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CHEMISTRY

UNITED STATES ATOMIC ENERGY COMMISSION

AIR CLEANING STUDIES

Progress Report for July 1, 1954 to June 30, 1955

By

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October 15, 1956

Air Cleaning Laboratory

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SUMMARY

This report covers progress on the air and gas cleaning project conducted by Harvard University for the Engineering Division of the Atomic Energy Commission during the period July 1, 1954 to June 30, 1955. Primary objectives of this project include (a) research and development on air and gas cleaning devices and methods for their testing and evaluation, (b) training and education of Commission and contractor personnel, (c) collection and correlation of information on air and gas cleaning techniques and (d) consultation services.

During the period covered by this report five unclassified Air Cleaning Laboratory publications were released and distributed to the AEC and its contractors. Seven publications relating to experimental work conducted in this laboratory were presented in the open literature.

Consultation services were furnished on several occasions to AEC and contractor personnel and student research programs were continued on basic problems relating to gas cleaning.

Investigations on the role of electrostatic forces in gas cleaning, studies on resistance and filtration characteristics of fiber media, a study of dust re-entrainment from filters exposed to shock waves, and rating of high efficiency roughing filters were continued during this period. New projects included determination of gas cleaning requirements for a pilot model institutional incinerator, a theoretical study of the behavior of null-type sampling probes, evaluation of miniature cyclones for gas sampling and laboratory testing of a new type wet scrubber and two commercial collectors employing electrified fiber mats.

I

INTRODUCTION

A. Scope of the Project

This progress report describes air and gas cleaning projects conducted at the Air Cleaning Laboratory of the Harvard University School of Public Health for the Engineering Division of the U. S. Atomic Energy Commission for the period July 1, 1954 to June 30, 1955. The basic objectives of this program have been outlined in previous progress reports (1,2,3,4) and for immediate reference are summarized below.

- a. Development of test methods for, and the evaluation of, air and gas cleaning equipment.
- b. Collection and correlation of information on air and gas cleaning research throughout the Atomic Energy Commission and related organizations, including annual site visits.
- c. Evaluation of proposed equipment for Atomic Energy Commission applications including consultation on air and gas cleaning problems at the projects and laboratories.
- d. Research and development on new air and gas cleaning equipment for specific applications.
- e. Training and education of Atomic Energy Commission and contractor personnel.

Development of testing procedures (a) included a study of the aerodynamic characteristics of a special "static balance" probe designed for isokinetic sampling. The object of the current investigation was to establish a sound theoretical basis for predicting performance of similar probe designs. An investigation of the dust retention and pressure loss characteristics of three miniature cyclones ($\frac{1}{2}$, 1, and $1\frac{1}{2}$ inch diameter) showed that collection

efficiency actually varied directly with cyclone diameter rather than inversely as predicted by the separation factor. Resistance to air flow, however, was in good agreement with values found in the literature.

Commercial apparatus testing during the current year included: rating of two collectors employing electric fields superimposed upon pleated paper and fiberglas filters, respectively; an evaluation of the effect of oil viscosity upon the performance of metal screen viscous filters; an investigation of the pollen removal characteristics of viscous filters; performance tests on a new type, multiple Venturi tube, wet collector; and further studies on reverse jet filtration in regard to cake resistance.

Specific site visits (b) made during this period are discussed in separate reports.

Consultation services (c) were provided for Carborundum Metals Company, Akron, Ohio; U. S. Bureau of Mines, FCDA; ANP Project at Pratt and Whitney Company, Middletown, Connecticut, through Charles T. Main Company Architectural Engineers.

Research and development on new methods of air cleaning included additional studies of the electrostatic mechanisms encountered in aerosol filtration and their role in the collection of fine particulates upon flat and fiber surfaces. Investigation of the filtration and resistance characteristics of special slotted, nickel screening was continued and a similar study initiated for a synthetic sponge media. The effect of shock waves upon filter structure and dust re-entrainment were continued during this period. The objective of the current tests was to relate the amount of dust dislodged from filters to blast pressure and filter loading.

The following complete project reports were issued during the year:

1. First, M. W., et al: Air Cleaning Studies. Progress Report for July 1, 1952 to June 30, 1953. NYO Report 1591, Harvard University, Aug. 5, 1954.
2. Billings, C. E., Dennis, R. and Silverman, L.: Performance of the Model K Electro-Polar Filter. NYO Report 1592, Harvard University, July 15, 1954.
3. Billings, C. E., First, M. W., Dennis, R. and Silverman, L.: Laboratory Performance of Fabric Fume and Dust Collectors. NYO Report 1590, Harvard University, Aug. 31, 1954.
4. Silverman, L. and First, M. W.: Hood Scrubber Unit for Perchloric Acid. NYO Report 1589, Harvard University, Nov. 30, 1954.
5. Rossano, A. T., Jr. and Silverman, L.: Electrostatic Mechanisms in Fiber Filtration of Aerosols. NYO Report 1594, Harvard University, May 11, 1955.

Results of research carried out on this project and published in technical journals during the past year include:

Dennis, R.: Measurement of Atmospheric Pollution. J. Boston Soc. of Civil Engrs., vol. 41, no. 3, pp. 322-34, July, 1954.

Silverman, L.: Modern Methods for the Control of Air Pollution. Ibid, vol. 41, no. 3, pp. 335-53.

Silverman, L.: New Developments in Air Cleaning. Amer. Ind. Hyg. Assn. Quart., vol. 15, no. 3, Sept. 1954.

Berly, E. M., First, M. W., Silverman, L.: Recovery of Soluble Gas and Aerosols from Air Streams. Ind. Eng. Chem., vol. 46, pp. 1769-77, Sept. 1954.

Billings, C. E., Dennis, R., and Silverman, L.: Performance of Three Types of Fabric Dust Collectors. Air Repair, vol. 4, no. 3, pp. 131-36, Nov. 1954.

Johnson, G. A., Friedlander, S. K., Dennis, R., First, M. W. and Silverman, L.: Performance Characteristics of Centrifugal Scrubbers. Chem. Eng. Prog., vol. 51, no. 4, pp. 176-88, April, 1955.

Silverman, L., Conners, E. W. and Anderson, D. M.: Mechanical Electrostatic Charging of Fabrics for Air Filters. Ind. Eng. Chem., vol. 47, no. 5, pp. 952-59, May, 1955.

B. Facilities

During the period covered by this report the facilities for the project were the same as described previously (2).

C. Personnel

<u>Project Classification</u>	<u>Name</u>	<u>University Classification</u>
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(Supervisory personnel, part-time)

Director	Prof. Philip Drinker	Professor of Industrial Hygiene
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Associate Director	Dr. Leslie Silverman	Assoc. Professor of Industrial Hygiene Engineering
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(Full-time personnel engaged on the project)

Senior Engineer	Richard Dennis	Research Associate in Industrial Hygiene
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Senior Engineer	Charles E. Billings	Research Associate in Industrial Hygiene
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Secretary	Patricia Donaldson	Assistant Department Secretary
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(Part-time personnel engaged on the project)

Graduate Student	David M. Anderson	Research Fellow in Industrial Hygiene
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Graduate Student	Harry M. Donaldson	Research Fellow in Industrial Hygiene
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Graduate Student	William R. Samples	Research Fellow in Industrial Hygiene
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Technical Aide	Robert M. Thomson	Assistant in Industrial Hygiene
----------------	-------------------	---------------------------------

Machinist	Fred E. Wiedeman	School Machinist
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Technical Assistants	(Cooperative Chemical Engineering students from Northeastern University)	
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Secretary	Marianne Sugarman	Department Secretary
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II

METHODS OF COLLECTION AND EVALUATION OF SAMPLES

A. Isokinetic Stack Sampling Probes

Investigations of the aerodynamic characteristics of special "null" type probes, designed for isokinetic sampling, were continued during this period. In the previous progress report (4) calibration data were furnished for two "null" or "static balance" type sampling probes (loaned for test purposes by the Bethlehem Steel Company and the Western Precipitation Corporation, respectively). Test results demonstrated that zero pressure differentials between static pressures measured on the inner and outer probe surfaces did not necessarily indicate isokinetic sampling velocities. Variations as great as 20 per cent from true isokinetic flow were observed in some instances.

Since the above probes were accurate only when used in conjunction with a special calibration curve, a special "null" type probe was constructed (Figure 1) to investigate quantitatively the deviations from true "null" behavior. Static pressures within the probe were measured simultaneously at three points (2, 4, and 6 diameters downstream from the nozzle tip) and compared to the static pressure in the main air stream for both isokinetic and non-isokinetic sampling velocities. Pressure in the main stream was measured with a standard static pressure tube (1/8 in. diameter) located about 2 in. from the sampling probe.

Table 1, Section a, compares the true average velocity within the sampling probe to the average velocity in the main air stream (over the area included by the nozzle cross-section) for static balance conditions. It should be noted that probe velocities were considerably lower than duct velocities at low flow rates. However, the deviations became smaller at increased air flows.

Fig. 1 - Experimental "Null Type" Sampling Probe

Fig. 2 - Schematic Drawing of Cyclone Testing Apparatus

TABLE 1
CALIBRATION DATA FOR EXPERIMENTAL "NULL-TYPE" PROBE

Duct Velocity fpm	Probe Velocity fpm	Sampling Error Per cent	Static Pressure* Inside Probe Surface Inches of H ₂ O	Duct Static Pressure* at Tip of Probe Inches of H ₂ O	Departure From Null** Inches of H ₂ O
(a) Null Tests					
680	485	-28.7	-0.172	-0.172	0
1000	730	-27.0	-0.377	-0.377	0
1500	1130	-24.0	-0.893	-0.893	0
2000	1610	-19.5	-1.680	-1.680	0
3000	2440	-15.3	-3.920	-3.920	0
4000	3600	-10.0	---		
(b) Isokinetic Tests					
1000	1000	0	-0.443	-0.410	+0.033
1500	1500	0	-1.000	-0.936	+0.065
2000	2000	0	-1.790	-1.690	+0.108
3000	3000	0	-4.100	-3.900	+0.200
4000	4000	0	-7.360	-7.080	+0.280

* Static pressure relative to outside air, two diameters from inlet.

** Pressure within probe more negative than duct pressure.

Section b of Table 1 shows the pressure differential recorded by the "null" manometer when average sampling velocity was adjusted to duct velocity. Under these conditions the pressure in the main air stream was consistently greater than that within the probe. The test probe and static pressure tube system represent the simplest type of isokinetic sampling device and according to Hemeon (5) shows a "null" or true static balance at isokinetic flow. However, a theoretical treatment of the flow conditions existing in the main air stream and in the sampling probe demonstrated that a significant decrease in static pressure must occur when a cylinder of air having an essentially flat velocity profile enters the sampling tube. The air stream confined by the probe wall rapidly assumes a characteristic turbulent velocity profile which is a function of probe Reynold's number and can be estimated by methods described by Prandtl (6). Based upon velocity distributions in the air stream before and after entering the sampling nozzle it was shown that the kinetic energy per pound of gas within the probe was approximately 10 to 12 per cent greater than in the main air stream. When streamline flow prevails in the probe, air stream kinetic energy is approximately twice that for turbulent flow. In the absence of a power source to replace that energy converted to kinetic energy, probe static pressure (inside) must show a corresponding decrease. On this basis the theoretical pressure decrease at a true isokinetic velocity of 3000 fpm is 0.1 in. water whereas experimental data show 0.2 in. water differential between duct and probe. Failure of fluid energy changes to completely account for observed losses was attributed to roughness effects at the tip of the nozzle and to eddy losses engendered by changes in velocity profiles. Theoretical considerations indicated that the relative

increase in kinetic energy of the probe air stream did not change appreciably over the Reynold's number range 5,300 to 26,600, i.e., 1,000 to 5,000 fpm velocity in a 5/8 in. diameter probe.

A paper covering the major points of this study was presented at the Buffalo Meeting of the American Industrial Hygiene Association in April, 1954. A more detailed NYO report is now in preparation.

B. Miniature Cyclones

Collection efficiency and pressure loss characteristics were determined for three miniature cyclones (approximately geometrically similar) having cylinder diameters of $\frac{1}{2}$, 1, and $1\frac{1}{2}$ in., respectively, Figure 2. They were constructed of brass and designed with removable outlet sections which facilitated cleaning. Ordinarily these devices would be employed for sampling particulate material greater than 1 micron in diameter. However, they may also be used in series with high efficiency collectors, to make a rough separation between coarse and submicron particles.

Test apparatus was arranged so that these cyclones could be operated simultaneously as shown in Figure 2. Fly ash was injected into a duct before a Stairmand disc. Sampling probes leading to the cyclones were placed in step positions to minimize distortion in loading pattern. A separate sampling probe was used to check the cyclone inlet loading. Weight efficiencies were based upon the total amount of dust removed by the cyclone and the quantity passed as measured by a Whatman thimble filter connected in series. HA Millipore filters were used for particle size determination.

Tests with fly ash ($M_g = 0.6 \mu$, $G_g = 2.7$) indicated that weight collection efficiency varied directly with cyclone diameter, Table 2. According to theory, efficiency should vary inversely with

TABLE 2
WEIGHT COLLECTION EFFICIENCY FOR MINIATURE CYCLONES
WITH
RESUSPENDED FLY ASH

Cyclone Diameter Inches	Entry Velocity fpm	Flow Rate cfm	Weight Collection Efficiency %
$\frac{1}{2}$	2000	0.109	81.2
$\frac{1}{2}$	4000	0.217	83.6
1	2000	0.434	86.6
1	4000	0.868	89.6
$1\frac{1}{2}$	2000	0.976	91.6
$1\frac{1}{2}$	4000	1.953	93.3

TABLE 3
MEASURED AND PREDICTED PRESSURE LOSSES FOR MINIATURE CYCLONES

Cyclone Diameter Inches	Pressure Loss Inlet Velocity Heads (IVH)*		
	Measured	First(8)	Lapple(9)
$\frac{1}{2}$	3.59	4.42	2.61
1	3.69	4.37	2.41
$1\frac{1}{2}$	4.52	4.78	2.48

* Inlet Velocity = 4.000 fpm $\approx$ 1.0 in. water IVH at STP

diameter since the separation factor (7), $\frac{v^2}{rg}$, increases with decreasing radius. Failure of these data to conform to theory was attributed to the fact that at constant inlet velocity the boundary layer thickness was reduced when the cyclone radius was decreased and turbulent shear was increased between the inlet and exit spirals. Both effects appeared to cause re-entrainment of dust according to our data.

A small efficiency increase (about 2 per cent) was noted for each cyclone when entry velocity was raised from 2,000 to 4,000 fpm. By using the separation factor as a rough index of cyclone performance a threefold increase in inertial forces would be anticipated for a decrease in diameter from $1\frac{1}{2}$ to $\frac{1}{2}$ inch. At the same time inertial forces would be increased fourfold by doubling the velocity in any one cyclone. Therefore, a twelvefold increase in separating forces should be present for a $\frac{1}{2}$ in. diameter cyclone operating at 4,000 fpm in comparison to a $1\frac{1}{2}$ in. unit operating at 2,000 fpm. Test data (Table 2) showed a decrease in collection efficiency from 91.6 to 83.6 per cent.

It is not believed that these data should be extrapolated to cyclones of larger diameter since turbulence and boundary layer changes may be minor factors in larger cyclones. It appears that the separation theory applicable to large diameter units is not valid for miniature cyclones.

Cyclone resistance varied approximately as the square of the inlet velocity, i.e. $\Delta p = CV^{1.98}$. Table 3 presents pressure loss data for the cyclone proper, based upon equal inlet and exit velocities and does not include pressure loss through the entry transition section. According to the relationship developed by First (8), in terms of inlet velocity heads:

$$\text{Pressure Loss (IVH)} = 12 \frac{bh}{ke^2} / \left(\frac{LH}{D^2} \right)^{1/3} \quad (1)$$

In consistent units b and h refer to entry width and height; e and D to exit pipe and cylinder diameter; L and H to cylinder height and cone height. k is a constant having a value of $\frac{1}{2}$ for cyclones without inlet vanes.

Lapple's formula:

$$\text{Pressure Loss (IVH)} = 16 \frac{bh}{e^2} \quad (2)$$

applied only to cyclones having relatively long cylindrical sections and cones, i.e. $\frac{L}{D}$ and $\frac{H}{D}$ equal to 2.0. A comparison of experimental results with predicted losses indicates that Equation (1) affords a good approximation of cyclone resistance. Although the theoretical loss was 23 per cent high for the $\frac{1}{2}$ in. cyclone, the deviation decreased with the larger cyclones and agreed within 5 per cent for the $1\frac{1}{2}$ in. model. Lapple's equation did not check the test data, since it was developed for cyclones having constant $\frac{L}{D}$ and $\frac{H}{D}$ ratios in the order of two. Substitution of the above ratios in First's equation reduces it to Lapple's expression, i.e.

$$\text{Pressure Loss (IVH)} = 15.1 \frac{bh}{e^2}$$

Present tests furnish an approximate idea of the applications and limitations of miniature cyclones for aerosol sampling. Future studies will include performance with representative aerosols and a detailed investigation of particle size efficiency.

III

EVALUATION OF COMMERCIAL DUST COLLECTOR PERFORMANCE

A. Electro-PL Model C

A series of performance tests were conducted on a dust collecting device, Electro-PL, manufactured by the American Air Filter Corporation for use in home and office air conditioning systems. The collector may have single or multiple cells mounted in parallel. The one cell unit tested in this laboratory contained 28.5 sq.ft. of 5 ply, Type S, Airmat paper pleated in a $23\frac{1}{2}$ in. x $23\frac{1}{2}$ in. x $7\frac{1}{2}$ in. deep metal frame. An electric field is imposed on the filter surfaces by positive high voltage terminals (12 Kv.) placed in contact with the center of each pleat and grounded negative terminals at each end. Cell construction and electrode arrangements are shown in Figure 3. Rated operating conditions for a single cell unit are stated to be 1,000 cfm at 0.12 in. of water. A power pack operating on nominal 115 volt-60 cycle current supplies the rectified high voltage output.

The Electro-PL unit was mounted by means of adapter sections within the NBS filter testing apparatus described in the previous progress report (4). Sampling ports were located immediately before and after the test unit. Test dusts were introduced approximately 12 ft. upstream of the collector and by means of a mixing baffle were distributed uniformly in the cross-section of the 20 in. x 20 in. test duct.

The following aerosols were used to evaluate the Electro-PL unit: atmospheric dust ($M_g = 0.5 \mu$, $\sigma_g = 1.5$), resuspended fly ash ($M_g = 0.6 \mu$, $\sigma_g = 2.7$), ragweed pollen ($M_g = 19.6 \mu$, $\sigma_g = 1.08$) and sulfuric acid mist.

Weight and stain efficiency were determined with atmospheric dust, stain efficiency for fly ash and count efficiency for pollen

Front Face

Rear Face

Fig. 3 - Electro-PL Filter

Front Face

Rear Face

Fig. 4 - Electro Klean Filter

grains. Analyses of filter paper stains were based upon a modified NBS technique described previously (4). Weight efficiencies were based upon long term (10 hour) tests with Type S pleated filters and Hi-volume samplers. Pollen samples were collected upon AA Millipore filters and counted by standard light field microscope techniques. Comparative tests were made at 1000 cfm air flow with and without application of the 12 Kv. electric field.

Results of efficiency tests for different aerosols and operating conditions are presented in Table 4. A significant rise in efficiency was noted when the filter media was electrified, regardless of aerosol. Maximum weight and stain efficiencies for atmospheric dust were in the order of 50 and 33 per cent, respectively. The stain data represent an average of several tests which ranged from 25 to 45 per cent depending upon the activities in progress in the laboratory. Fly ash removal was considerably higher (86 per cent by stain) and pollen efficiencies were 100 per cent for practical purposes, even without electrification. Attempts to collect a sulfuric acid mist were unsuccessful because plate current rose to prohibitive values soon after starting the tests. According to the manufacturer the electrified (Electro-PL) unit should show stain efficiencies around 60 per cent for atmospheric dusts. The lower results indicated in Table 4 may perhaps be due to variation in size characteristics of atmospheric dust or to faulty filter assembly or power pack. Our plans call for repeating these tests with new media.

B. Electro-Klean

The Electro-Klean collector, also manufactured by the American Air Filter Corporation has air cleaning applications similar to those of the Electro-PL unit and operates on essentially the same

TABLE 4

COLLECTION EFFICIENCY FOR THE ELECTRO-PL, MODEL C, FILTER
AT
RATED AIR FLOW
(1,000 cfm)

Dust	Voltage Kv.	Pressure Loss In. Water	Efficiency Per Cent		
			Weight	Stain	Count
Atmospheric Dust Mg = 0.5 μ	12.0	0.13	49.0	32.7	-
Atmospheric Dust Mg = 0.5 μ	0.0	0.13	38.0	9.0	-
Ragweed Pollen Mg = 19.6 μ	12.0	0.13	-	-	>99.9
	0.0	0.13	-	-	>99.9
Resuspended Fly Ash	12.0	0.13	-	86.0	-
Mg ¹ = 12.0 μ	0.0	0.13	-	80.0	-

TABLE 5

COLLECTION EFFICIENCY FOR THE ELECTRO-KLEAN FILTER
AT
RATED AIR FLOW
(1,000 cfm)

Dust	Voltage Kv.	Pressure Loss In. Water	Efficiency Per Cent		
			Weight	Stain	Count
Atmospheric Dust Mg = 0.5 μ	12.0	0.17	62.0	32.0	-
	0.0	0.17	42.0	18.0	-
Ragweed Pollen Mg = 19.6 μ	12.0	0.13	-	--	99.3
	0.0	0.13	-	-	96.5
Sulfuric Acid Mist Mg = 4.0 μ	0.0	0.13	23.0	-	-

principles. A typical 1,000 cfm unit, Figure 4, consists of three filter frames containing pleated glass fibers. Opposite faces of each frame are connected to a ground and a 12 Kv. D.C. voltage source, respectively. To insure symmetry in the electrical field across the filter media the outer edges of each pleat are given an aluminized coating.

Efficiency runs were made by mounting the collector within the NBS test duct. Table 5 indicates performance of the Electro-Klean unit with atmospheric dust, ragweed pollen and sulfuric acid mist (no voltage). At rated operating conditions (1,000 cfm, 12 Kv.), stain measurements with atmospheric dust showed 32 per cent efficiency. With no electrification an average efficiency of 18 per cent was obtained. Comparison of these data with Electro-PL tests in Table 4 show no significant difference for normal operation, although without applied voltage a slightly higher efficiency is noted. However, it has been pointed out in a previous annual report (4) that atmospheric dust is not dependable for filter rating due to variability in its size and composition. As in the case of Electro-PL tests, the performance of the Electro-Klean did not correspond to the manufacturer's test data. Differences in test dust composition, air leakage or faulty power pack, may account for the lower efficiencies reported here.

Efficiency for ragweed pollen exceeded 99 per cent with applied voltage but dropped to slightly lower levels, 96.5 per cent, with no voltage.

Attempts to filter sulfuric acid mist with electrification were unsuccessful due to the high conductivity of the wetted fibers. Tests without applied voltage showed relatively low efficiency, 23 per cent. Repeat tests with the Electro-Klean with new filters will be made to confirm the present data.

C. High Velocity Filters - Adhesive Coatings

Previous testing of high velocity filters (4) indicated that the manner of application of viscous coatings and the quantity of adhesive retained by the filters had a direct bearing on stain efficiency. Spray coating of filters frequently results in "bare" spots which reduce dust removal efficiency. Similarly, prolonged drainage of relatively low viscosity oils causes a detectable decrease in collection efficiency.

Comparative studies were undertaken during this period on the effects of low and high viscosity lubricants on stain efficiency and dust holding capacity. Three filter designs, HV-2A (American Air Filter Corporation) Far-Air (Farr Filter Corporation) and P-5 (Airmaze Corporation) were tested for stain efficiency and holding capacity according to methods described in the previous progress report (4). The above filters were very similar in structure, each containing several pleats of window screen (approximately 12 mesh) supported by a 20 in. x 20 in. x 2 in. metal frame. Tests with Viscosine B (AAF adhesive equivalent to SAE 40-50 motor oil) after a 24 hour drainage period showed negligible differences in stain efficiency for the three filters. After draining for seven days, HV-2 efficiencies decreased by about 5 per cent (60-55 per cent). Figure 5 indicates the Viscosine B drainage loss as a function of time. A series of drainage tests with Calol (a high viscosity oil containing a micro-crystalline wax (Standard Oil Company of California)) showed much greater oil retention (Figure 5) and no significant change in stain efficiency was noted after a seven day drainage period.

Life tests with Viscosine B adhesive showed approximately the same dust holding capacity for all three filter designs, i.e. 400

Fig. 5 - Effect of Viscosity on Adhesive Retention of Viscous Filters

grams/sq.ft. projected filter surface "seen" by the filter. Holding capacities were based upon the amount of dust retained at the time when the initial (clean) filter resistance had been doubled. Efficiencies obtained showed a slight but progressive decrease with filter loading (60-57 per cent) over the three to four day test period. Calol coated filters tested in a similar manner indicated essentially the same holding capacities and changed very little in stain efficiency over the test period. Although laboratory studies did not reveal any important differences in efficiency for low and high viscosity adhesives, the Standard Oil Company of California (10) has indicated that long range field tests with Calol-coated Farr filters showed extended use in comparison to filters employing low viscosity oils. It is our impression that standard holding capacity tests are inadequate insofar as evaluation of filter life are concerned since even accelerated tests require a three to five day running period.

The advantages of increased oil retention associated with high viscosity oils are somewhat offset by the more complicated techniques required to lubricate the filters. Whereas low viscosity oils may be applied by simple dipping at room temperature, high viscosity oils require heating to about 175° prior to filter dipping. It is also important that excess oil be removed rapidly, either by centrifuging or by draining in a hot chamber so that oil will not congeal and plug the wire mesh. However, a Calol type adhesive appears preferable if filters must be stored an appreciable time before use. From a collection point of view, the less viscous oil should permit more rapid wicking or occlusion of particles such that more clean collection surface is available. The presence of less oil upon Viscosine B lubricated filters, due to drainage, may very

well counteract or reduce this advantage. Future tests are planned to obtain better quantitation on the effect of adhesive viscosity upon filter performance.

D. High Velocity Filters - Pollen Efficiency

A series of count efficiency tests on various thicknesses of (20 in. x 20 in. frame) fiberglas filters at 800 cfm filtration rate indicated that ragweed pollen aerosols afforded a convenient means of rating roughing type filters. Because of the high degree of uniformity of ragweed pollen, $M_g = 19-20 \mu$, $\sigma_g = 1.07$, efficiencies obtained for bed depths of $\frac{1}{2}$, 1 and 2 in. (45 to 91 per cent) conformed to the log-penetration law. However, it was necessary to correct the "apparent or manufacturers rated thickness" on the basis of the observed pressure losses through the various bed depths to obtain the logarithmic correlation. Additional tests on HV-2A viscous filters (American Air Filter Corporation) showed count efficiencies against ragweed pollen of 95 and 97 per cent at 800 and 1200 cfm, respectively, whereas Dust-stop (fiberglas) filters averaged 90 per cent at 800 cfm for 2 in. thick filters. It was noted that fly ash tests showed the fiberglas filters to be slightly more efficient than viscous filters on a stain basis (70 vs. 65 per cent). This inconsistency was explained by the fact that the heavier adhesive coating on the HV-2 filter apparently minimized re-entrainment of pollen grains.

Special apparatus was constructed to prepare dilute suspensions of pollen grains (Figure 6). Approximately 0.5 gram of pollen was placed in a perforated metal tube encased by a concentric barrel screen (200 mesh). An automatic rapping device coupled with screen rotation (40 rpm) discharged small quantities of pollen from which small fractions were withdrawn by an aspirating tube inserted in the settling chamber. Since preliminary screening prevented passage

Fig. 6 - Pollen Generator

of large agglomerates, the air aspirator and jet system produced an aerosol consisting primarily of discrete pollen grains. Air samples were collected on AA Millipore filters (supported by the porous blotting paper nutrient pads supplied with the filters) located in the nozzle section of the stain sampling equipment described previously (4). Concentrations were established by counting every pollen grain upon a $\frac{1}{4}$ or $\frac{1}{2}$ section of the filter. With a total sampling volume of 20 cu.ft., typical upstream counts ranged from 300 to 1,500 grains per filter (400 to 2,000 individual grains/cu. yd.). Practically no agglomerates were observed on the filter, except large quantities at the edges due to the action of the immersion oil.

E. Solivore Wet Collector

At the request of the Division of Engineering, Atomic Energy Commission, Washington, D. C., a new type experimental wet collector was shipped to this laboratory for testing and evaluation. The "Solivore" unit is slated for manufacture in the United States by the Ventil Corporation, a subsidiary of Barium Iron and Steel Corporation under license by Ateliers Ventil in Lyon, France.

This collector consists of four Venturi sections connected in series and housed in a cylinder 5 ft. in diameter and 10 ft. tall. Each Venturi section is preceded and followed by plenum chambers into which water sprays are directed at right angles to air flow, Figure 7. A unique feature of this device is the use of mechanical spray generators in lieu of conventional hydraulic or pneumatic nozzles. An impeller wheel, with short beveled blades attached to its periphery, rotates at high speed in the immediate path of water jets ejected from a disc shaped manifold and by intercepting them produces the spray droplets. A total of eight spray generators are

Fig. 7 - Schematic Diagram of Experimental Four Stage
"Solivore" Wet Collector

employed in the Solivore, each delivering 9 gpm at 7 psi manifold pressure and requiring a $1\frac{1}{2}$ HP motor to drive the impeller. Rated air flow for the present unit is 600 cfm and the estimated pressure loss for 4 stages is 8 to 10 in. water. According to the manufacturer applications for this collector lie in the cleaning of hot gas streams where ordinary fabric filtration fails, i.e. open hearth fume, fly ash, etc.

The height of this unit required that a 7 ft. x 7 ft. x 4 ft. deep concrete lined sump be constructed in the laboratory prior to testing. The unit is now installed and preliminary calibrations of water and air flow metering devices have been completed.

The tentative evaluation program calls for single and multi-stage operation with several test aerosols including talc, fly ash, calcium carbonate, copper sulfate microspheres, iron oxide fume, and atmospheric dust.

F. Reverse Jet Cloth Collector - Filter Cake Studies

Tests upon a reverse jet filter (Day Company) were continued during this period in an attempt to relate the physical characteristics of the dust cake (porosity, particle size, thickness) to pressure loss and total collection efficiency. Further structural modifications were required including replacement of filter bags (to insure proper blow-ring contact) and extensive sealing of cabinet leaks. Several tests were run with fine calcium carbonate ($M_g = 0.6 \mu$, $\bar{U}_g = 2.0$) in order to establish equilibrium pressure losses for constant inlet loading and reverse jet cleaning rate. Results were consistent with past studies (11) but showed too much variation for evaluation of cake porosity. Although porosity, α , may be determined theoretically by measuring cake thickness, l , and pressure loss, H_D , examination of the basic filter resistance

equation in terms of H_D and α , i.e.:

$$H_D = K \frac{(1 - \alpha)^2}{\alpha^3}$$

indicates that small changes in porosity may lead to large changes in estimated pressure loss. If porosity estimation is known within ± 2 per cent, calculated cake resistance will only be accurate to ± 10 per cent. Therefore it appeared that smaller test apparatus affording a chance of finer control would be desirable for this study. Arrangements have been made through Mr. H. J. Hersey to obtain a small experimental reverse jet unit.

IV

RESEARCH AND DEVELOPMENT ON AIR CLEANING METHODS AND EQUIPMENT

A. Pyramid Screens

Test apparatus has been constructed to determine the weight collection efficiency of 160/40T slotted, electro-deposited nickel screening (4) (0.001 in. x 0.0169 in.). Suspensions of atmospheric dust and fly ash will be used as test aerosols. Present studies with atmospheric dust indicate that ordinary washing, brushing and wiping do not return the screen to its initial, i.e. clean resistance. Weight efficiencies varied from 30 to 50 per cent based upon tests at a filtration velocity of 150 fpm. Since pressure loss ranged from 0.75 to 0.85 in. of water during sampling periods it is planned to collect intermittent stain samples in order to evaluate the effect of filter plugging upon efficiency.

B. Electrostatic Mechanisms in Aerosol Filtration

Previous studies (4) indicated a need for further research on the fundamental mechanisms of electrostatic capture of fine particulates in the atmospheric dust category which possess only natural charges and whose motion is predominantly streamlined. Therefore, an investigation was initiated with an atmospheric dust aerosol moving in streamline flow between a vertical, directly-charged parallel-plate condenser unit, Figure 8. This represents the simplest configuration capable of theoretical development. With this apparatus it was planned to relate collection efficiency to a) particle retention time in an electrostatic field, b) field strength, c) field configuration, and d) position of the collection surface with respect to the aerosol. Collecting faces consisted of polished aluminum sheets or plates covered with "Metlon"* cloth which produced uniform and non-uniform fields, respectively. Plates

*Metlon - Aluminum-polystyrene woven cloth

Fig. 8 - Sectional Schematic of Parallel Plate Device for Atmospheric Dust

were charged directly with a 20 Kv. power supply and field strength measured by plate voltage and capacitance. In the case of non-uniform fields the "apparent" field strength was measured which was accurate except at very short distances from the cloth surfaces. Results of stain tests with atmospheric dust were averaged by a statistical method since any one individual stain measurement was influenced by uncontrollable variations in aerosol charge and size characteristics.

Electrical forces acting upon a particle passing between a parallel plate system consist of the field force, F_c , which is a direct function of field strength, E , and particle charge Q_p ,

$$F_c = E Q_p \quad (1)$$

and the image force, F_I , which is related to particle charge, Q_p , and the distance, y , from the plates (which need possess no charge).

$$F_I = \frac{Q_p^2}{4y^2} \quad (2)$$

Inertial forces tending to resist any change in particle motion are defined by Stokes' Law as corrected for Brownian diffusion. Gravitational effects are eliminated by vertical orientation of the unit. If image forces are neglected and a parabolic flow distribution is assumed the collection efficiency, η , for the parallel plate system may be expressed by the following equation:

$$\eta = \frac{X}{Y V_{avg}} \frac{E Q_p (1 + A L/r)}{6 \mu r} = \frac{X}{Y} \frac{V_e}{V_{avg}}, \quad \eta \leq 1.0 \quad (3)$$

Here X refers to the plate length in the direction of air flow, Y the plate spacing, V_{avg} the air velocity, and V_e the particle migration velocity.

Rigid application of Equation 3 requires a homogeneous aerosol

and a precise knowledge of charge distribution. Insofar as atmospheric dust was concerned no more than a qualitative relationship was anticipated.

Test results are summarized in Figures 9 through 11. Figure 9 shows variation in stain efficiency with field strength at a constant filtering velocity of 5 fpm and a plate spacing of 1.9 cm. With a theoretical maximum charge of 25 electron units per particle, very high collection is suggested by Curve 3. However, an average charge in the order of 0.4 e/particle, which conform to tests reported by Kunkel (12), Curve 4 (based upon Equation 3) agrees well with the present tests, Curve 1. Since an average charge of less than one implies that some dust particles bear no charge, collection efficiencies would approach a definite upper limit somewhat less than 100 per cent. Curve 2 indicates that field heterogeneity affords better collection due to dielectrophoretic mechanisms which may exert considerable effect near the surface of the "Metlon" plates.

Figure 10 shows that closer plate spacing (1.91 versus 4.44 cm) enhances collection as predicted by Equation 3. Similarly, Figure 11 indicates that decreased air velocity between the plates favors higher dust retention. In the absence of a charge on the plates, Curve 4, significant collection is observed at low filtration velocities, <5 fpm. Since particle capture by diffusion mechanisms can be shown to be negligible in this velocity range, particle collection in this instance was attributed to image forces, F_I .

Studies are now in progress to evaluate image forces under more rigid experimental conditions. In order to quantitate charge characteristics, a methylene blue aerosol of known size and charge is passed through the parallel plate system. Generation and charging apparatus have been described in previous reports. Samples are

Fig. 9 - Field Strength Effect on Efficiency

Fig. 10 - Effect of Velocity and Plate Spacing on Efficiency

Fig. 11 - Effect of Velocity and Heterogeneity on Efficiency

collected on membrane filters and efficiencies expressed on a weight basis. Although the equation for particle motion under the action of image and opposing Stokes forces can be simply expressed, i.e.

$$\frac{m}{dt} \frac{dV_y}{dt} + \frac{6\pi\mu r V_y}{1+A(L/r)} - \frac{Q_p^2}{4y^2} = 0 \quad (4)$$

a rigorous mathematical solution in terms of conventional calculus appears difficult. Present efforts are directed toward graphical methods or electrical analog techniques.

C. Resistance and Filtration Characteristics of Synthetic Sponge Media (O-Cel-O)

The resistance and dust filtration characteristics of commercially available, synthetic sponges (O-Cel-O) were investigated to determine their applicability as roughing filters for high efficiency air cleaning at Atomic Energy Commission installations. According to the manufacturer (General Mills, Inc., Buffalo, New York) the standard porosity sponges contain about 62 and 38 per cent by weight, respectively, of cellulose and humectant (a glycol plus urea). Pore structure is controlled by leaching out crystals of sodium sulfate decahydrate. Fiber size and shape, and channel form are more irregular in this media than that encountered in beds composed of bulk mineral or synthetic fibers. Sponges are available in blocks as large 18 in. x 18 in. x 9 in. Pads tested in the laboratory were 2.85 in. x 4.5 in. in cross-section and 1 in. thick.

Pressure losses were determined for various bed depths (1 to 5 in.) at face velocities ranging from 2 to 110 feet per minute. Resistance curves of Figure 12 indicate that total pressure loss for a fixed bed thickness can be approximated by the general equation

$$\Delta p = KV^{1.2}$$

According to fiber Reynold's number criteria (0.02 to 1.0 for 2 and 100 fpm face velocity), air flow through the beds should be in the

Fig. 12 - Resistance Characteristics of O-Cel-O Sponges
For Different Thicknesses

laminar range. However, experimental data reported by Blasewitz (13) and this laboratory indicate that the transition from laminar to intermediate flow occurs at a Reynolds' number in the order of 0.1. Carman (14) has reported that a voids correction should be applied to high porosity beds (0.9555 for O-Cel-O sponges) which may reduce the critical Reynolds' number by as much as 10 times. It was observed that the slopes (velocity exponents) of all resistance curves, Figure 12, were less than 1.1 for velocities lower than 10 fpm ($RN = 0.1$). Furthermore, by applying a correction factor based upon a perimeter to area ratio, P/A , (3) the actual slopes of these curves were shown to approach unity, 1.01 to 1.03. Therefore, the assumption of laminar flow appears valid for the low velocity range. Although some increase in the velocity exponent may be attributed to bed compressibility when dealing with low density bulk fiber packings, the deviations noted in this study (where no compression was observed) were believed to be caused by a change in gas flow pattern from laminar to intermediate flow. It appears that inconsistencies in friction factors calculated for fiber beds are due in many cases to the simplifying assumption that the boundaries of laminar flow extend to an upper limit of one for Reynolds' number.

A linear relationship existed between pressure loss and bed depth as predicted by theory. Although a change in velocity profile may be anticipated as the gas enters the fiber bed, i.e. flat to parabolic in the case of a small cross-sectional area, the increase in gas stream kinetic energy is too small to be reflected by static pressure changes (< 0.001 in. water at 100 fpm). Average resistance values of 1 in. O-Cel-O sponges varied from 0.03 to 0.74 in. water for velocities ranging from 10 to 100 fpm. Corresponding values for a 5 in. pad were 0.165 to 3.1 in. water for 10 and 100 fpm velocities, respectively.

TABLE 6
STAIN EFFICIENCY OF O-CEL-O SPONGES (ONE INCH THICKNESS)
ON
ATMOSPHERIC DUST

Face Velocity fpm	Mean Efficiency %
1.1	18.8
2.8	21.4
5.6	16.9
11.2	16.7
22.5	22.1
56.2	30.6
112.0	19.6
280.0	30.9

Table 6 summarizes the results of several atmospheric dust stain efficiency tests for 1 in. O-Cel-O sponges at filtration velocities ranging from 1.1 to 280 fpm. These data, representing average efficiencies, were obtained at different times wherein the composition and size characteristics of the dust were subject to variation. In general, they indicate higher dust retention than coarse fiber (100 μ) roughing filters at the expense of an increased pressure loss. Final evaluation of these filters lies in the determination of their effective "life" or dust holding capacity.

D. Blast Damage To Filters - Re-entrainment Studies

The experimental methods and objectives of this investigation have been outlined in a previous progress report (4). Shock waves generated in a 20 in. diameter shock tube by bursting laminated paper diaphragms were allowed to impact on pleated filters (AEC #1, absolute) in a direction opposite to normal air flow. Physical damage to 24 in. x 24 in. x 6 in. filters occurred at shock overpressures of 5 to 6 in. of mercury. This report discussed dust re-entrainment from 24 in. x 24 in. x 6 in. and 12 in. pleated filters which were subjected to overpressures just below those causing damage.

The quantity of dust dislodged during shock tests conducted at sub-damage levels was determined by sampling the air stream produced by the blast with high volume pleated filters and all-glass impinger tubes. Test filters were loaded in a special test duct in which high concentrations of calcium carbonate were filtered for short periods of time. Comparison of clean and loaded filter weights (after equilibration with room moisture content) indicated that approximately $\frac{1}{2}$ and 1 pound of calcium carbonate (maximum loading) was required to increase the filter pressure loss by 1 in. for 500 and 1,000 cfm filters, respectively. These figures are approximately

the same as those reported for atmospheric dust. Several filters were also prepared containing known percentages of the maximum loading. Re-entrainment was determined by installing the loaded filter in the test section of the shock tube, impressing a sub-damage level shock wave across the filter, and then reweighing the filter. During the test, air samples were taken by simultaneous operation of high volume samplers and impingers placed in the shock tube 2 ft. behind the filter ("near") and at the exit of the shock tube 22 ft. beyond the filter ("far"). From the change in filter weight and the amount of dust in the air samplers, the re-entrainment was expressed as percentage weight loss and air concentration, respectively.

Four re-entrainment tests were conducted on 24 in. x 24 in. x 6 in. pleated filters using the techniques discussed above. These were loaded to 100, 78, 56 and 10 per cent of maximum dust holding capacity (226 grams, based on 1 in. rise in filter resistance at 500 cfm air flow). When tested at an average shock pressure of 3.6 in. Hg, they lost 55, 98, 59 and 32 per cent of the original weight of dust, respectively. The filter loaded to 100 per cent capacity suffered slight structural damage which apparently reduced the amount of dust re-entrained. The average dust concentrations in the shock tube for these four tests were 1.5, 4.8, 2.4 and <0.1 grains per cubic foot. The air concentration was usually slightly higher at the "near" (2 ft.) location than at the "far" (at the exit of tube, about 22 ft. beyond filter).

Three 12" AEC filters were tested for dust re-entrainment at an average shock over-pressure of 5 in. Hg. They had been previously loaded to various percentages of their maximum dust holding capacity by placing the filters in a dust laden gas stream. Maximum dust

holding capacity was defined as the quantity of dust deposited upon the filter surface, 454 grams, which would increase the pressure loss by 1 in. of water at rated flow. Re-entrainment for filters containing 100, 100 and 8 per cent of the maximum loading amounted to 84, 95 and 51 per cent of the original dust, respectively, and average air concentrations were 13.4, 13.6 and <0.1 grains per cubic foot, respectively. Under these conditions, the "near" (2 ft.) dust concentration was about twice as high as the "far" (at end of shock tube, 22 ft. from filter).

Pleated paper filters (AEC No. 1) 500 and 1,000 cfm capacity were found to lose varying quantities of dust when subjected to shock wave over-pressures below those causing physical damage. The average amount of dust re-entrained was about 90 per cent for fully loaded filters (100 per cent) and about 40 per cent for partially loaded (10 per cent) filters. Air concentrations ranged from 20 to less than 0.1 grains per cubic foot, depending on the amount of dust originally present on the filter. It appears quite probable that a large fraction of the dust dislodged and resuspended by a shock wave would be swept back to its point of origin, i.e. laboratory or process areas. The pressure levels (and positive pressure durations) reported for these tests correspond to those occurring at distances of 5,500 to 8,000 ft. from the blast point of a nuclear weapon.

E. Incineration Studies - Bureau of Mines

BOMAEC-30 Incinerator. At the request of the Division of Engineering, Atomic Energy Commission (Dr. Joseph A. Lieberman) the Air Cleaning Laboratory conducted stack sampling for gas cleaner evaluation tests on a special incinerator (BOMAEC-30) designed by the Combustion Research Section, U. S. Bureau of Mines, Pittsburgh, Pennsylvania for the disposal of radioactive waste materials from hospitals and research laboratories.

Several tests were conducted at the Pittsburgh laboratories during December, 1954 and June, 1955 to establish the air cleaning requirements for the BOMAEC-30 unit in relation to the stack effluent and to evaluate the over-all performance of the original gas cleaning system.

Figure 13 illustrates schematically the incineration equipment and shows (a) sampling points for determination of particulate loadings, oxygen and carbon dioxide content, and (b) the location of thermocouples and static pressure taps.

An exhaust fan (20) draws supply air into the incinerator shell (1) through inlet pipe (2) and exhausts hot combustion gases through an outlet pipe attached to the top of the incinerator. Effluent gas passes downward through a heat exchanger (11) for cooling and thence upward and through a tangential entry to the bottom of the baghouse (18). Particulate material, not separated inertially at this point, passes upward with the gas stream to seven glass cloth bags. Bag effluent enters chamber (19) (designed to contain all glass absolute filters) and then discharges through the blower to atmosphere.

Figure 14 shows the modified BOMAEC-30 incineration and gas cleaning system as tested in June, 1955. Major design changes included lengthening of the combustion chamber by 18 in., reduction in width of the four air entry slots from $\frac{1}{4}$ to $\frac{3}{16}$ in. and substitution of a simple spray cooling tower (one concurrently-directed, pneumatic spray nozzle, 9 gal./hr. capacity) for the Ross tubular heat exchanger employed in the original unit (Figure 13). The incineration process and operation of temperature and gas concentration recording equipment was under the supervision of the Combustion Research Laboratory. A continuous record of gas stream temperatures in the preheating shell and incinerator, heat exchanger (or spray tower) and final stack outlets were obtained. Total air

FIGURE 13 - LEGEND

1. Incinerator (29" Inside Diameter, 29 1/2" High)
2. Air Inlet, Metered by 2" Orifice in 4" Pipe
3. Incinerator Inlet Static Pressure Tap
4. Sight Glass for Observing Combustion
5. Pre-Heat Air (Jacket) Temperature, Thermocouple Nos. 1 and 4
6. Incinerator Outlet Gas Temperature, Thermocouple No. 3
7. Incinerator Outlet Static Pressure Taps
8. Incinerator Outlet Sampling Probe
9. Gas Temperature Entering Heat Exchanger, Thermocouple No. 6
10. Inlet to Heat Exchanger Static Pressure Tap
11. Ross Heat Exchanger
12. Cooling Water Inlet and Outlet
13. Heat Exchanger Outlet Static Pressure Taps
14. Gas Sampling Tube to Oxygen Recorder
15. Gas Sampling Tube to Carbon Dioxide Recorder
16. Drain Plug, Condensate from Stack Gas
17. Heat Exchanger Sampling Probe
18. Bag House (Seven Glass Cloth Bags)
19. Final CC-6 Filter Housing (No Filters Used)
20. Buffalo Fan
21. Ash Drums (35 Gallon Size)
22. Sampling Probe to High Volume Sampler
23. Temperature After Fan, Thermocouple Nos. 2 and 5
24. Bag Pressure Loss Taps
25. Fan Static Pressure Tap

1. INCINERATOR (29" INSIDE DIAMETER ,
63" OVERALL HEIGHT)
2. NEW EXTENSION ON INCINERATOR
(18" HIGH)
3. AIR INLET
4. PRE-HEAT AIR (SLOT) TEMPERATURE
THERMOCOUPLE NO. 5
5. BACHARACH SMOKE METER
6. INCINERATOR STACK TEMPERATURE , NO. 4
7. INCINERATOR OUTLET SAMPLING
PROBE
8. GAS TEMPERATURE ENTERING SPRAY
TOWER, THERMOCOUPLE NO.1
9. GAS SAMPLING POINTS FOR OXYGEN
AND CARBON DIOXIDE RECORDERS
10. AIR TO SPRAY NOZZLE
11. WATER TO SPRAY NOZZLE
12. PNEUMATIC ATOMIZING NOZZLE
(CONCURRENT OPERATION)
13. SPRAY TOWER
14. DRAIN PLUG
15. SPRAY TOWER SAMPLING PROBE
16. TO GLASS FILTER BAGS AND
FAN

Fig. 14 - Schematic Drawing of Revised Institutional Incinerator (BOMAEC-30) Showing Sampling Points

flow was metered at the incinerator inlet and oxygen and carbon dioxide concentrations in the incinerator outlet pipe were recorded continuously.

Test Results. The combustion of 25 and 33 pound sawdust charges in the original (Figure 13) and modified BOMAEC unit (Figure 14) indicated that structural changes and a slight increase in air flow made no significant change in the concentration and composition of the stack effluent. At average air flow rates ranging from 50 to 60 cfm, exit gas temperatures rose rapidly to 1200 to 1400°F and oxygen concentrations decreased to less than 1 per cent during the first third of a 45 to 60 minute burning period. Solid materials emitted during the first 10 to 20 minutes of burning were primarily combustibles which caused a rapid increase in pressure loss through the glass bags.

BOMAEC-100 Incinerator. A series of stack effluent tests were run on a larger model incinerator, BOMAEC-100, Figure 15, to determine whether the air cleaning requirements would be similar to those of the BOMAEC-30 unit. Typical tests with 100 pound, boxed sawdust charges indicated combustion periods ranging from 60 to 80 minutes for air flow rates of 193 and 155 cfm, respectively. During these tests the supply air was admitted only through the two upper air ports. Incinerator stack temperatures rose to 1300°F to 1500°F and at peak temperatures excess oxygen in the gas stream was reduced to less than 5 per cent.

Burning of office wastes containing 10 to 15 per cent moisture showed that stack temperatures were less than 1200°F for the last two-thirds of a run. Minimum oxygen concentrations were in the order of 2.5 per cent at 155 cfm operation. Total solids emitted were generally higher than that for sawdust due to the mineral filler in the paper stock.

Fig. 15 - Schematic Drawing of BOMAEC-100 Incinerator Showing Sampling Points

Comparison of BOMAEC-30 and BOMAEC-100 Incinerators. Table 7 summarizes the comparative performance of the BOMAEC-30 and BOMAEC-100 incinerators.

Air flow rates in excess of those recommended by the Combustion Research Laboratory resulted in increased stack emission of both mineral and combustible materials although burning rates were increased by about 20 per cent.

With both units the overall combustion efficiencies, based upon total weight of combustible effluent, were greater than 99 per cent. However, combustion efficiency of the BOMAEC-100 incinerator appeared higher than that of the BOMAEC³⁰ during sawdust burning. Combustible loadings were equal to or less than those of the BOMAEC-30 unit, the air to charge ratio lower and the burning rate approximately 65 per cent greater. However, waste combustion tests indicated a lower stack emission with the BOMAEC-30 unit at the expense of a lower burning rate and greater air to charge ratio.

A higher moisture content and possible variation in composition in the waste may have accounted for the increased stack emission in the case of rubbish charges in the BOMAEC-100 unit.

Bases solely upon sawdust tests it appeared that the position of air jets within the BOMAEC-100 unit may have been responsible for its improved combustion. It should be noted, however, that since no preheating of inlet air took place in the BOMAEC-100 incinerator, the combustion conditions should have been less favorable than in the BOMAEC-30 unit.

Results of current tests indicate that minor changes in design or operating conditions should be considered before development of the final incinerator air cleaning systems. From a practical viewpoint, the emission of combustibles, particularly condensable materials, should be minimized since their presence may cause

rapid plugging of high efficiency filters. Recommendations for ultimate design features are contingent upon results of further testing.

TABLE 7

COMPARATIVE PERFORMANCE OF BOMAEC-30 AND BOMAEC-100 INCINERATORS

Total Charge lbs.	Air Flow Rate cfm	Air To Charge Ratio cfm/lb.	Burning Rate lbs/hr.	Stack Emission Rate		Percent Combustibles in Stack Effluent
				Total lbs/hr/ lb. of charge	Combustible lbs./hr./lb. of charge	
A. BOMAEC-30; SAWDUST CHARGE						
25	60	2.4	45	0.0033	0.0011	33.3
25	79	3.2	65	0.012	0.0075	62.3
B. BOMAEC-30; WASTE CHARGE (10-15% MOISTURE)						
60	63	1.05	33*	0.0043	0.00016	3.8
C. BOMAEC-30; WASTE CHARGE (50% MOISTURE)						
69	63	0.91	22*	0.0071	0.0047	66.2
D. BOMAEC-100; SAWDUST CHARGE						
100	155	1.55	75	0.0043	0.0011	25.2
100	193	1.93	100	0.0120	0.0023	18.8
E. BOMAEC-100; WASTE CHARGE (10-20% MOISTURE)						
100	155	1.55	75	0.012	0.0035	29.4
112	193	1.72	124	0.030	0.0110	37.4

* Burning rate based upon weight of dry charge completely burned.

CONSULTING AND TRAINING SERVICES TO THE AEC

A. Consultation and Site Visits

Visits were made to major operating sites in conjunction with the specific air cleaning problems discussed below:

a. Carborundum Metal Company, Akron, Ohio, August 28, 1954. Air cleaning problems relative to zirconium metal production and a local air pollution problem were discussed with Dr. Leslie Silverman. A separate report on this subject was submitted.

b. University of California at Los Angeles, AEC Project, September 20, 1954. Messrs. Leonard Baurmash and James W. Neil visited the Air Cleaning Laboratory to discuss automatic sampling methods for airborne particulates during fallout investigations.

c. U. S. Bureau of Mines, Pittsburgh, Pennsylvania, September 22, 1954. Arrangements were made between Mr. Richard C. Corey, U. S. Bureau of Mines, Combustion Research Laboratory and Dr. Leslie Silverman for stack gas evaluation studies on the BOMAEC-30 institutional incinerator. This phase of the program was considered as a preliminary study related to the design of a final gas cleaning system by this laboratory.

d. FCDA tests, Nevada Proving Grounds, February 16, 17, 1955. Mr. Richard Dennis of this laboratory visited Mr. Robert Corsbie to discuss use of FCDA structures as a means of determining blast damage to AEC absolute filters and filter assemblies.

e. Pratt-Whitney ANP Project - Charles T. Main Company AE, June 25, 1955. Representatives of the Charles T. Main Company visited the Air Cleaning Laboratory to discuss gas filtration problems for the Fox project with Dr. Leslie Silverman.

B. Education and Training

1. Student Research Program

A student research program discussed previously (4) was continued during this period by Mr. David M. Anderson. This included a further investigation of mechanically charged electrostatic filters and fundamental studies on the nature and relationships of the various charging phenomena. The performance characteristics of miniature cyclones (Section II b) were determined by Mr. Edward Krystal (part-time technical assistant) in conjunction with his senior thesis program at Northeastern University, Boston, Mass.

VI

RESEARCH IN PROGRESS AND FUTURE PLANS

1. Continuation of basic investigations on electrostatic charge phenomena are planned with particular emphasis on image forces.

2. Performance characteristics of newly developed filtration media will be investigated, i.e. synthetic, natural, and mineral fibers and metallic (Pyramid) screens to determine their applicability to AEC filtration problems.

3. The effects of shock waves on air cleaning devices will continue in the laboratory. It is hoped that arrangements can be made for field tests during either nuclear or high explosive weapons evaluation tests.

4. Laboratory investigations of commercial air cleaning apparatus will continue with immediate testing scheduled on a new design wet collector and a high velocity cyclone.

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