure drop in a Venturi scrubber ranges from 10 to 30 inches of water (due to energy requirements of atomization) as compared to three inches of water per collection stage of the Solivore. The expansion of the gas stream taking place in the Venturi throat is stated by the manufacturer to produce a cooling effect (Joule-Thomson effect) with condensation resulting on the dust particles which serve as nuclei.

A special feature of this collector is the spray generating device which uses mechanical means rather than air or water pressure to produce a fine water spray.

This report describes results of tests with representative aerosols under a variety of operating conditions. Dust concentrations varied from 2 grains per 1000 cubic feet to 2 gr./cu.ft. and water rates from 6 to 12 gallons per minute per spray generator. Several combinations of spray generators were employed during multi-stage operation.

Description and Operation

Description

The experimental Solivore unit consists of four similar collection stages in series each stage containing one Venturi tube and two spray generators as shown in Figure 1. This is a schematic diagram of the experimental four stage Solivore collector. The spray is directed normal to the direction of air flow. Oversized spray generators were installed in the test unit since the manufacturer could not obtain smaller ones. Therefore, water rates were stated to be high with respect to air handling capacities in comparison with large commercial sized units. The spray generator consists of a fixed, circular manifold (11 in. diameter) having eight, relatively large orifices (3/16 inches in diameter) equally spaced on the periphery. When water is supplied, the resulting jets are intercepted continuously by sixteen bevelled vanes extending from a rapidly rotating disc (3300 rpm) located directly in front of the manifold. The spray generator in the test unit has a rated water capacity of 9 gpm at 7 psi and requires a 1 1/2 horsepower motor to energize the spinning disc, Figures 2 and 3. The outstanding advantage of this type spray generator in comparison with conventional hydraulic or pneumatic spray nozzles is its non-clogging feature. The use of large diameter orifices makes possible extensive recycling of spray water without requiring a special filtration system to remove suspended solids.

During laboratory testing two devices were used to remove entrained water droplets. For one and two stage operation an enlarged circular chamber containing six layers of a coarse "metex"* knitted wire screen was attached to the collector outlet. For three stage operation, a vertical riser was attached to the collector outlet so that the gas made an abrupt 90° turn upward upon leaving the collector. This arrangement served as the droplet eliminator.

* Metal Textile Corporation, Roselle, New Jersey

Collection Mechanisms

Collision between spray droplets and dust particles will occur in the plenum chamber. Some of these spray droplets will be removed by inertial forces before entering the Venturi tube. Some collisions will also occur as the aerosol approaches the Venturi throat, due to an increase in relative velocity between the larger particulates (dust and water droplets) and the accelerating gas stream. The velocity of smaller particles stays essentially the same as the gas velocity so that they pass through a zone of relatively slow moving large particles which increases the probability of capture by impaction. A temperature drop will occur during the expansion of the water saturated gas stream at the Venturi throat. However, our calculations show the temperature change based upon a Joule-Thomson expansion to be quite small. In addition, the short retention time during which dust particles can act as condensation nuclei in the area of supersaturation, appears to eliminate this mechanism as an important factor in collection.

Test Methods

Aerosol Generation

Several test aerosols were employed in this study. Fly ash, at concentrations greater than 0.2 grains per cubic foot, calcium carbonate, talc and vaporized silica aerosols were produced by redispersing the dry dust with the Harvard generator (1). In this device the dust is fed from a Syntron Vibrator onto a turntable (1 to 2 rpm). An adjustable wiping arm removes the excess dust from the turntable leaving a ribbon of any desired width along the circumference of the plate. A compressed air aspirator* operating at approximately 25 psi lifts the ribbon of dust from the turntable and ejects it into the inlet duct of the test system. For low dust loadings in the range of 20 gr. per 1000 cu.ft., the National Bureau of Standards dust generator was used. In this device dust is fed by gravity from a small storage hopper to a slowly rotating spur gear. Dust in the grooves is removed by an offset aspirating tube which ejects a steady

* 3/4 inch McDaniel water lifter with Venturi section, Walworth Company, New York, New York -- Cat. 47, 1947.

flow of dust into the test air stream. Sulfuric acid mist was generated by aspirating 2N H_2SO_4 with compressed air at 90 psi and impinging it against a baffle to remove coarse droplets (2).

A finer sulfuric acid mist was obtained by allowing drops of concentrated sulfuric acid to fall on a heated crucible which rapidly formed a fine sulfuric acid mist. A copper sulfate aerosol was generated by atomizing a ten per cent $CuSO_4$ solution with compressed air (100 psi) through a pneumatic nozzle. Large droplets settle out in an elutriating chamber while the finer fraction passes through a pipe heated to 500 to 600°F which produces anhydrous $CuSO_4$ microspheres.

Iron.oxide fume was generated by burning undiluted iron pentacarbonyl in a high temperature air-butane flame. The iron pentacarbonyl is conveyed to the gas flame by entrainment in a nitrogen stream in order to eliminate fire and decomposition problems. This procedure for generating Fe_2O_3 is superior to the burning of iron powder since it eliminates the possibility of coarse, metallic iron particulates. A limitation of this technique is that loadings above 20 gr. per 1000 cu.ft. are difficult to obtain without introducing a potential fire and explosion hazard. Table I gives the size parameters for the dusts, fumes and mists used in this study.

Sampling Methods

Two separate sampling methods were employed to determine the dust concentration in the effluent gas stream. In the first method gross concentration was obtained by inserting into the effluent gas stream a sampling probe which led directly to the sampling device, that is, a pleated filter (3), paper thimble (4) or an impinger tube (5). In the second method, the amount of dry or unwetted material in the collector effluent was determined by inserting a settling bottle in the downstream sampling line to remove coarse droplets, greater than 10 microns.

The weight collection efficiency of the Solivore collector has been determined with representative aerosols for several typical dust loadings, several

water rates, and 1, 2, and 3 stage operation. Some data has also been obtained on the amount of wetted dust which has passed through a droplet eliminator compared to the gross amount of dust in the collector effluent.

Results

The Effect of Dust Loading Upon Weight Collection Efficiency

The effect of dust loading upon weight efficiency was observed for one stage operation with fly ash and calcium carbonate. Fly ash efficiencies (Table 2) increased from 99.0 to 99.4 per cent when the inlet dust concentration increased from 0.02 to 1.60 gr. per cu.ft. (an eighty fold increase in loading). With $CaCO_3$, an increase in efficiency from 88.2 to 93.4 per cent was observed for a six fold increase in dust loading (0.25 to 1.50 gr. per cu.ft.).

These data indicate that variations in inlet dust loading have little effect for aerosols collected at high efficiencies (fly ash). However, in terms of penetration, the outlet fly ash concentration is reduced 40 per cent (i.e. 1.0 to 0.6 per cent passage).

For finer aerosols such as $CaCO_3$ the increase in collection efficiency with dust loading becomes more significant (88 to 93 per cent). Increased retention with higher dust loadings is probably due to the greater opportunity for agglomeration which results from a higher particle count density.

The Effect of Water Rate Upon Weight Collection Efficiency

The per cent passage (100 per cent minus collection efficiency) for fly ash, $CuSO_4$ microspheres and coarse H_2SO_4 mist at 6, 9 and 12 gpm per spray generator was obtained for single stage operation, Figure 4 and Table 2a. All tests showed an inverse relationship between per cent passage and water rate within the range tested. The extent of this variation over the range of water rates studied depended largely upon the efficiency for a given aerosol at rated water flow per stage (18 gpm). For the aerosols tested, doubling the water rate caused a reduction of approximately 50 per cent in dust passage.

Wetted Dust Contained in Collector Effluent

By using the two procedures for effluent sampling previously described, it was possible to estimate the quantity of wetted dust (water droplets containing dust) in the effluent gas stream. The amount of dust contained by the water droplets may make a significant contribution to the total effluent loading at the sampling location as shown in Table 3. However, it is expected in commercial installation that only a very small amount of dust bearing water droplets (< 10 microns) would be present in the stack effluent due to their settling and inertial separation in the exit duct, fan and stack.

Effect of Particle Size on Collection Efficiency

Sulfuric acid mist was generated by two methods; impaction of a 2 normal solution on a baffle followed by elutriation and decomposition of acid in a heated crucible followed by water condensation on sulfur trioxide nuclei. The larger size ($mg = 4.0\ \mu$) generated by impaction, was collected by one stage of the Solivore at a collection efficiency of 95.5 per cent. The fine mist (submicron), formed by condensation, was collected by one stage at an efficiency of less than 5 per cent. These data show the wide range in collection efficiency that may be found when particle size is varied.

Multistage Operation of Solivore

Tests discussed so far have described only single stage operation of the Solivore collector, that is, one Venturi tube and two spray generators. Preliminary efficiency data for multistage operation with $CuSO_4$ and Fe_2O_3 aerosols are reported in Table 4. Although this phase of the investigation has not been completed, present tests indicate that the collection efficiency can be estimated by the log-penetration law when additional collection stages are added in series. Theoretically, the log-penetration law applies only to the collection of uniform aerosols (with respect to both size and composition) when two or more similar air cleaning devices are connected in series. Since neither copper sulfate nor

iron oxide particles as formed represented uniform aerosols, this relationship merely provides a convenient means for estimating multistage efficiency. In order for the second and third stage of the Solivore unit to be as efficient as the first stage, the effluent from any preceding stage must have undergone sufficient conditioning (through agglomeration, particle and water contact, and possibly condensation) to approach the size distribution of the original aerosol. In the absence of particle conditioning multistage operation of the Solivore unit would, of course, be impractical.

Effect of Droplet Eliminators Upon Over-all Collection Efficiency

Efficiency tests indicated that the Metex screen droplet eliminator contributed little to total dust removal (0.7 and 2.0 per cent collection efficiency for fly ash and coarse sulfuric acid mist, respectively) while removing approximately one gallon of water per hour from the collector effluent. The vertical riser, used in three stage operation, removed (by inertial separation) about the same amount of water droplets (1 gph) as the Metex screen.

When the last spray generator of the final collection stage was not operated, water droplet carry-over was reduced considerably. The data presented in Table 5 indicates that shutting off the final spray generator with single stage operation (a 50 per cent reduction in water rate) decreases the collection efficiency by less than 2 per cent.

Effect of Varying Number of Spray Generators on Collection Efficiency

A series of tests were undertaken to determine whether the Solivore unit could be operated with fewer spray generators (decreased water rate) without causing an appreciable change in collection efficiency. A 50 per cent reduction in water rate with a single Venturi tube showed a decrease in collection efficiency of about 2 per cent. Passage however, increased by as much as 50 per cent. Under two stage operation removal of the fourth spray generator, located downstream of the second Venturi tube decreased the water rate by 25 per cent and caused no

significant reduction in collection efficiency (Table 6). When either the second (lower) or third (upper) spray generators were shut off a significant reduction in collection was observed in comparison to normal two stage operation. Based upon a rated, two spray generator per stage, water demand in this case was reduced by 25 per cent. Collection efficiencies were reduced from about 32 to 20 per cent for iron oxide fume and from 98 to 86 per cent for copper sulfate microspheres. Results of these tests indicate that the number of water droplets present (total water volume) is an important factor in multistage operation. One spray generator between Venturi stages did not furnish sufficient droplets to bring about efficient contact with the small particles entering the second stage of the collector. Relatively high efficiencies for one stage operation were attributed to removal of the coarser fraction of the aerosol.

Application to Gases

Sulfur dioxide was selected for investigating the collection efficiency of the Solivore unit on gases as they exist in operations where iron fume and fly ash are formed. For an inlet gas concentration of 180 mg/m^3 and three stage operation of the Solivore a collection efficiency of 91.4 per cent was obtained. This high efficiency suggests that corrosion problems may result from extensive recycling of the acid spray water. As the percentage of sulfurous acid in the spray water increases, due to recycling, it is expected that the collection efficiency would be reduced.

Conclusions

It is difficult to compare several types of wet collectors since the available performance data are often based upon entirely different dust loadings and dissimilar operating conditions. For this reason comparisons between several units should not be interpreted too rigidly. Fortunately, collection efficiency data from a prior investigation by the Harvard Air Cleaning Laboratory on a Dynamic centrifugal wet collector (7) is available for some of the dusts and at loadings similar to those used for the Solivore study. The wet collector

studied (the Hydrovolute)* operated at 1000 cfm with a water rate of 6.5 gpm at 5 to 15 psi. A comparison of the collection efficiencies of the Hydrovolute and Solivore collectors for similar aerosols is shown in Table 7. The Solivore collector has a higher collection efficiency, but this is not achieved without an appreciable higher water rate. Collection efficiency data for a Pease-Anthony cyclonic scrubber (8), a Pease-Anthony Venturi Scrubber (8) and a Fog Filter (9) are also shown in Table 7.

Power requirements for one stage operation of the experimental model Solivore is estimated to be 0.1 HP for water delivery, 0.5 HP for air flow and 3 HP for spray generator operation, making a total of 3.6 HP. In comparison, a 600 cfm Venturi scrubber operating at a pressure loss of 20 inches of water is estimated to require 2 HP.

Since the experimental model does not conform completely either in geometric propertions or operating conditions to large scale designs, the results of laboratory tests should not be extrapolated freely until field test data are available.

* Buffalo Forge Company, Buffalo, New York

Table 1

Size Parameters for Test Aerosols

Material	Median Diameter Microns		Geometric Standard Deviation
	Count	Mass	
Resuspended			
Fly Ash	0.6	1.3	2.7
Vaporized Silica*	0.4	0.6	1.5
Talc	1.3	2.5	1.6
Calcium Carbonate	0.6	2.6	2.0
Sulfuric Acid Mist	4.0	13.8	1.9
Copper Sulfate Microspheres	0.48	0.744	1.46
Iron Oxide Fume	.03	0.6	2.0

Table 2**

Relationship between Inlet Dust Loading and Weight Collection Efficiency for One Stage Operation, a Water Rate of 9 gpm per Spray Generator and 600 cfm at Room Temperature

Aerosol	Inlet Dust Loading gr./cu.ft.	Weight Collection Efficiency %	Passage %
Fly Ash	0.02	99.0	1.0
	1.60	99.4	0.6
$CaCO_3$	0.25	88.2	11.8
	1.50	93.4	6.6

Table 2a

Relationship between Spray Generator Water Rate and Weight Collection Efficiency for One Stage Operation at 600 cfm and Room Temperature

Aerosol	Water gal/ 600 ft^3 of air	Inlet Dust Loading gr/cu.ft.	Weight Collection Efficiency %	Passage %
Fly Ash	6	0.2	99.2	0.8
	9	0.2	99.4	0.6
	12	0.2	99.6	0.4
$CuSO_4$	6	0.6/1000	78.9	21.1
	9	0.6/1000	85.0	15.0
	12	0.6/1000	90.2	9.8
H_2SO_4	6	2.5/1000	92.8	7.2
	9	2.5/1000	95.5	4.5
	12	2.5/1000	96.2	3.8

*Size data refer to freshly generated amorphous vaporized silica

**Date presented in these tables are based on a minimum of three experimental runs

Table 3

Effect of Sampling Method on Estimation of Effluent Loading (One Stage Only) for a Water Rate of 9 gpm per Spray Generator and 600 cfm of Air at Room Temperature

Aerosol	Inlet Loading	Outlet Loadings			Efficiency	
		Dry	Wetted	Total	Dry	Wet
					%	
Fly Ash	0.15	0.00086	0.00154	0.00240	99.4	98.4
Talc	1.5	0.0565	0.0270	0.0835	96.2	94.4
H_2SO_4 coarse mist*	0.0025	1.12×10^{-4}	2.70×10^{-4}	3.82×10^{-4}	95.5	84.7

"Dry" refers to dust passing settling bottle in sampling line

"Wet" refers to dust entrained in water droplets retained in settling bottle

Table 4

Stage Collection Efficiency of Solivore Unit for a Water Rate of 9 gpm per Spray Generator and Air Flow of 600 cfm at Room Temperature

No. Stages	1	2	3
Aerosol	percent	weight	collection
Fe_2O_3	20	32	
$CuSO_4$	85	98	99.5+

Table 5

Collection Efficiencies for One Stage Operation with Second Spray Generators On and Off, a Water Rate of 9 gpm per Spray Generator and an Air Flow Rate of 600 cfm at Room Temperature

Aerosol	Weight Collection Efficiency %		Passage %		Inlet Loading
	2 spray generators	1 spray generator	2 spray generators	1 spray generator	gr./ft^3
Fly Ash	99.4	98.7	.6	1.3	1.65
$CaCO_3$**	93.4	91.2	6.6	8.8	1.5
Talc	96.2	94.4	3.8	5.6	1.5
Vaporized Silica**	96.3	97.6	3.7	3.3	1.0
H_2SO_4	95.5	94.0	4.5	6.0	2.5/1000

*No droplet eliminator in collector

**Efficiencies given are based on gross (wetted and dry dust) effluent samples

Table 6

Weight Collection Efficiencies for Various Combinations of Spray Generators during Two Stage Operation of the "Solivore" Unit at 9 gpm per spray generator and an Air Flow of 600 cfm at Room Temperature

Aerosol	Spray Generators Used*	Inlet Loading gr./1000 cu.ft.	Weight Collection Efficiency %
Iron Oxide Fume	1,2	10	19.9
	1,3	14	20.6
	1,2,3	10	30.1
	1,2,3,4	15	31.6
Copper Sulfate Microspheres	1,2	0.4	86.8
	1,2,3	0.4	98.0
	1,2,3,4	0.4	98.0

Table 7

Comparative Performance of Several Wet Collectors

Unit	Run No.	Aerosol	Loading Gr./cu.ft.**	Water Rate gal/1000cu.ft.	Spray Liquid	Water Pressure psi	Collec. Effic. %
SOLIVORE	1	Fly Ash	1.65	30	water	7	99.6
One Stage	2	$CaCO_3$	1.5	30	water	7	93.4
Operation	3	Talc	1.5	30	water	7	96.2
	4	Vaporized Silica	1.0	30	water	7	96.3
	5	Fe_2O_3	19/1000	30	water	7	21.8
	6	H_2SO_4 (mist-coarse)	2.5/1000	30	water	7	95.5
	7	H_2SO_4***		30	water	7	<5
	8	$CuSO_4$ (microspheres)	0.6/1000	30	water	7	85.0
Three Stage Operation	9	SO_2	180 mg/m^3	90	water	7	91.4
HYDROVOLUTE		Fly Ash	1	6.5	water	5-15	98.4
		Talc	1	6.5	water	5-15	77.1
		Vaporized Silica	1	6.5	water	5-15	94.0
		$CuSO_4$ (microspheres)	1	6.5	water	5-15	81.1
PEASE-ANTHONY CYCLONIC SCRUBBER		Fly Ash (2-5+μ)	.5-2.6	3-10	water		88-98.8
		SO_2	100-150 mg/m^3		water + weak alkali		94.5-96.8
PEASE-ANTHONY VENTURI SCRUBBER		Fe_2O_3 (.02-.50 μ)	1-6		caustic water		99
		Humidified SO_3, H_2SO_4 mist	10.6 mg/m^3	2-6	water		99.4
FOG FILTER		SO_2	230 mg/m^3	30****	caustic water	450	98.3
		Chamber process SO_2, SO_3, H_2SO_4	150 ppm	70	water	500	99

*Number refers to a specific spray generator and indicates its location relative to direction of air flow.

**Unless noted.

***Formed by evaporation and condensation of H_2SO_4 -fine particle size.

****Stated to be lower for larger unit.

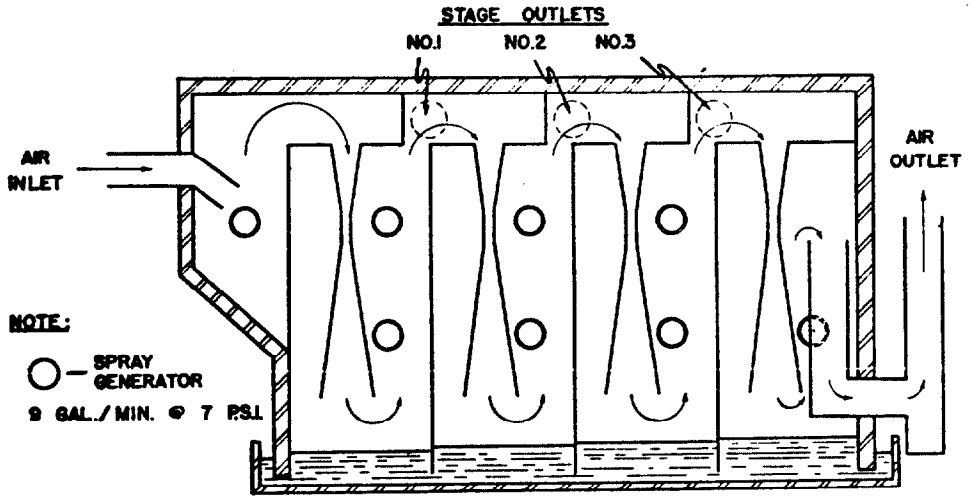

Fig. 1--Schematic Diagram of Experimental Four Stage "Solivore" Wet Collector.

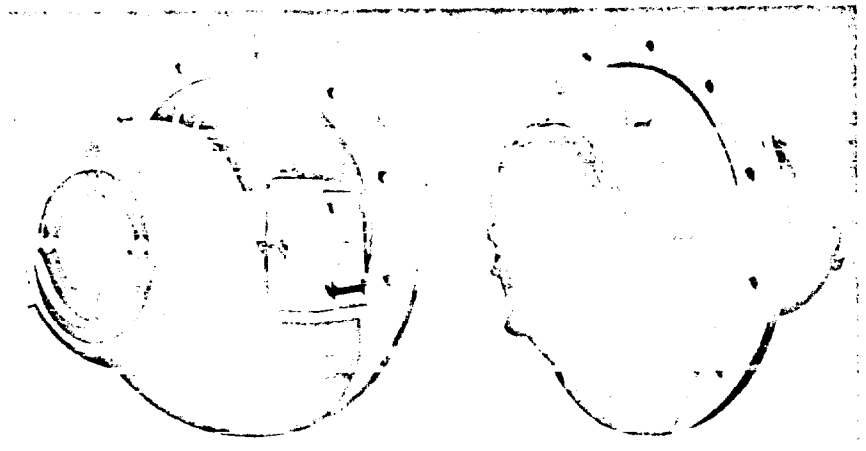

Fig. 2--Large Size Spray Generator.

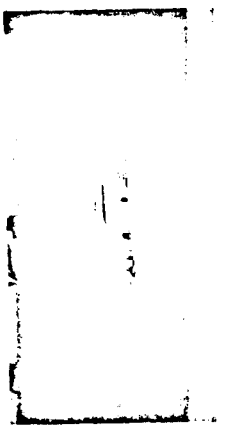

Fig. 3--Spray Generator in Operation.

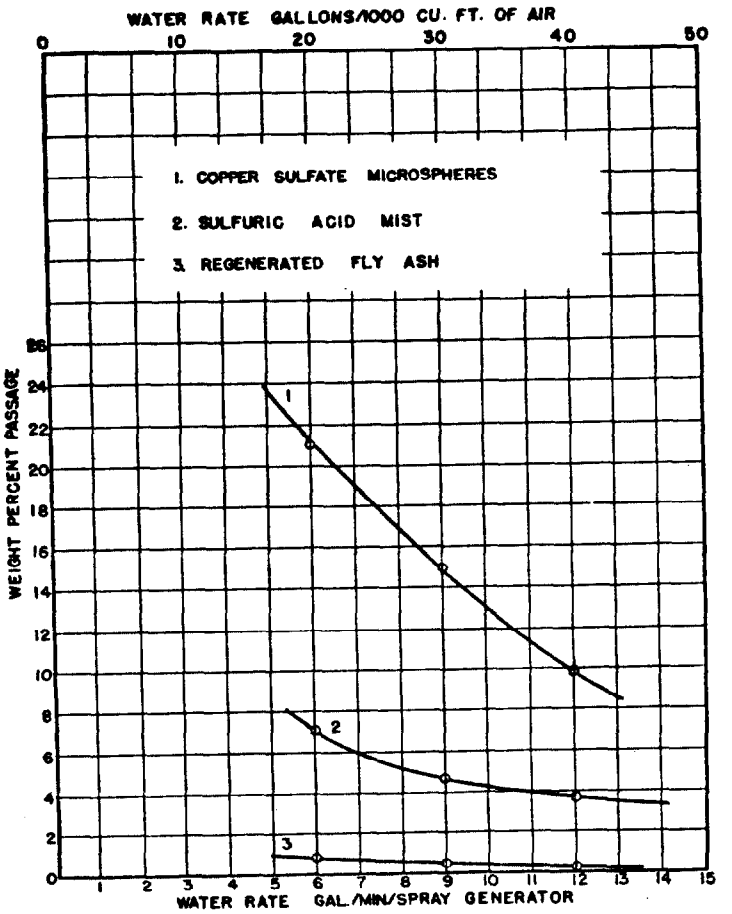

Fig. 4--Effect of Varying Water Rate on Percent Passage for One Stage "Solivore" Operation.

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