

# **Fifth Atomic Energy Commission Air Cleaning Conference**

held at the Harvard Air Cleaning Laboratory

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## **PREFACE**

This report represents a compilation of papers presented during the last two days of the Fifth AEC Air Cleaning Seminar. This continuing series of seminars provides AEC and AEC contractor personnel, and for the first time private industry, with an opportunity to discuss and evaluate air cleaning operations and problems and new developments in the field. Operational experiences in the processing of gaseous effluents from fuel fabrication plants, in reactor facilities, and in other AEC National Laboratory and contractor activities were related. This phase of the meeting was unique in that attendance was open to access permit holders for the first time.

The first two days consisted of a review of air and gas cleaning fundamentals and was conducted by staff of the Harvard Air Cleaning Laboratory and guest lecturers. Attendance was limited to Commission and Commission-contractor personnel directly engaged in air and gas cleaning activities.

The seminar was sponsored by the Division of Reactor Development, U. S. Atomic Energy Commission, in cooperation with the Harvard School of Public Health, and was held at the Harvard Air Cleaning Laboratory, Boston, Mass.

# CONTENTS

	Page
Preface . . . . .	iii

## REVIEW OF SITE ACTIVITIES

Session I, June 26, Morning  
Chairman: Joseph A. Lieberman

<u>Particulate Airborne Contamination at Start-Up</u> of the EBWR . . . . .	J. J. Hartig and J. A. Pagliaro	1
Air Cleaning Activities at ANL . . . . .	D. P. O'Neil	5
<u>Air Sampling in Relation to the Meteorological</u> <u>Program at BNL . . . . .</u>	Robert M. Brown	8
Two Gas Cleaning Problems at the Idaho Chemical Processing Plant Site . . . . .	D. M. Paige, P. N. Kelly, and E. S. Grimmett	17
Air Cleaning Activities at Brush Beryllium Company . . . . .	Hal J. Shafer	23
Air Cleaning Activities of the Beryllium Corporation . . . . .	A. Epstein	24

Session II, June 26, Afternoon  
Chairman: Abel Wolman

Air Cleaning Activity at Oak Ridge Gaseous Diffusion Plant . . . . .	R. C. Smith	26
Air Cleaning Operations at the Rocky Flats Plant . . . . .	Robert J. Walker	28
AEC Bettis Plant Air Cleaning Activities . . . . .	P. R. Bolton and J. E. Ross	30
Air Cleaning Experience at the Naval Reactor Facility . . . . .	J. R. Horan	32
Air Cleaning Activities at GE-ANP Idaho Test Station . . . . .	R. M. Chatters	33
Air Cleaning Operations at KAPL . . . . .	W. H. Truran	35
Air Cleaning Activities at Atomics International . . . . .	A. A. Jarrett	40
Air Cleaning Activities and Associated Studies at Goodyear Atomic Corporation . . . . .	Ben Kalmon	41
Developments in High Efficiency Air Filtration . . . . .	Paul M. Engle	44
Developments in the Manufacture of Absolute Filters . . . . .	A. R. Allan, Jr.	45

	Page
Developments in the Manufacture of Ultra-Aire Space Filters . . . . .	Robert A. Bub 47
Fire-Resistive Filter Progress at HAPO . . . . .	Don J. Keigher 50
Moisture and Burning Tests of Space Filters . . . . .	J. H. Palmer 53
Application of Fire-Resistant Air Cleaning Filters at HAPO . . . . .	F. E. Adley 65

NEW DEVELOPMENTS

Session III, June 27, Morning

Chairman: Philip Drinker

Design and Calibration of an Improved Cascade Impactor for Size Analysis of Aerosols . . . . .	R. I. Mitchell and J. M. Pilcher 67
A Multibed Low Velocity Air Cleaner . . . . .	Robert E. Yoder and Fleming M. Empson 84
Air Cleaning Operations at UCRL . . . . .	M. D. Thaxter 91
Economic Survey of Air and Gas Cleaning Operations Within the AEC . . . . .	Richard Dennis, Charles E. Billings, and Leslie Silverman 92
Air Cleaning Costs—A Study of Three Systems . . . . .	Harry S. Jordan 98
Study of the Fundamental Properties of Aerosols . . . . .	H. F. Johnstone 108

Session IV, June 27, Afternoon

Chairman: Leslie Silverman

Air Cleaning Studies at Harvard University, 1956-57 . . . . .	Leslie Silverman 109
Further Investigations of the Continuous Slag Wool Filter . . . . .	C. E. Billings, C. Kurker, Jr., E. C. Hickey, L. H. Levenbaum, and L. Silverman 114
Slag Wool for Acid Gas and Mist Removal . . . . .	Charles Kurker, Jr., Charles E. Billings, and Leslie Silverman 120
Agglomeration of Particulate Materials . . . . .	Edward C. Hickey, C. E. Billings, and Leslie Silverman 130
Progress Report on Filtration of a Freshly Generated NaK Fume . . . . .	Edward Kristal, Richard Dennis, and Leslie Silverman 133
Development of a "Triboelectrified" Fluidized Bed for Aerosol Filtration. . . . .	David M. Anderson and Leslie Silverman 140

# PARTICULATE AIRBORNE CONTAMINATION AT START-UP OF THE EBWR

J. J. Hartig and J. A. Pagliaro  
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Associated with the initial full power operations of the Experimental Boiling Water Reactor were high levels of radioactive airborne particulate matter found within the reactor shell. Concentrations up to  $5 \times 10^{-7}$   $\mu\text{c}/\text{cc}$  were measured. As this activity was not predicted from the borax experiments, there was an immediate concern as to its presence.

Questions to be answered were three: (1) what was the major radioisotope (or isotopes) accounting for the activity; (2) from which component of the plant was the activity escaping; and (3) (depending upon answers one and two) how could the level be reduced.

Identification of the major contaminant was conducted by decay studies and gamma pulse height analysis. It was found that about 99 per cent of the activity had a 32-min half life and had gamma energies of 1.4, 1.0, and 0.46 Mev. This fits very well the corresponding data reported for the isotope  $\text{Cs}^{138}$ . Cesium-138 beta decays to the stable isotope  $\text{Ba}^{138}$  and is the daughter of the beta decay of  $\text{Xe}^{138}$ .

The above evidence pointed to the possibility that the activity was escaping from one or more of the reactor components as xenon gas and was then decaying to the particulate  $\text{Cs}^{138}$ . It would be expected that if  $\text{Cs}^{138}$  were present there should also be other xenon daughters plus some associated krypton daughters. With this lead a radiochemical analysis of the filter papers was conducted and the isotopes given in Table 1 were identified.

Table 1— ISOTOPES IDENTIFIED FROM RADIOCHEMICAL ANALYSIS OF FILTER PAPERS

Isotope	Concentration, $\mu\text{c}/\text{cc}$	Per cent of maximum permissible level (MPL)*
$\text{Cs}^{138}$	$5 \times 10^{-7}$	1.0
$\text{Sr}^{89}$	$1 \times 10^{-10}$	0.5
$\text{Sr}^{90}$	Tracer	<<1
$\text{Ba}^{140}$	$2 \times 10^{-11}$	<<1

\*Obtained or calculated from data in National Bureau of Standards Handbook 52.

Table 1 shows that although the total activity concentration is much higher than normally tolerated, the levels are not excessive when MPL's are considered. In spite of this, it was decided to spend every effort to reduce the activity concentrations.

Before considering from which component the activity was escaping, a very general view of the EBWR Plant should be considered (see Fig. 1).

The EBWR Plant differs from standard power plants only in the use of a reactor to produce steam in place of a boiler. The steam formed in the reactor vessel, about 20 Mw, is collected above the core and brought through the steam dryer. A portion of the steam goes directly to the turbine and then to the condenser. The remaining steam bypasses the turbine and passes directly to the condenser, the amount bypassed being inversely proportional to the demand of the generator. From the condenser the condensate is returned to the reactor via the feed water pumps to complete the cycle. In the design it was realized that gases would be present in the

system and would tend to collect in the condenser. The expected gases were oxygen and hydrogen from the dissociation of steam, and air due to "in leakage." To remove these gases and also to keep the condenser under a slight negative pressure, an air ejector system was introduced at the top of the condenser. Sampling showed that the activity within the shell was due to leakage from this air ejector.

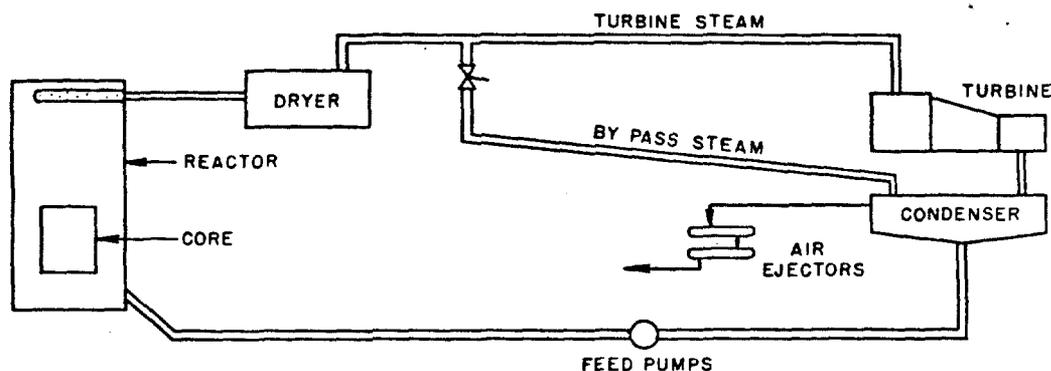


Fig. 1— General view of EBWR.

To determine just which radioisotopes were leaking from the ejector, numerous samples of the ejector gases were collected and analyzed utilizing decay schemes and gamma pulse height analysis. From the results of these analyses, the following isotopes were definitely identified:

Xe <sup>133</sup>	Xe <sup>138</sup>	Cs <sup>138</sup>	Kr <sup>85</sup>	Kr <sup>88</sup>
Xe <sup>135</sup>	Cs <sup>137</sup>	Ba <sup>139</sup>	Kr <sup>87</sup>	Rb <sup>89</sup>

The identified isotopes may better be seen from Fig. 2, which shows the isotopes as they would be seen on a chart of the nuclides. The absence of several of the expected isotopes is easily explained. First, it must be remembered that the data are from gamma analysis and some of the radioisotopes have only betas associated with their decay. Others were not identified due to low specific activities. Among those which were not identified but were expected are Xe<sup>137</sup>, Cs<sup>139</sup>, and Cs<sup>135</sup>.

From the evidence so far presented it was concluded that the gaseous fission products xenon and krypton were escaping from the air ejectors. After the gases escaped they decayed to the particulate radioisotopes. Due to half life and specific activity considerations, the major contaminant found on filter samples taken within the EBWR shell was Cs<sup>138</sup>. Other contaminants were present but to a much lesser degree.

One may ask the question, how are the gaseous fission products reaching the air ejectors when the fuel elements are supposedly well clad. To date this question has not been satisfactorily answered; however, there have been several mechanisms suggested. These are as follows:

1. During the autoclave testing of the elements, some were found to be faulty (having leaks). These faulty elements uranium contaminated the autoclave which in turn possibly cross contaminated the accepted elements. The amount of uranium contamination needed was calculated to be approximately 35 mg.

2. The gases could be diffusing through the Zircaloy cladding.

3. The Zircaloy cladding could have contained some natural occurring uranium.

It must be remembered that these are merely possibilities and none have been proven or disproven to date.

The first suggestion to remedy the shell airborne activity was to stop the air ejector leakage and pass the ejector exhaust directly to the building stack. This would result in stack activity which when considering MPL's would be quite acceptable; however, there are several low level counting labs located within a half mile of the EBWR Building, which under proper meteorological conditions could be effected. As a compromise a "Vapor Recovery System" was

					La 139	La 140			
Ba 133	Ba 134	Ba 135	Ba 136	Ba 137	Ba 138	Ba 139 X	Ba 140 X		
Cs 132	Cs 133	Cs 134	Cs 135	Cs 136	Cs 137 X	Cs 138 X	Cs 139	Cs 140	
Xe 131	Xe 132	Xe 133 X	Xe 134	Xe 135 X	Xe 136	Xe 137	Xe 138 X	Xe 139	Xe 140

		Zr 90						
Y 87	Y 88	Y 89	Y 90					
Sr 86	Sr 87	Sr 88	Sr 89 X	Sr 90 X				
Rb 85	Rb 86	Rb 87	Rb 88	Rb 89 X	Rb 90			
Kr 84	Kr 85 X	Kr 86	Kr 87 X	Kr 88 X	Kr 89	Kr 90		

Ba 138

STABLE ISOTOPE

X

Cs 138

IDENTIFIED ISOTOPE

Xe 137

UN-IDENTIFIED ISOTOPE

Fig. 2—Radioisotopes identified.

suggested in which the activity would be held up. It was found that the use of the vapor recovery system as a whole reduced the stack activity by a factor of 10 when compared to exhausting the activity directly to the stack. A sketch of the system is seen in Fig. 3.

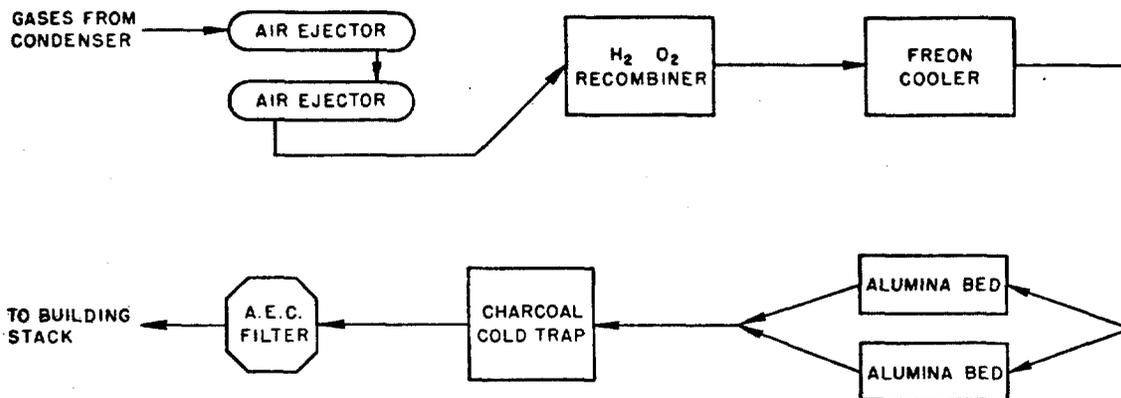


Fig. 3—Vapor recovery system.

The gases from the air ejector (about 2 cfm) are first brought through a recombiner in which the oxygen and hydrogen are united. The gases then are brought through a Freon cooler in which the water vapor is condensed. Then the water and particulate activities are trapped in an alumina bed. The remaining gases are circulated to a charcoal cold trap where they are adsorbed. The main purpose of this charcoal trap is to give the gases additional hold-up time for decay. Then the decayed gases are filtered and exhausted from the building by way of the stack. As mentioned above the vapor recovery system as a whole reduced the stack activity by a factor of 10. It was found that the alumina beds contributed a factor of 5 and the charcoal trap a factor of 2.

With this system in use the shell airborne activity was reduced to about  $3.5 \times 10^{-9} \mu\text{c}/\text{cc}$ ; again about 99 per cent of the activity is due to  $\text{Cs}^{138}$ , and represents less than 1 per cent of MPL.

In conclusion, it has been shown that if monitoring is conducted in the early stages of a power plant utilizing reactor steam and if proper steps are taken to iron out the bugs, the plant can be operated without releasing excessive airborne contamination.

# AIR CLEANING ACTIVITIES AT ANL

D. P. O'Neil  
*Argonne National Laboratory*

Since the last Air Cleaning Conference at Argonne in September 1955, there have been no major air cleaning developments at the Laboratory. However, I would like to discuss the status of some of the air cleaning systems we have mentioned previously and describe what we are doing or planning to do in some of our new facilities.

## 1 FUEL FABRICATION FACILITY

At the last conference, A. B. Shuck of Argonne described the Fuel Fabrication Facility, then under construction, which will be a plant for the development and fabrication of reactor fuel components containing plutonium and  $U^{233}$ .

The building is divided into three areas: the Administrative, Technical, and Fabrication Areas. Each area will be isolated from the other by means of air locks.

The static pressure in the Administrative Area will be maintained at +0.05 in. water, relative to the Technical Area which will be at 0.05 in. wg below ambient barometric pressure. The Fabrication Area will be kept at -0.075 in. wg relative to the Technical Area.

Operations in the Fabrication Area will include all the common metallurgical manipulations such as, alloying, melting, casting, heat treating, pressing, extruding, and rolling, in addition to machining, welding, and brazing. All work will be done in large hoods with gloves on both sides and all hoods will be interconnected to facilitate the passage of material from one operation to another.

Some of the hoods will contain an air atmosphere while others, because of the pyrophoric nature of some of the alloys that will be used, will contain an inert atmosphere; helium, in this case.

The ventilation of the Fabrication Facility will consist of a once-through system for the hoods, a standby purge system should a break occur and a once-through filtered air system to exhaust the room air and ventilate the equipment located beneath the primary hoods; such as, vacuum pumps, motors, and other accessory equipment.

Air to the hoods will pass through 12- by 12- by 6-in. high efficiency filters at the hood inlet and outlet and again through high efficiency filters in the fan loft. The small filters at the hood will be changed from within the hood. Final filtration for the purge system will be through two banks of high efficiency noncombustible media filters in series. The first filter of each series will be changed by the bag technique.

The first stage of the construction work is complete. The ventilation equipment, including filter banks, blowers, and ducts up to the Fabrication Room, are installed and have been helium, leak tested. However, some difficulty has been encountered in obtaining a contractor for the fabrication of hoods and the inert gas system. Argonne was unable to obtain acceptable bids from a general contractor and has found it necessary to subcontract the work.

Contracts for fabrication and the erection of hoods and process equipment are out for bids. Separate contracts must be let for pipe fitting, connecting the existing duct to the hoods, electrical work, and painting. It is expected that the job will be completed Feb. 1, 1959.

## 2 SENIOR CAVE

In October 1956, the Laboratory let a contract for a Senior or Hot Chemistry Cave for use by our Chemical Engineering Division and construction is now under way. This cave has been designed to handle up to 10,000 (1 Mev gamma) curies of irradiated plutonium and the associated mixed fission products. Both wet and dry chemistry and high-temperature operations will be performed in the cave.

The cave will consist of approximately 640 sq ft of operating area (manipulator side of cave); 860 sq ft of service area back of cave, and approximately 180 sq ft of cell area. The air, after being rough prefiltered upon entering the building, will be fed to the operating room, thence to the service area to the rear of the cave, and then to the isolation room where it will pass through high efficiency filters and into the cells.

High efficiency filters located at the cave will be used to filter the inlet air to the cells for two reasons; first, to avoid the possibility of dumping unfiltered air from the cells to the operating or service areas through the isolation rooms, should some occurrence in the cell result in a pressure buildup great enough to overcome the 0.8 in. wg negative that will be maintained in each cell and, second, to remove as much of the atmospheric dust from the supply air as possible and, thereby, delay as long as possible the changing of the high efficiency filters on the exhaust system which will involve working with highly gamma and alpha contaminated filters.

The air supply to the operating area of the cave, that is, the area where the manipulator controls will be located and, therefore, the personnel load will be heaviest, will be 1520 cfm with an additional expected leakage of approximately 240 cfm. An additional 240 cfm leakage is expected into the service area. This leakage will result because of the intention to keep the operating and service areas negative with respect to the corridor. The 1520 cfm supply will be shut off automatically whenever the doors to the operating or the service areas are opened to assure a flow in through the doors at all times. The 1520 cfm supply will be reduced should experience indicate leakage through the walls or doors is greater than now anticipated. Both the operating and service areas will be air-conditioned by means of packaged air conditioners in each area.

The air cleaning system to be used on the exhaust air from the cave will consist of double filtration through high efficiency noncombustible filters. The first filter will be shielded since it probably would be highly contaminated should a fire occur. Provision will also be made for future shielding of the second filter should the first fail. Should contamination result, of course, remote changing of the filters will be necessary.

The technique to be used for the remote changing is that described at the last Air Cleaning Conference by R. A. Blomgren of Argonne. This method involves the pushing of the contaminated filter out of the exhaust system into a metal disposal container with a clean replacement filter by means of a hydraulic ram. Special gaskets on the filter keep the opening sealed at all times although air flow continues at all times through the filters.

### 3 INERT GAS CAVE

Another facility still in the planning stage is the addition to our existing cave facility. The addition will be an inert gas cave for work on one million curie fuel elements of 1 Mev gamma energy. The conventional air flow pattern from the office space, to the operating area, to the service area, to the equipment repair section of the cave will be used. The air, before entering the equipment repair area of the cave, will pass through high efficiency filters for the same reasons stated for the Chemical Engineering cave. The air from the equipment repair cell, which is back to back with the inert gas cell, will be double filtered through high efficiency filters, with the first filter located in the cave itself and the secondary filters in the fan loft.

The helium atmosphere cell, which may also be used with an air atmosphere, will have a 1000 cfm exhaust blower in operation at all times. When the cell is used with an air atmosphere, the air will exhaust through a high efficiency filter located in the cell then to a second high efficiency filter in the fan loft. For inert operation of the cave, the blower would remain in operation but the duct would be sealed off at the cell by an O-ring gasketed butterfly valve. Should a sensing device, which will be located in the cell, detect a rise in the static pressure in the cell as a result of a break or rupture of the shield (the cell will be maintained at a negative static during normal operation), the butterfly valve will open exposing the cell to the 1000 cfm exhaust blower assuring a flow in through all cracks or openings.

The philosophy of operation dictates that everything within the cell, including all tools, supplies, and wastes, will be canned before removal. This includes the high efficiency pre-filter in the cell which will be changed remotely by means of slave robots. The push-through technique will be used on the secondary filters in the fan loft.

#### 4 PREFILTER EVALUATION

In addition to those new facilities, we are still working on the evaluation of hood pre-filters; that is, trying to determine what they do for us and whether they do it economically.

The original philosophy at Argonne, when our large 200 Area buildings were being designed, was that the air should be prefiltered at the hoods for two main reasons: (1) To remove as much of the atmospheric dust as possible from the exhaust air and, thereby, prolong the life of the final AEC filter, and (2) To retain as much of the activity at the hood and, thereby, reduce contamination of the duct work.

Since then, there has been considerable discussion concerning the justification for these filters. As a result of this, we have undertaken a study that we hope will give us some of the answers.

As a little background, the air flow through a typical laboratory is as follows: the supply air to the building passes through two banks of filters in the basement; Type PL-24, manufactured by American Air Filter, the first bank using 5-ply paper and the second bank using 10-ply paper. The air then passes through heating and cooling coils to the offices, corridors, and laboratories, with the air to the offices and corridors then passing into the laboratories and with the laboratory air out through 25FG prefilters in the hoods to the final filters in the fan loft.

We are attempting to determine where the dirt comes from that is retained on the various filters. What percentage of it passes through our fresh air cleaning filters, what percentage of it is carried into the laboratories by people in the building, and what percentage is generated in the laboratories by the various operations going on there. In addition, we are trying to determine what amount and size distribution of airborne particulate is removed by each of the four filters the air passes through as it makes its cycle through the building. Knowing this, we would have a basis for decisions on new buildings as well as existing facilities.

The first portion of the study has been under way now for approximately two months. Four days each week, for over 23 hr per day, air samples are taken at six locations in the air stream as it passes through the building.

The samplers are Sutorbilt Constant Flow Units, designed by Dr. L. Silverman, with which we use MSA 1106-B filter paper. This paper was selected because of its high efficiency and also because of the very slight absorption of water vapor and resultant weight gain during sampling. Since we are determining dust loads by weighing the filters, this was an important consideration. The fact that desiccation is not necessary has saved us considerable time.

Sample stations are located just upstream of the first (5-ply) inlet filter; between the first and second inlet filters; just downstream of the second (10-ply) inlet filter; in a laboratory adjacent to a hood; just upstream of the final filter; and just downstream of the final filter servicing that hood. With these sample locations, we have all filters bracketed and, in addition, have sample locations that will give us an indication of the dust loading that occurs as the air moves from the supply outlets in the offices, corridors, and laboratories to the hoods.

We had hoped, originally, that this first phase of the study would have been completed by now; however, difficulties have arisen and delays have resulted.

Because of the high flow of air through the Silverman Sampler Head, averaging about 30 m<sup>3</sup>/hr, the paper has torn or has been drawn in from the edge seal permitting air to bypass the filters occasionally. Whenever this occurs, the sample must be thrown out and at least one efficiency determination sacrificed although absolute dust load values for the untorn filters are still of value. Another bit of difficulty was caused by a fine break in a rotameter on the sampler head downstream of the final filter which made uncertain the accuracy of a number of the samples and, of course, the efficiencies based on them.

However, from our results to date, we know that the fresh air entering the buildings has a dust loading ranging from 30 to 215  $\mu\text{g}/\text{m}^3$  with an average of 82  $\mu\text{g}/\text{m}^3$ .

As the air passes through the 5-ply filter, it is cleaned with an efficiency varying from 35 to 81 per cent, with an average of 58.8 per cent by weight. The second bank of filters, although of 10-ply material, has an average efficiency of 25.4 per cent, less than half that of the 5-ply because the 5-ply removes the larger particles and the efficiency of the 10-ply is then based on a smaller particle size.

The combined average efficiency for the 5 and 10-ply filters is 68.8 per cent for the removal of atmospheric dust.

The efficiency of the 25FG prefilters in the hoods will be determined in the second phase of the work. Since the exhaust from the hood combines with the exhaust from another hood and a laboratory bypass before reaching the next sample location, the samples taken at that location are not truly representative of the air passing through the hood prefilters in question.

Results for the final filter are still inconclusive because of the rotameter failure.

One unexpected result, so far, has been the fact that about 50 per cent of the time the air in the laboratory has apparently been cleaner than the air passing through the second of the supply air filters. This we believe is due to the cleaning effect of the heating and cooling coils through which the air must pass before reaching the laboratories. We are now attempting to determine whether we are correct in this assumption.

Now that the sampling program is moving smoothly, we hope to soon start making some size determinations of the dust at the same locations where we presently have our samplers—using both the Millipore filter-optical microscope and the electron microscope techniques.

## AIR SAMPLING IN RELATION TO THE METEOROLOGICAL PROGRAM AT BNL

Robert M. Brown  
*Brookhaven National Laboratory*

The Meteorology Group at the Brookhaven National Laboratory has been studying dispersion of atmospheric pollutants in the lower 400 ft of the atmosphere since 1947.

The group was originally formed at Brookhaven because of a dispersion problem which dealt with the release of  $\text{Ar}^{41}$  from the 355-ft stack of the nuclear reactor. The reactor is air-cooled, and even though the air is filtered before and after leaving the core, one of the constituents of the air, namely argon, becomes radioactive. The Meteorology Group was established for the purpose of determining the pattern of the diffusion of the invisible  $\text{Ar}^{41}$  under different weather conditions and the extent of ground-level concentrations downstream from the reactor stack.

To solve this problem, a program was formulated which revolved about the measurement of certain basic meteorological elements as well as atmospheric sampling. Two meteorological towers, (Fig. 1) modeled after those at Hanford, were built and equipped with instruments for sensing the wind direction, wind speed, and the temperature at several levels in the vertical to 410 ft and across a horizontal span of 900 ft. The data from the instruments on the towers were and continue to be transmitted by underground cables to the main building 720 ft from the towers and are charted on a recording panel (Fig. 2). The 410-ft tower is equipped with an Army M-1 smoke generating system to produce an oil-fog which is forced up a 20-in. diameter stack attached to one leg of the tower to a height of 355 ft (Fig. 3). The oil-fog particles have a mean radius of 0.3  $\mu$ , ranging from 0.05 to 3.0  $\mu$ , and behave as a true aerosol. The oil-fog can be observed visually, photographed, and measured.

Three photoelectric densitometers are used in determining ground-level concentrations. They use the principle of the right-angle scattering of light and have several ranges of sensitivity. They consist basically of a light source, a black chamber, and a photocell (Fig. 4).

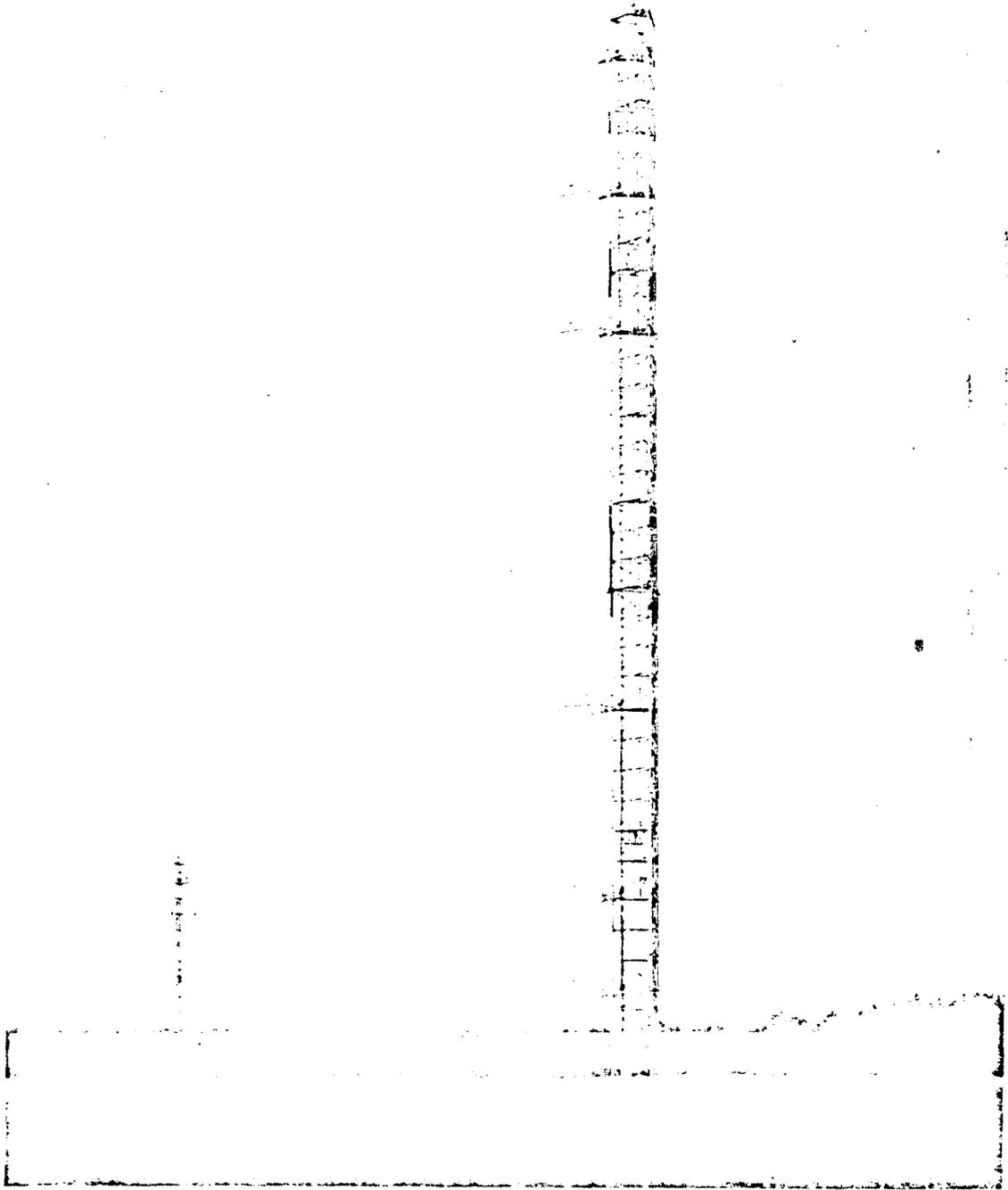


Fig. 1—Meteorological towers.

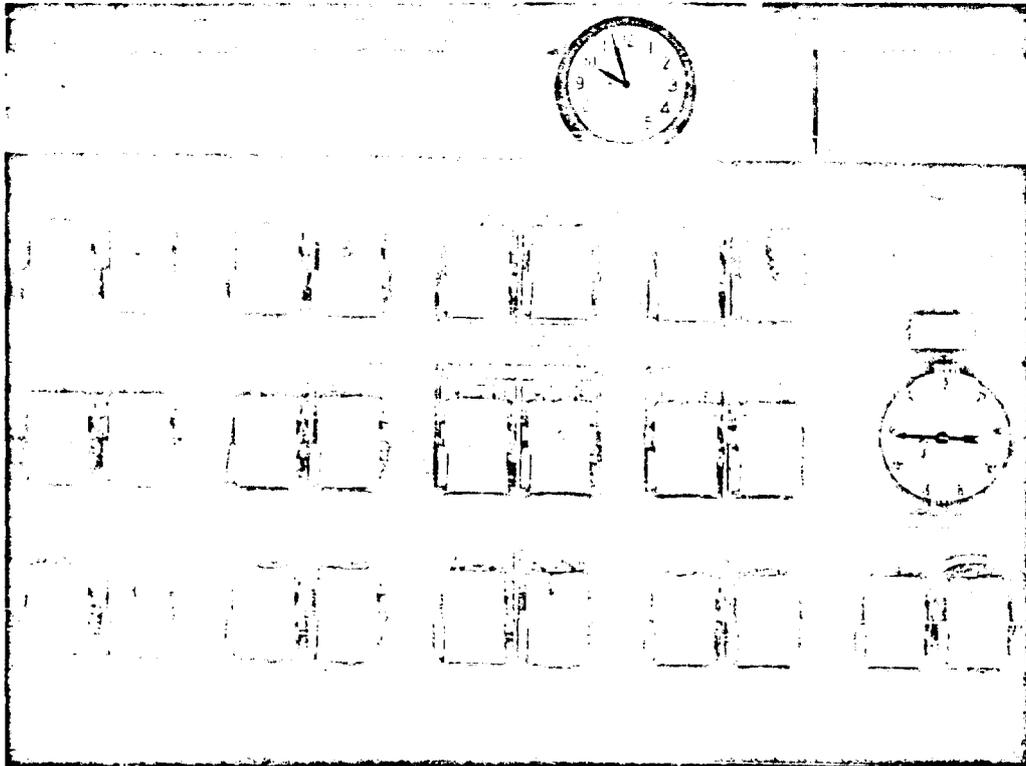


Fig. 2—Recording panel for meteorological towers.

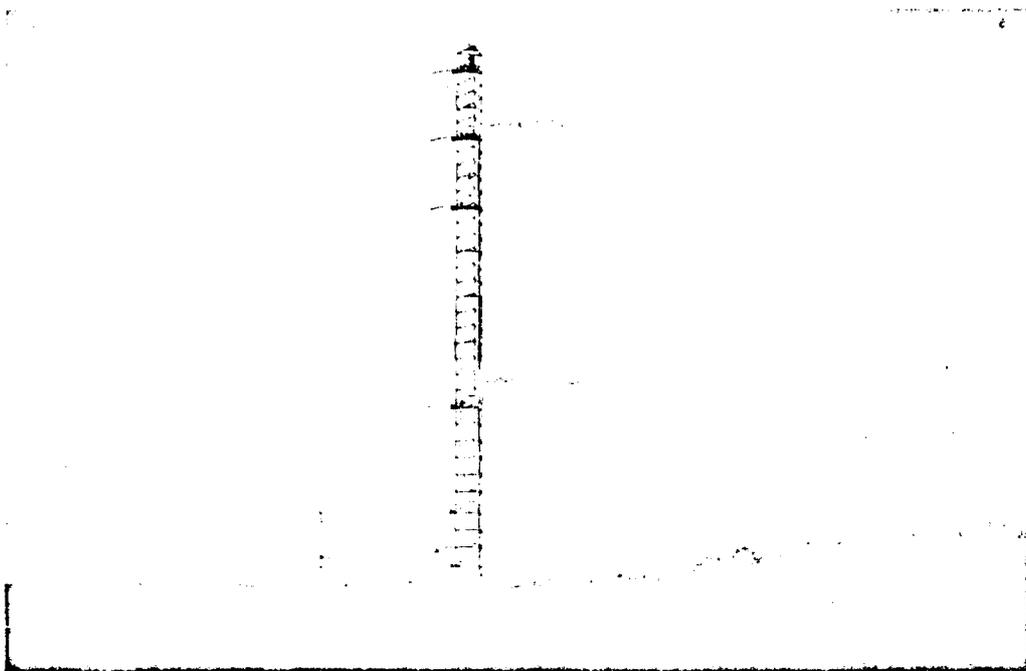


Fig. 3—Oil-fog from 410-ft tower.

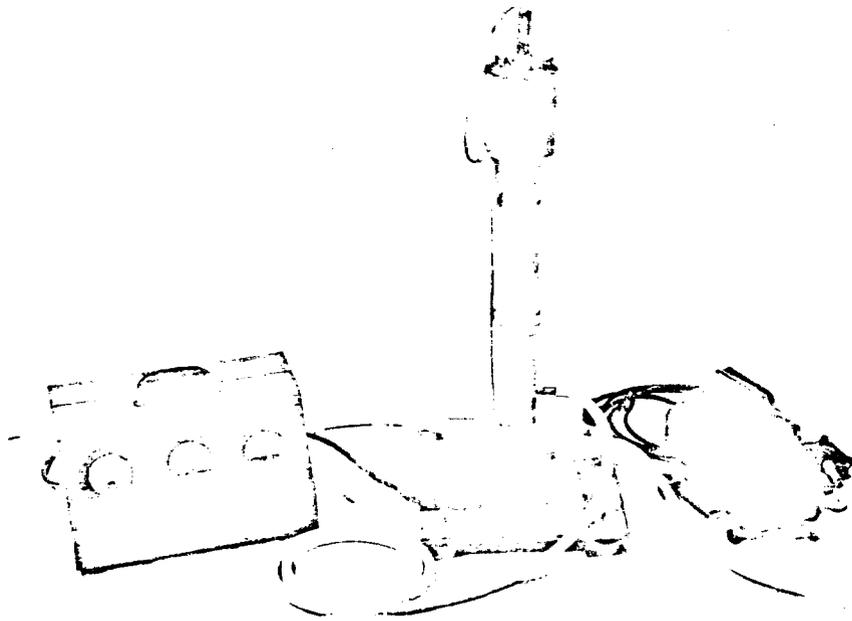


Fig. 4—Photoelectric densitometers.

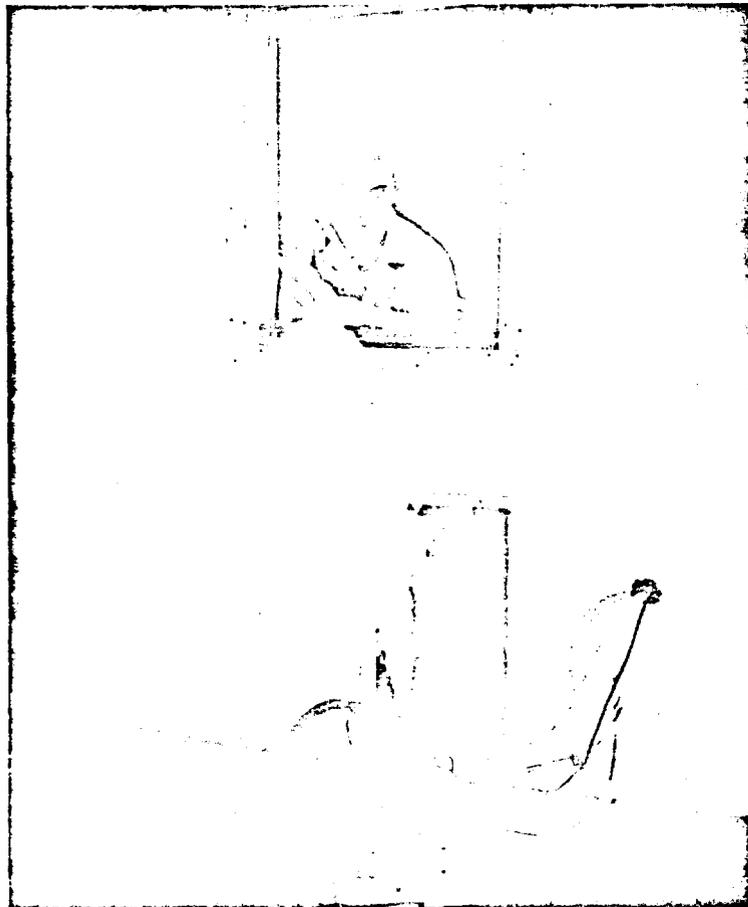


Fig. 5—Calibrating room.

These densitometers are calibrated before and after each smoke run in a special calibrating room of known volume (Fig. 5). A miniature smoke generator is used to produce a known concentration of oil-fog in the room, and by taking a series of readings at various concentrations, a calibration can be obtained.

Cost and maintenance of a complete densitometer with its accessories prevent the use of many of these devices. Therefore, a less expensive method of sampling concentrations downstream from the stack was needed. The oil used in producing the fog fluoresces when excited by ultraviolet light; therefore, some method of collecting the oil-fog for measurement later seemed desirable. After much detailed study, the Millipore filter produced by the Lovell Chemical Company was selected. A filter holder, (Fig. 6) developed at Brookhaven, consists of a modified A-N connector and a sintered glass filter used as backing for the fragile Millipore filter. Each filter and holder is checked for flow rate and pressure drop before being used in the field. This filter, together with its holder, has been used with several types of vacuum pumps.

The need for an inexpensive, portable d-c sampling unit led to the development of the first of the samplers (Fig. 7). This unit consists of a 6-volt car battery, a small vacuum pump and motor (Trico) together with the filter and holder. Many of these units can be made, used, and maintained at relatively small cost. The Meteorology Group has used 20 of these units satisfactorily in field sampling. This and all other units mentioned have been checked for reliability in the calibrating room and are all trustworthy devices.

The main objections to this particular sampler are that it is heavy (approximately 55 lb), the batteries need recharging after each hour of sampling time, and the pump is designed for intermittent use and should be cooled. However, all of these difficulties can be coped with and the unit is still being used with satisfactory results.

It is also desirable to make measurements of the concentration of oil-fog aloft in the smoke stream itself. Many fruitless hours were spent in devising some method of raising an entire unit which would consist of power supply, vacuum source, and filter components or various combinations of ground and airborne components. It was finally decided that the first method was the best, since it eliminated equipment such as tubes and power lines. However, most of the sampling devices were too heavy or too expensive to be carried aloft.

A light weight (1.8 lb) model airplane engine, attached to a Dewey and Almy #8000 Kytoon was finally adapted for use in airborne sampling (Fig. 8(a)). The first model employed part of the air intake from the engine as a source of vacuum. This model was used several times with success. However, the flow rate through the filter was very small (0.1 cfm at 0.6 in. Hg). This meant long sampling periods which were not convenient. The second model (Fig. 8(b)) used a stripped-down vacuum pump of the ground-level sampler driven by the model airplane engine. This increased the air flow through the filter to 0.3 cfm at 4.5 in. Hg. However, the weight increased from 1.8 to 3.4 lb and required the use of two model 8000 Kytoons. A third and final revision to the airborne sampler was made (Fig. 8(c)). This unit includes two airplane engines, one serving as a vacuum pump and the other as a driver. The entire air intake is utilized from the driven engine and the device can pull 0.3 cfm at 2.7 in. Hg. It weighs 2.7 lb complete with fuel, and has been used successfully in smoke runs during inversion conditions.

The most difficult problems in the use of these airborne units are the start-up on cold mornings and the effects of temperature change as they rise vertically. The first of these problems has been solved by the use of small electric starters. The propeller is attached to the shaft of the motor and electrically turned as fuel and air are fed to the engine. As soon as the engine starts it is pulled away from the starter and adjusted for proper mixture. The problem of temperature change has not been solved entirely as yet, but it is not a very serious one if the proper mixture of fuel and air is attained before ascent.

A versatile automatic sampling device has recently been developed at Brookhaven (Fig. 9). It consists of three main sections: (1) a sampling unit which has ten solenoid valves connected to a main chamber, (2) a basic timing unit which has interchangeable motors and several cams, and (3) a program unit consisting of a plug board and control relays. The unit allows for various sampling cycles, time delays, and sampling periods.

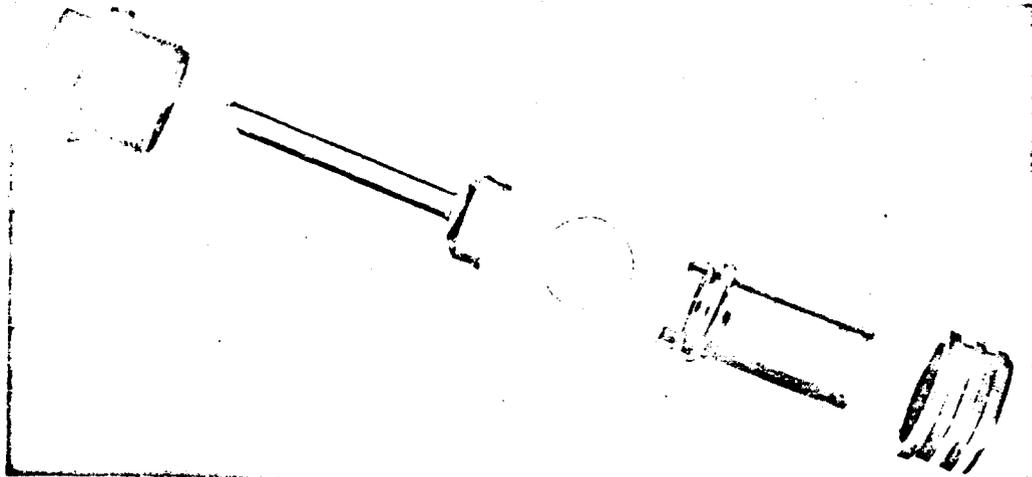


Fig. 6—Filter holder.

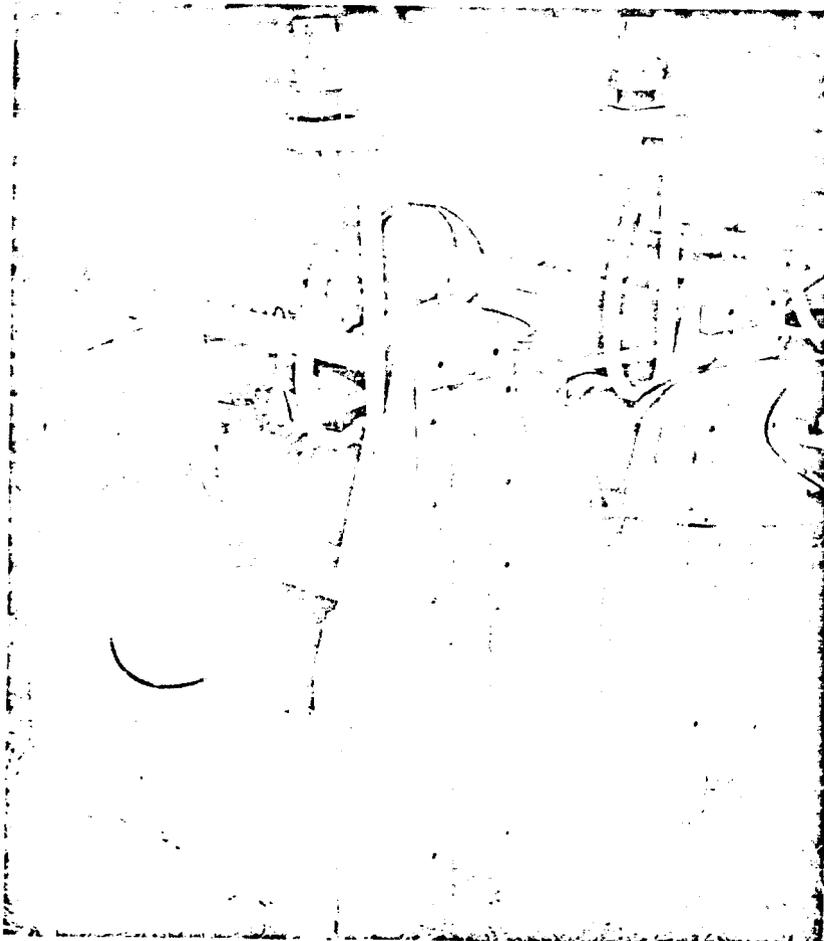
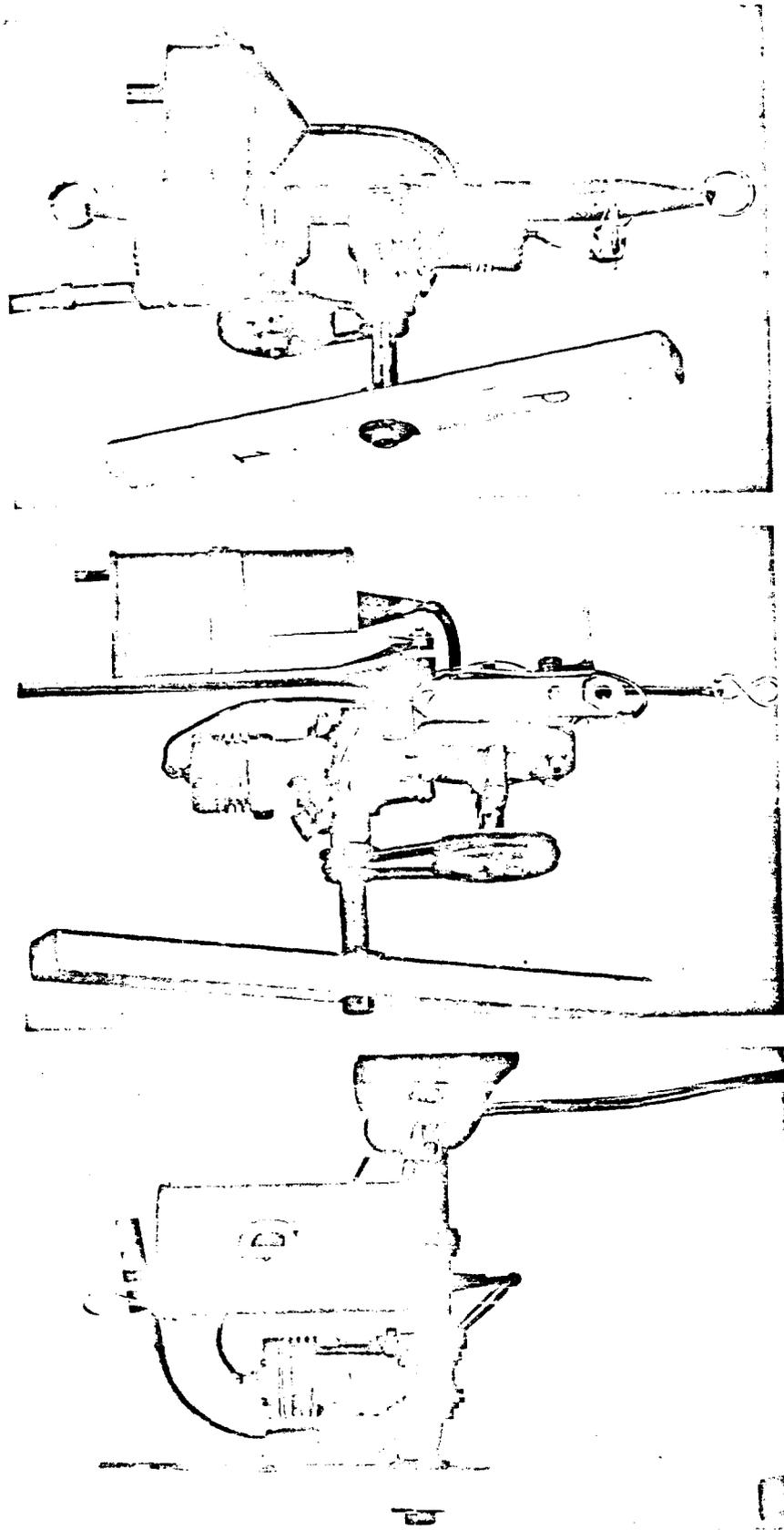


Fig. 7—Portable d-c sampling unit.



(a)

(b)

(c)

Fig. 8—Airborne samplers: (a) First model, (b) Second model, (c) Third model.

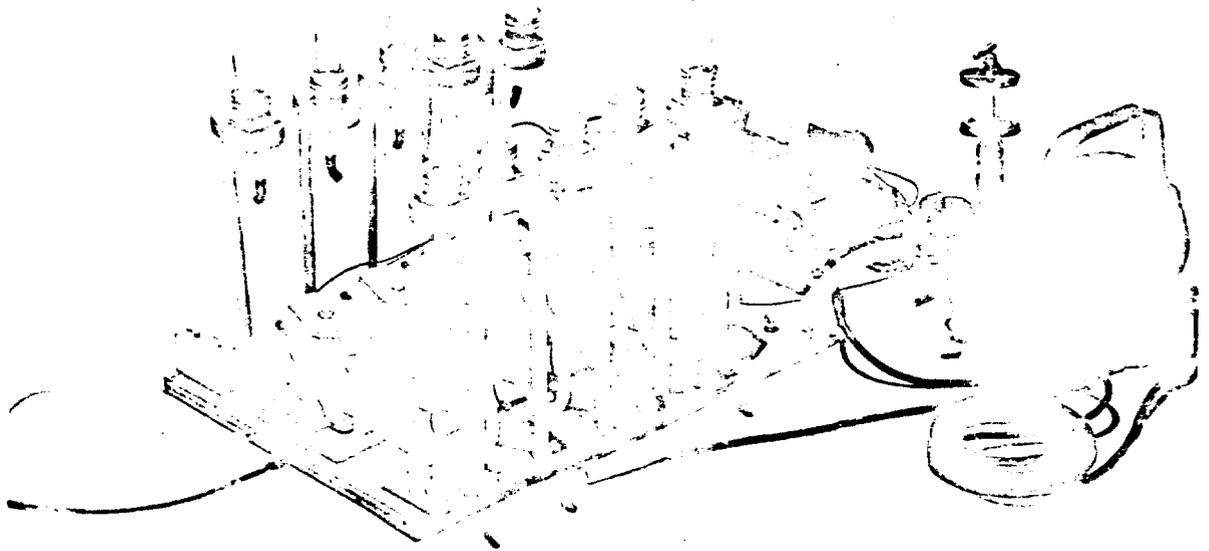


Fig. 9—Automatic sampling device.

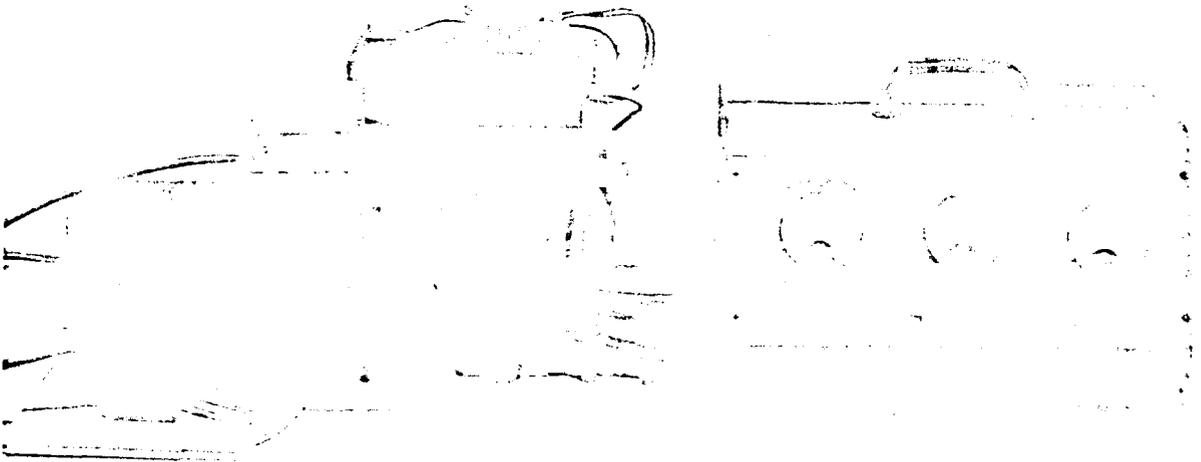


Fig. 10—Fluorometer.

The analysis of the material collected on the filter is accomplished by fluorometric techniques. As was mentioned earlier, the oil used in these tests is fluorescent under ultraviolet light. A fluorometer (Fig. 10) is used to determine the amount of filtered oil present. It consists of a sliding chamber, which holds the sample, two glass filters, a photocell, and an amplifier and meter. The oil on the filter is "washed out" by immersing the filter in 1 ml of benzol for a given time interval (45 sec). The source of ultraviolet light is a G.E. 4-watt hairpin germicidal lamp. The first glass filter, a Corning #5860, removes visible light and allows only the ultraviolet light from the lamp to reach the sampling chamber. The second glass filter, a Corning #3484 located below the sample, removes all of the ultraviolet light and transmits only the fluorescent light to a #929 phototube. The signal from the phototube is amplified and indicated on an appropriate meter. Various controls and adjustments have been incorporated into the system to insure stable and reliable readings. Cleanliness must be strictly adhered to in such a system. Each filter holder unit must be carefully washed and kept clean until sampling time. Background tests are run on all glass holders used in the sampling chamber. These are tedious and time consuming duties, but ones which must be performed.

Many criticisms have been made concerning the washing out procedure. However, investigations prove this technique has given satisfactory results. Many filter tests have been made in the calibrating room, where the filters were exposed to the same oil-fog concentrations, and after the washing out procedure had been completed, the indicated fluorescence of the oil and benzol was identical. The instrument is calibrated by sampling prepared solutions of oil and benzol to determine meter readings vs strength of solution.

The most recent sampler, presently under investigation, is a new jet air sampler. The ejected stream from a small container of Freon gas is passed through a small venturi tube creating a usable vacuum. The air sampling rate is controlled by choice of orifice between the venturi and the Freon container. The unit uses a regular Millipore filter to sample particulate matter and a standard impinger for sampling gases. It is a small unit weighing less than two pounds. Investigations of air flow and pressure drop are being made at the present time.

The future sampling program at Brookhaven will consist of continued measurements of ground-level and airborne concentrations of oil-fog in stable and unstable smoke trails. Other studies involve new techniques of filtration in relation to ragweed pollen collection during the late summer months. Measurements of total amounts of pollen are being made at several levels in a vertical plane and investigations are being made of total amounts captured from a forced draft blown over the collecting slides and filters. Meteorological measurements and oil-fog sampling at relatively long distances are being planned in the near future utilizing a helicopter for airborne use.

# TWO GAS CLEANING PROBLEMS AT THE IDAHO CHEMICAL PROCESSING PLANT SITE

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## INTRODUCTION

The Idaho Chemical Processing Plant has been principally engaged in recovery of uranium from spent reactor fuel of the aluminum-uranium alloy, aluminum clad type exemplified by the Materials Testing Reactor. However, the two gas cleaning problems to be discussed are not directly connected with this process. One of these problems is associated with the recently installed process for the recovery of radioactive barium from short-cooled (one or two days) MTR elements. This process is popularly known among AEC people as RaLa. The problem here is the removal of iodine from the dissolver off-gas.

The second gas cleaning task is associated with the proposed fluidized bed calcining of our liquid radioactive waste solutions. This process is scheduled to go into operation sometime in 1959.

## 1 IODINE REMOVAL FROM RaLa OFF-GAS

The RaLa process<sup>1</sup> briefly consists of the following simplified steps:

1. Caustic dissolution of the aluminum
2. Separation of uranium particulates
3. Acid dissolution of the uranium
4. Precipitation and separation of the barium and strontium
5. Separation of barium from strontium by sodium dichromate selective precipitation
6. Metathesis of the barium to the nitrate
7. Drying to final product barium nitrate

It was planned to vent the process directly to a tall stack when meteorological conditions were favorable or store a portion of the off-gas in a 1500 scf gas holder until favorable conditions arose. However, when actual runs were started, it was determined by stack monitoring that the bulk of the iodine was not evolved during the caustic dissolution, the caustic neutralization, and the acid dissolution as had been expected. Instead, the iodine (approximately 300 curies over the period) continued to evolve for days and even weeks after completion of a processing batch. It may be noted here that the xenon gas evolved during processing as expected. To more effectively control the evolved iodine from RaLa processing, study was undertaken.

Off-gas studies were divided into two general phases: (1) tie up the iodine in solution to prevent its elution as a gas, and (2) absorb iodine from the off-gas stream by means of an additional scrubber or scrubbers, a silver nitrate reactor, or some other means such as carbon beds. Concerning the first phase of study, no chemical additive compatible with the flow-sheet was found that would theoretically tie up the iodine in solution any better than the caustic used for dissolution. This part of the study was entirely a literature search. However, operational means for reducing the evolved iodine were found. These included, (1) limiting the disturbance of vessel solutions, (2) lowering the jetting temperature of the caustic slurry, and (3) limiting decontamination work. Also the addition of 0.1M/liter of sodium thiosulfate to the 1.0M sodium hydroxide scrubber solution aided in scrubber efficiency.

For the second phase of the off-gas study, that of determining the best means for removing iodine from the off-gas system, an experimental facility was built. Summarily, the system provided for drawing four parallel sample lines from the off-gas line at the in-cell scrubber exit. Flow in these parallel lines was controlled between 1 and 5 scfh compared to 15 scfm in

the main line. The driving force in the system was a nitrogen jet, and gas drawn through the system was returned to the off-gas line. Gas scrubbing bottles of 500 ml capacity with gas entry through a fritted glass disc were used for experimental lines, and standard 1-in. pipes were used for solid bed experiments. Piping to the experimental lines was  $\frac{1}{8}$ -in. tubing.

Experiments conducted during RaLa run 003RP began using 0.1M  $\text{Na}_2\text{S}_2\text{O}_3$ -1.0M NaOH to determine if successive scrubbers of that media would be effective and in general to determine something of the nature of the iodine in the off-gas. Further experiments were conducted to compare the thiosulfate caustic medium with other type solutions and with solid beds. All experiments were made on one RaLa run since we have made a very limited number of runs.

Table 1—RESULTS: RaLa RUN 003RP, BEGUN APR. 5

Experimental test	1						
Time interval	1245, Apr. 5 → 2205, Apr. 5—9.67 hr						
Description	Four series 0.1M $\text{Na}_2\text{S}_2\text{O}_3$ -1.0M NaOH scrubbers						
Flow	5 scfh						
Iodine absorbed							
Scrubber position	A	B	C	D			
mc/hr	0.366	0.0611	0.0306	0.0207			
Experimental test	2						
Time interval	2205, Apr. 5 → 1245, Apr. 6—14.67 hr						
Description	Four series 0.1M $\text{Na}_2\text{S}_2\text{O}_3$ -1.0M NaOH scrubbers						
Flow	5 scfh						
Iodine absorbed							
Scrubber position	A	B	C	D			
mc/hr	0.577	0.176	0.0806	0.0746			
Experimental test	3						
Time interval	1300, Apr. 6 → 1400, Apr. 6—1.0 hr						
Description	Three series 0.1M $\text{Na}_2\text{S}_2\text{O}_3$ -1.0M NaOH scrubbers						
Flow	5 scfh						
Iodine absorbed							
Scrubber position	A	B	C				
mc/hr	0.0873	0.0465	0.0309				
Experimental test	4 (4, 5, and 6 are parallel lines)						
Time interval	1040 Apr. 9 → 1530, Apr. 9—4.83 hr						
Description	Six series 0.1M $\text{Na}_2\text{S}_2\text{O}_3$ -1.0M NaOH scrubbers						
Flow	5 scfh						
Iodine absorbed							
Scrubber position	A	B	C	D	E	F	
mc/hr	0.0667	0.0280	0.0188	0.0173	0.0129	0.0132	
Experimental test	5						
Time interval	Same as 4						
Description	Two series 1M NaOH scrubbers						
Flow	5 scfh						
Iodine absorbed							
Scrubber position	A	B					
mc/hr	0.0125	0.00862					
Experimental test	6						
Time interval	Same as 4						
Description	Two series ~2% NaOCl scrubbers						
Flow	5 scfh						
Iodine absorbed							
Scrubber position	A	B					
mc/hr	0.0323	0.0162					

Table 1—(Cont'd)

Experimental test	8 (8, 9, and 11 are parallel lines)									
Time interval	1030, Apr. 10 — 1530, Apr. 10—5.0 hr									
Description	Six series 0.1M Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> —1.0M NaOH scrubbers									
Flow	2.5 scfh (Data normalized to correspond to 5 scfh flow)									
Iodine absorbed										
Scrubber position	A	B	C	D	E	F				
mc/hr	0.0874	0.0384	0.0169	0.0174	0.0206	0.0206				
Experimental test	9									
Time interval	Same as 8									
Description	Two series 0.1M Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> scrubbers									
Flow	5 scfh									
Iodine absorbed										
Scrubber position	A	B								
mc/hr	0.0419	0.0366								
Experimental test	11									
Time interval	Same as 8									
Description	Two series CCl <sub>4</sub> scrubbers									
Flow	3.5 scfh (Data normalized to correspond to 5 scfh flow)									
Iodine absorbed										
Scrubber position	A	B								
mc/hr	0.147	0.000094								
Experimental test	12 (12, 13, and 14 are parallel lines)									
Time interval	1215, Apr. 12 — 1600, Apr. 12—3.75 hr									
Description	Ten series 0.1M Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> —1.0M NaOH scrubbers									
Flow	5 scfh									
Iodine absorbed										
Scrubber position	A	B	C	D	E	F	G	H	I	J
mc/hr	0.411	0.0611	0.0371	0.0373	0.0263	0.0251	0.0181	?	0.0101	0.00902
Experimental test	13									
Time interval	Same as 12									
Description	12 in. of carbon in 1-in. D pipe followed by two series 1.0M Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> —1.0M NaOH scrubbers									
Flow	5 scfh									
Iodine absorbed										
Scrubber position	A (Carbon Bed)	B	C							
mc/hr	No analysis	0.00166	0.000862							
Experimental test	14									
Time interval	Same as 12									
Description	18 in. of 1/4-in. ceramic Raschig rings coated with AgNO <sub>3</sub> in 1-in. D pipe followed by two series 0.1M Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> —1.0M NaOH scrubbers									
Flow	5 scfh									
Iodine absorbed										
Scrubber position	A (AgNO <sub>3</sub> Bed)	B	C							
mc/hr	No analysis	0.00142	0.000137							
Experimental test	16 (16, 17, 18, and 19 are parallel lines)									
Time interval	1100, Apr. 16 — 1515, Apr. 16—4.25 hr									
Description	18 in. of 1/4-in. tygon Raschig rings in 1-in. D pipe followed by two series 0.1M Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> —1.0M NaOH scrubbers									
Flow	5 scfh									
Iodine absorbed										
Scrubber position	A (Tygon Bed)	B	C							
mc/hr	No analysis	0.280	0.0626							

Table 1 — (Cont'd)

Experimental test	17		
Time interval	Same as 16		
Description	18 in. of copper turnings in 1-in. D pipe followed by two series 0.1M Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> -1.0M NaOH scrubbers		
Flow	5 scfh		
Iodine absorbed			
Scrubber position	A (Copper Bed)	B	C
mc/hr	No analysis	0.655	0.103
Experimental test	18		
Time interval	Same as 16		
Description	Gas passed over solid iodine so that "carrier" iodine would be added to stream, followed by two series 0.1M Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> -1.0M NaOH scrubbers		
Flow	5 scfh		
Iodine absorbed			
Scrubber position	A	B	
mc/hr	0.690	0.103	
Experimental test	19		
Time interval	Same as 16		
Description	Two series 0.1M Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> -1.0M NaOH		
Flow	5 scfh		
Iodine absorbed			
Scrubber position	A	B	
mc/hr	0.819	0.017	
Experimental test	20		
Description	Blank for laboratory analysis check		
mc/hr	0.000111		

## 2 DISCUSSION OF RESULTS

By intercomparison of the data obtained from parallel scrubber experiments the following list indicates the relative apparent efficiency of scrubbers. These comparisons were made relative to the Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub>-NaOH scrubber as previously stated.

- silver nitrate (heated)\*
- carbon\*
- carbon tetrachloride
- sodium thiosulfate 0.1M-sodium hydroxide 1.0M
- sodium thiosulfate 0.1M
- sodium hypochlorite 2 per cent
- sodium hydroxide 1M
- Tygon (polyvinyl chloride) packing\*
- copper packing\*

## 3 CONCLUSIONS

Our tentative conclusions are to use Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub>-NaOH scrub in the present equipment in place of the original NaOH scrub and to install a cleanup carbon bed at a later date. Carbon tetrachloride was discarded on the basis of volatility and toxicity. Since silver nitrate must be heated to be effective, it was felt that the possible hydrogen explosion hazard was not worth the risk. The present in-cell scrubber has an estimated efficiency of 95 per cent for iodine absorption and it is hoped that the carbon bed will increase this so that RaLa runs can be made even under unfavorable weather conditions.

\*Success of solid bed scrubbers was deduced by the amount of iodine picked up on the Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub>-NaOH scrubbers immediately following the solid scrubber in question.

#### 4 GAS CLEANING PROBLEMS EXPECTED IN THE FLUIDIZED BED CALCINATION OF RADIOACTIVE WASTE SOLUTIONS

Investigators generally agree that the problems of storing radioactive liquid wastes could be simplified if these wastes could be converted to a free-flowing granular solid.

A potentially attractive method of converting liquid waste into granular solid was first demonstrated by workers at Argonne National Laboratory<sup>2</sup> and later proposed by the Idaho Chemical Processing Plant Technical Group<sup>3-5</sup> as a process for aluminum waste calcining. This process involves the direct calcination of the waste solution from processing aluminum fuel elements in a fluidized bed reactor. It may be possible to process wastes from zirconium or stainless steel fuel element processing by the same means. The solutions are sprayed through a combination air-liquid spray nozzle into a solids bed, fluidized with air, at a temperature of between 400°C and 600°C. At the temperature of operation, water is instantaneously flashed off, and in the case of aluminum fuel wastes the nitrate anion content decomposes to oxides of nitrogen, the cations forming metallic oxides. Solids formed by the reaction are fluidized by the air and eventually escape through an overflow pipe in the middle of the vessel. When equilibrium operation is reached, the amount of solids escaping is equal to the convertible solid content of the aqueous feed solution introduced. An average volume reduction of seven-fold is thereby obtained.

Heat is supplied to the calciner by means of heat transfer surfaces placed directly in the bed and possibly heated by means of circulated NaK metal. The NaK is heated in an oil-fired heater which is connected by appropriate controls to the calciner. Operation would be automatic.

Figure 1 shows a simplified equipment flowsheet.

Preliminary study has indicated that one of the major problems connected with this operation will be a suitable treatment of the off-gas (~2000 cfm) such that disposal can be made safely to the atmosphere. Since only limited technical time has been available for this work, the present discussion will attempt only to point out the major problems and some of the possible solutions to be studied in detail.

The gas cleaning problems can be broken down into five items: (1) particulate matter, (2) volatile fission products, (3) volatile nonradioactive material, (4) oxides of nitrogen, (5) steam.

Steam can, of course, be removed by condensation and possible re-evaporation in existing equipment until suitable for dumping to waste wells. At the present time, the concept for disposal of oxides of nitrogen is to allow escape to the atmosphere via our off-gas stack assuming that they are low enough in fission product contamination. However, if it is necessary to recover part or all of the nitric acid, this will be accomplished by standard equipment.

The only volatile nonradioactive material found so far has been mercury and this can be handled by providing a take-off at a low, cool point in the system. Possibly the mercury can be reused as a catalyst in the HNO<sub>3</sub> dissolution step.

Work at Argonne National Laboratory and the Idaho Chemical Processing Plant indicate that the only volatile fission product is ruthenium tetroxide. Experimental data obtained have indicated that nearly 100 per cent will volatilize from the calciner. Some experimental work has been done along the lines of preventing volatilization by providing a nonoxidizing atmosphere; however, with little apparent success.

The present thinking is that the RuO<sub>4</sub> must be removed from the off-gas in some manner. Success has been obtained in a condenser scrubber. One run has been made using cold ruthenium where up to 95 per cent was removed. However, this work and hot work at Argonne National Laboratory has indicated that extensive study of the problem will be required before a method for removal up to 99+ per cent can be devised. Another solution being considered is a quick quench of the off-gases. However, no experimental work has been done as yet.

Perhaps the most formidable problem will be the complete removal of particulate material since each particle is sure to contain some of all fission products. It has been fairly well established that a simple cyclone or cyclones in service will knock out most of the larger particles. The problem would therefore resolve itself into removing particles whose size

ranges from 100 mesh down to submicron. A study will shortly be made on the experimental calciner to determine this range using a cascade impactor.<sup>6</sup> Preliminary experiments have been performed using mesh and Raschig ring packing. This data has indicated efficiencies up to the range of 90 per cent. However, reliable results have been difficult since obtaining representative samples of the gases and solids has been difficult due to the high temperature

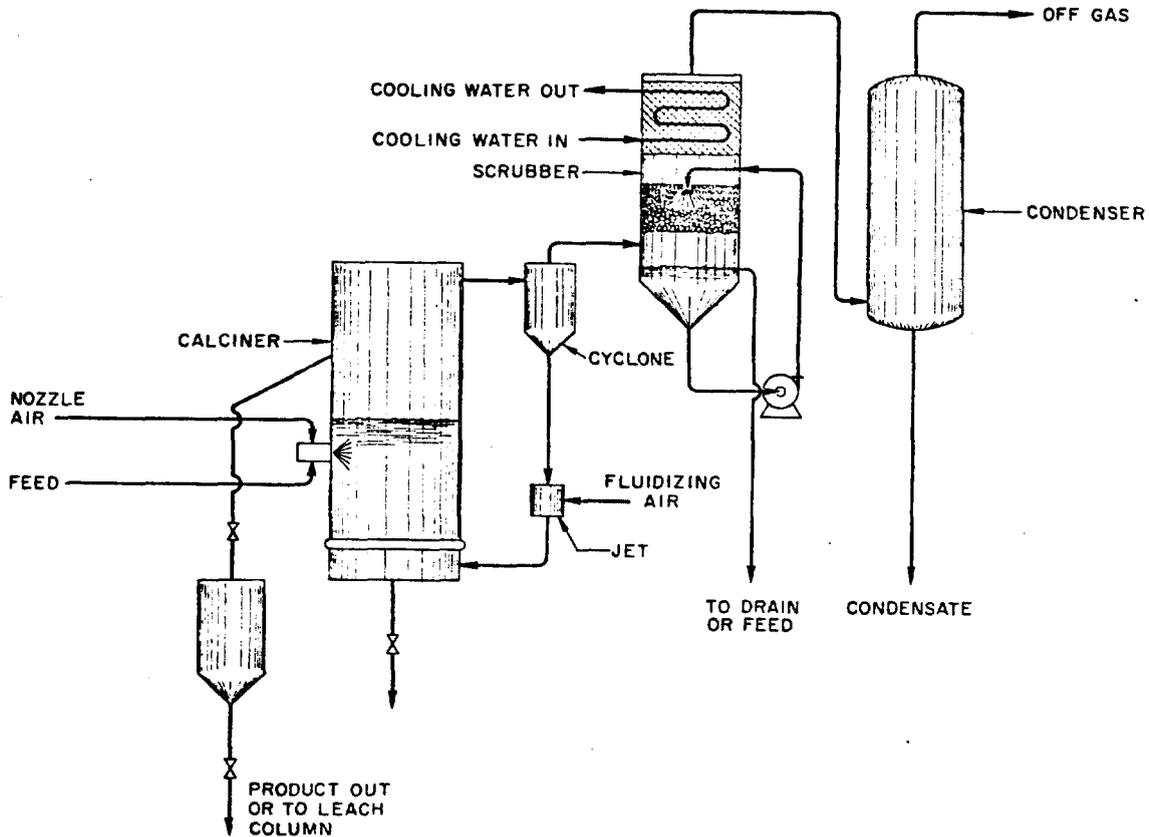


Fig. 1— Calcining equipment, Chemical Engineering Laboratory.

A proposal based on present knowledge would seem to indicate that particulates could be removed by an efficient scrubber design followed by a positive filter such as a CWS filter. We are planning to study such scrubber designs as packed scrubbers (Raschig rings, Beryl saddles, and mesh) Pease Anthony scrubber, multistage wet collectors and others as may be suggested.

The successful solution of this gas treatment problem seems to be the key to the whole calciner operation, and therefore will involve a very intensive engineering study over the next year at the Idaho Chemical Processing Plant.

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## AIR CLEANING ACTIVITIES AT BRUSH BERYLLIUM COMPANY

Hal J. Shafer

*Brush Beryllium Company*

We, at Brush Beryllium, have most of the air problems of chemical firms and foundries, as well as some peculiar to our own field. We do not deal with radioactive material. Our product, beryllium, produced by the sulfate-fluoride process, a process generally accepted to produce high purity metal, appears to be toxic in most of its compounds to certain people, and I believe it is more of an allergy than a definite intolerance by human beings in general. Consequently, we have the problem of careful ventilation and air cleaning.

Safe operation requires that we keep our beryllium concentrations to very low levels, not more than  $2 \mu\text{g}/\text{m}^3$  of general plant air, and  $0.01 \mu\text{g}/\text{m}^3$  in the air outside the plant. Air sampling at numerous points within the plant, as well as outplant air sampling, is a continuous program with us.

We follow conventional, as well as specialized, practices in the design of hoods, conveying duct work, and especially the cleaning of the air before it is finally discharged into a stack. All equipment, such as tanks, must be ventilated, and all outplant air ends up in the stack. The stack at our new plant is 300 ft high and the height of our present stack at the Alloy Division is 175 ft.

We usually use two cleaning stages, i.e., preliminary cleaning by one collector and final cleaning by a back-up cleaner. In the wet collection this consists of a primary scrubber handling the concentrated fumes, and the secondary scrubber handling the effluent from the primary scrubber as well as the less concentrated fumes from the secondary hooding, if required.

We believe in primary hooding 100 per cent. Secondary hooding or enclosures are used only as a safety measure, or where it is impossible to collect the fumes or dust at the source of liberation. Also, scrubbers are more efficient when handling concentrated fumes rather than fumes diluted with ordinary room air.

Our machine shop is located in our Cleveland Plant. In this operation we grind the vacuum-cast billets produced at the Luckey Plant in a series of attrition mills. This material is then pressed into approximate shapes in sintering furnaces. From there, the pure metal is machined to various shapes as required by the Atomic Energy Commission as well as industry.

All of the machines, such as lathes, mills, and saws, are equipped with ingenious pickup points immediately at the tool itself. The capture velocity is about 15,000 ft/min. This air, plus dust and chips, is precleaned by the use of multiple high velocity, high efficiency cyclones. These cyclones are backed up either by bag collectors or electrostatic precipitation.

Collection of dust from our electric arc furnace for the production of beryllium alloys is accomplished by the use of a dry type bag collector and backed up by a polishing filter, also of the cloth type. The temperature of the effluent leaving the furnace bay is from  $500^\circ\text{F}$  to  $600^\circ\text{F}$ , and the temperature entering the first collector is as high as  $370^\circ\text{F}$ . This presented

quite a problem of bags scorching, with the resultant bag failure. We used Orlon bags, but they seemed to shrink and tear at this temperature. After numerous approaches, we decided to try evaporative cooling. This is accomplished by the use of air atomizing nozzles. We use 50-lb water pressure and 60-lb air pressure. Four nozzles are used and are automatically controlled by the temperature of the effluent entering the first collector. This controller is set at about 215°F, which is safe for Orlon bags and also for fire resistant cloth sateen bags, which we have been testing the last several months. This system has been in use about six months with very good results. We have replaced only a few bags which failed at the seams, due to shaking, but none has failed because of the temperature. Also, the water vapor in the gas stream seems to agglomerate the dust particles and improve collection. Although the dust collected may contain as high as 20 per cent water solubles in the form of carbonates, no trouble has been experienced from this source. The average loading is about 1 g/cu ft but varies considerably during the cycle.

In one of the final stages of our sulfate-fluoride process, we deal with beryllium fluoride and its other components directly. In our process we use a 5-ft packed tower with 1-in. Raschig rings backed up by an irrigated type electrostatic precipitator of our own design.

We will have five fluoride furnaces, the fumes of which go first through the packed towers and then through electrostatic precipitation. This precipitator is unique inasmuch as it will be five single tube units operated from a common unit developing the required 75 kv.

We plan on using 10-in. tubes, 12 ft long and in this stage to pick up only what the scrubber misses, which is some ammonium fluoride and beryllium fluoride. Both of these compounds are highly corrosive, and very valuable, so collection is a desirable as well as an economic venture.

Our ventilation system, as well as our various types of air cleaning equipment, requires continuous policing by visual inspection as well as logs of pressure drops. Some of this equipment is provided with recording manometers. Naturally, immaculate housekeeping is a must.

We also continue to improve our method of collection, and this usually results in lower air counts which, of course, is our ultimate goal.

## AIR CLEANING ACTIVITIES OF THE BERYLLIUM CORPORATION

A. Epstein

*Beryllium Corporation*

During the refining of beryllium metal from its ore, we generate the gamut of physical air-borne contaminants. Dusts are evolved at crushers and mills, fumes at metal reduction furnaces, mists are produced at agitated reaction and leaching vessels, and gases and vapors must be handled from sintering and calcining operations. All these are the unwelcome legacy of the beryllium producer.

At our new plant near Hazleton, Pa., where nuclear grade metal will be made for the Atomic Energy Commission, we have installed air cleaning devices for the control of these different contaminants. Selection of these units was based on the usual considerations coupled with a number of criteria that are perhaps unique to our kind of industry. We evaluated the usual problems of dust loading and particle size, temperature and moisture content, abrasiveness and corrosiveness, ad infinitum, plus the always present and sometimes decisive consideration of cost. But in addition to these deliberations, we were heavily influenced by both the recognized toxicity of the collected material and the known value of its re-introduction to the process flow stream. Consequently it became important to consider ease of disposal as well as efficiency of collection. These factors, individually or combined, in more than one instance

forced the abandonment of an accepted method of materials handling in favor of a technique that otherwise might be considered less desirable.

For example, pneumatic conveying at first seemed like an excellent method of transferring submicron size BeO from a calciner to a storage bin. But simple calculation based on expected dust loading indicated that despite high efficiency collection, the amount of material still escaping would be intolerable. We substituted a completely enclosed jacketed screw conveyor and eliminated part of the system dust loading.

Conversely, for a series of covered leach tanks to be maintained at a slightly negative pressure, a collector with an efficiency of 80 per cent was considered adequate. And with this wet type unit, we keep recirculating until the liquor has achieved a predetermined concentration, when it is simply pumped into one of the leach tanks that it serves.

Again, where widely separated ventilated equipment could be linked in regard to contamination potential, it was necessary to evaluate the cost of additional sheet metal and its effect on fan size and horsepower against the cost of multiple air cleaning units.

This approach was used during repeated reviews of equipment layout and process flow with good results. On the first go-round we came up with 23 individual air cleaning units, and by final design time this number had been reduced to the 11 units now installed.

Because of the variations in the characteristics of the particulate matter we collect, these 11 units include a venturi agglomerator, cyclones, hydraulic and packed towers, wet cell absorbers, and reverse jets.

Where practicable we have arranged for more than a single cut at our contaminated exhaust. For example, where temperature dictated the use of a wet scrubber with known inadequate efficiency, we mixed this unit discharge with high volumes of dry contaminated air and took a second cut at the combination with a high efficiency dry collector.

All the units are arranged with the exhausters on the clean air side so that everything before the inlet to the fan is under negative pressure. Each of the exhaust fans discharges into a common manifold duct which extends around the perimeter of the building. The manifold duct which receives the essentially clean combined effluent from the individual systems is itself carried to a final clean-up filter.

This last air cleaner, which is equipped for application of asbestos floats as a filter aid, is itself under negative pressure through the operation of a final exhauster. This high-capacity fan is located at the base of, and discharges into a stack 200 ft high.

Our boiler plant consists of three 10,000 lb/hr steam generators equipped with forced draft fans rated at 15,000 cfm each. The opportunity offered by this appreciable amount of hot flue gas could not be ignored, and we decided to combine the boiler and dust collection system effluents. We expect that, under most meteorological conditions, this added thermal influence will give us a considerable increase in effective stack height.

To eliminate the possibility of generating back pressures in the boiler breeching, our final fan discharge was designed and fabricated as an eductor nozzle which will develop negative pressures in the breeching in excess of what might be achieved from natural thermal effect. Dampers are installed in each boiler smoke box for control against excessive combustion chamber draft.

The manifold duct, final clean-up filter, and large exhauster were all intentionally sized for 150 per cent of calculated design capacities. This was done for little added cost and was easily justified by the flexibility it provides.

However, to minimize the added operating costs for make-up air (especially during the winter season) imposed by this oversizing, a simple but effective scheme was devised. Because our perimeter walls are completely of masonry without sash, and since we expect the occupational activity to be other than sedentary, we decided we could effectively heat the building and furnish make-up air simultaneously with an overhead distribution system. This was accomplished by installation of 10 coil and fan units with motorized face and bypass dampers across the blast coil, and full size fresh air and return air dampers in the unit intake box. These air handling units are equipped with swivel elbow outlets and double deflection discharge louvers for directional control.

A simple thermostat actuates the face and bypass damper at the blast coil to maintain predetermined temperatures. The opposed action dampers in the intake box are modulated by static pressure regulators to maintain a slightly negative pressure within the plant. Thus the amount of fresh air we temper through our units is directly dependent on the amount of air being exhausted. When our exhaust systems are inoperative, the pressure regulators will set the dampers for 100 per cent recirculation.

Because much of the duct work in the plant required interior protective linings, special emphasis was placed on methods of fabrication and installation. We decided on a modular arrangement with a 10-ft maximum section length. For straight duct work up to 12 in. in diameter, longitudinal joints are of double lock seam construction. Girth joints are of the Van Stone type with flanged ends, slip-on "O" rings and either rubber or asbestos gasketing. The larger duct work and the fittings and transition pieces of all sizes are of welded construction with angle rings welded at the ends for transverse joining. All the sheet metal is supported by wrap-around tension straps without penetration of the duct walls. Capped nipples to accommodate pitot tubes and sampling probes were included in the original fabrication of the duct work. Although the "balanced system" concept was used as a basis for design, we still included a number of blast gates at critical points. Some additional adjustability was achieved by specifying variable pitch sheaves for all fan motor drives.

Finally, if we assume that everything we have talked about is perfectly planned and executed, there still remains the single most important preliminary prerequisite for successful dust control design. Without the judicious selection of process equipment, all subsequent efforts are doomed to dismal failure. If the equipment is wrong, the battle is lost before it has begun. The right selection is not always the more expensive choice.

And here the Industrial Hygiene Engineer, out of his element, must be supported not only by his technically expert co-workers, but also by the members of Management, who in the final analysis must assume responsibility for the success or failure of the complete operation. We of the Beryllium Corporation sincerely feel that our Hazleton Project is just such a culmination of concentrated cooperative effort.

## AIR CLEANING ACTIVITY AT OAK RIDGE GASEOUS DIFFUSION PLANT

R. C. Smith

*Oak Ridge National Laboratory*

Since there are several locations at Oak Ridge Gaseous Diffusion Plant where fluorine is a component of a waste gas, there exists a problem of disposal of this gas in a safe manner. When the fluorine concentration is low or when small flows or short periods of time are involved, such waste gases may be vented to atmosphere. To dispose of this fluorine without the necessity of dumping into the atmosphere, a method of reaction between preheated fluorine and superheated steam has been employed. This method is described by S. H. Smiley and C. R. Schmitt.<sup>1</sup> They investigated this reaction using undiluted fluorine and air-diluted fluorine in concentrations varying from 13 per cent to 75 per cent and determined conditions for maximum conversion of fluorine to hydrogen fluoride.

A reactor in which fluorine gas was consumed in a reaction with oxides of uranium has been described in a paper by Clouse, Dykstra, and Thompson.<sup>2</sup> Though primarily used as a part of a uranium recovery process, it showed one means of reacting fluorine with uranium compound which results in the formation of a useful product and the removal of fluorine from feed gas. In this process, the dry oxide is fed directly to a screw type reactor and is treated at a high temperature with fluorine gas.

The method employing superheated steam was superseded by one using a reactor which not only disposes of the fluorine effectively but also utilizes this gas to form a useful product. Waste gases containing fluorine from several locations are routed to a common point and passed into a reactor. Under the conditions in the reactor the fluorine reaction is quite complete. Over a wide range of fluorine inlet concentration, the outlet gas is free of fluorine, at least to well below 0.5 per cent. Additional information on the details will be forthcoming in reports presently being prepared.

Air sampling data, which might be used to evaluate the effectiveness of the reactor as a means of reducing air pollution are not yet complete. The problem of measuring the quantitative improvement is quite difficult since a change in locations of discharge points was also made. This method is doubly attractive because the product of the reaction is  $UF_6$ , a useful material. It may be expected that more data on the effectiveness of this method will be available in the near future.

One of the more widely used methods for disposal of halogen gases, specifically fluorine in this case, is by scrubbing with caustic either in the form of NaOH or KOH. The fluorine is consumed by the caustic and converted to sodium or potassium fluoride. This method can be employed in conjunction with a lime slurry regenerative process whereby the lime slurry is circulated through the caustic scrubber to remove fluorides and regenerate caustic.

Concentrations in the outlet gas are of the order of a few parts per million with any inlet concentrations of fluorine. This same process for fluorine removal from air is completely applicable for HF.

Standard caustic equipment can be used since the corrosion effect of fluoride ion is negligible under the operating conditions employed.

A mass spectrometer especially adapted to the measurement of small amounts of fluorine has been developed. It is particularly adapted to the measurement of fluorine in the presence of  $UF_6$ , but its applicability to determination of fluorine in air samples may be inferred from its behavior in the former role. The limit to its capabilities as an air sampler for fluorine is imposed by the presence of the argon isotope  $Ar^{38}$  in air to the extent of about 6 ppm. This will impose a background on the fluorine signal measurement approximately equivalent to the signal from fluorine, itself, when the fluorine concentration is 12 ppm. In the presence of  $UF_6$ , fluorine sensitivity is still less than 50 per cent of the argon sensitivity, even though improvements in technique, particularly with reference to consumption of fluorine have increased sensitivity to fluorine by a factor of 5. If not in the presence of  $UF_6$ , a further relative increase may be expected which will make the fluorine and argon sensitivities approximately the same. Thus the spectrometer may be used to see a few parts per million of fluorine in an air sample, but accurate quantitative results will be limited to cases in which the amount of fluorine exceeds 6 ppm.

The problem of measurement of air contamination by radioactive dust at Oak Ridge Gaseous Diffusion Plant is being attacked by the development of an impaction type air sampler designed to collect dust of particle size  $1 \mu$  and larger.<sup>3</sup> It appears that particles of sizes from 1 to  $5 \mu$  are more readily deposited in the lungs than those of other size ranges.<sup>4</sup> Small particles (in the order of  $0.01 \mu$  to  $0.1 \mu$ ) are not retained in the lungs and large particles (above  $10 \mu$ ) do not enter the lungs to comparable extent.

The air sampler being tested at K-25 provides a continuous method of sampling using an oiled moving tape and impaction of dust in air on the tape. The time delay between sampling and counting can be adjusted to be as low as ten minutes. It is designed to collect dust particle sizes of  $1 \mu$  and above. Collection efficiency at  $1 \mu$  is approximately 90 per cent as determined using samples of  $UO_3$  powder. At  $0.4 \mu$  the collection efficiency is about 50 per cent as determined by using samples of  $UO_2F_2$  and  $UF_6$ . These are preliminary data.

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## AIR CLEANING OPERATIONS AT THE ROCKY FLATS PLANT

Robert J. Walker  
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Air filtration requirements at the Rocky Flats Plant have been typical for AEC operators, but thanks to a wealth of information and cooperation of many parties we have had no major problems in this field in recent years. At the Third Air Filtration Conference, the various ventilation systems in use at Rocky Flats Plant were described, so that information need not be repeated. At that time we had a total of approximately 1,150,000 cfm of air being handled. The systems consisted of standard ventilation components such as supply system, heating, air washing and air filtration, and exhaust system filtration.

Our expansion program involved about 600,000 cfm additional and all major components were designed to the same general criteria as used in the original plant. As a standard feature, we have always practiced the philosophy of containment in its highest economically feasible form. In addition to careful design in the process enclosures, this has included providing special prefiltration at hoods and providing separate "booster" exhaust systems for extremely contaminated operations. All air, however, eventually passes through a final filtration of AEC type Absolute filters.

Actually, the Absolute filters we have used have been very good for us, in both efficiency and cost. In general, our stacks have never run greater than 10 per cent of tolerance. We have also had the very minimum of maintenance problems with the Absolute filter banks. We cannot report any of the more drastic ailments such as filter media falling from the frames and filter media cracking around the dividers. In short, the filters have just existed with little or no work being done on our part. In a very few instances we have used a vacuum cleaner to remove large lint deposits from the face of Absolute filters, and in one of our buildings we have used a humidification process to extend the life of Absolute filters when loaded with a chemical salt. The life of these filters has in most cases exceeded our most optimistic original estimates; in fact, we have one building in which the filters have run continuously for slightly in excess of four years and still have less than 1 in. pressure drop.

Some of the items that have assisted us in getting such good service from these filters were designed into the systems, and others have been due to careful operation of the ventilation systems. In all of the major filter banks, enough filters were installed so that instead of the normal 1000 cfm going through a 24- by 24- by 12-in. filter we have only 400 cfm/filter. As a further help, all of the major ventilation systems are set up with three operating speeds that are roughly equivalent to one-third, two-thirds, and full fan capacity. We use the two-thirds quantity, medium speed, for all normal operating periods in the building. We use the one-third quantity, low speed, for all off-shift, nighttime and weekend operations. The high speed of full capacity of the fans is used only during emergencies in which the building has to be purged of its contaminants in the least possible time.

Provision for prefiltering at every possible operation has helped to extend the life of these filters, while more than ordinary filtration of supply air has also assisted in attaining this end. Thus, the average dirt load in the air going to the final filters is in the order of 0.03 grain per 1000 cu ft of air. The operators of these plants have greatly assisted the extension of filter life

by keeping their fans on the lower speeds as much of the time as possible and by continuously maintaining the prefilters in their best possible condition. Further help has been the immediate addition of prefilters at any process that begins to show great amounts of dust and at any new processes that have been added.

In the process of operating these filters without change for periods up to four years, we have in some instances loaded a 24- by 24- by 12-in. filter with 13 lb of dirt. Our more normal loadings, however, have been in the order of 6 to 10 lb of dirt per filter. These loadings have been in our multiple-speed systems and at the derated filter air flows mentioned before. In addition, these loads have been obtained at rather nominal filter pressure-drop change points. As a general thing, we have to change our filters at 2.5 in. water gauge pressure drop across the filter because of the design limitations of our exhaust fans. With such loadings we feel we are getting the optimum in filtration efficiency, along with filter life at the least possible dollar expense. With a combination of original installed costs having run only \$2/cfm and filter life such as this, any other type of filtration has to really be good to be considered.

Actually, then, our only complaint or worry with this type of filter is the danger of fire. We have always been very concerned over the danger of fire in our filter banks, and the recent reports of fires at other AEC installations have increased this concern. We have taken a number of steps to minimize this danger in the form of providing the best possible fire-detection system, by having the filter banks enclosed in rooms made of concrete, and by pretreating any air coming from a source of possible fire. From our early tests on filters, we had felt that normally when a single filter was ignited by a spark or some such means, with the air flow still going through the filter it would not tend to propagate to the rest of the filter bank. At present, however, we find that the dirt load in the filter itself is actually a very great contributor to the amount of combustible materials in a particular filter. As noted earlier, 13 lb of combustible dirt (lint, etc.) in a filter is approximately 50 per cent of the weight of the combustible dividers and media. Recent tests we have made on filters loaded in this way have shown a very definite tendency for fire to propagate from one filter to the next, so that if a fire started in one of these loaded filters much of the filter bank would burn before we could do much about it. Our problem in this field is further complicated in our new buildings because they are steel frame construction, and the structure itself could not stand the effect of a fire in a filter bank.

As a result of this, then, we have been very interested in the new, all-glass filters being developed by the major manufacturers of AEC type filters. We have also been actively following the work of the Hanford people in developing a specification for the most feasible fire-resistant filter. No matter how good the fire-resistant qualities are, however, it is our feeling the outstanding problem with these new filters is "what will the dirt loading be?" This sounds rather innocent at first but when you realize that we are attempting to get upwards of five years of life out of a filter, and have dirt loads approaching 10 lb, you realize that this is of great importance. Also, when you consider that we have approximately 3500 of the large 24- by 24- by 12-in. filters in use, an appreciable change in the life characteristics would greatly affect the operating costs for these filters. Our plant has therefore performed some very rough loading tests on the all-glass filters involving accelerated, artificial loadings. These tests so far have indicated that with our particular loadings we can expect filter life of only 10 per cent of our present filter life. Granted the method of test and measurement in such a limited time is somewhat questionable, it still indicates a trend of such a magnitude as to cause extreme concern on our part. Also consider that if we can get these new filters up to the loadings shown in our present ones, we then have 13 lb of combustible dirt in 25 lb of noncombustible filter. Can we then afford the added costs for the all-glass filters?

We are, therefore, quite eager to receive whatever data is available from the filter manufacturers who are to make presentations at this conference. We are also quite interested in the results of the tests that the Hanford group has performed on these filters. Therefore we are turning the tables, so to speak, in that we are posing a problem or asking questions of the conference rather than contributing any great and profound answers to your problems.

# AEC BETTIS PLANT AIR CLEANING ACTIVITIES

P. R. Bolton and J. E. Ross  
*Bettis Plant*

The air cleaning problems at the Bettis Plant, which is operated for the Atomic Energy Commission by Westinghouse Electric Corporation, consist principally of the removal of radioactive particulates and acid fumes and mists from process air. Wet and dry collectors are used for the various cleaning requirements encountered.

Approximately 30 wet collectors ranging in capacity from 2000 cfm to 8000 cfm are used where the exhaust air contains acid fumes and mists, or pyrophoric metals, or where it is at an elevated temperature. Typical uses are for acid pickling facilities, chemical laboratories, and uranium metal working operations such as melting, rolling, and machining. In other operations involving higher levels of radioactive contamination, the wet collector is used as a pre-cleaner for a more efficient collector.

These wet collectors are either the American Air Filter Type N Roto-clone or the Schmiegl Centri-merge.

For operations such as metal working, where the exhaust air does not contain highly corrosive materials, the body of the collector is constructed of carbon steel and the impellers are either type 304 or type 316 stainless steel. Corrosion is most severe on the impeller, hence the reason for using stainless steel. Corrosion of the carbon steel body progresses most rapidly at the water interface, i.e., where the metal is alternately covered with water and exposed to air. The average life of these units has been approximately 5 years although some have operated continuously for about 7 years before requiring replacement.

Units servicing acid pickling operations have a stainless steel body and impeller. Type 316 stainless steel is preferred, but type 304, being more readily available, is sometimes used. The corrosion resistance of these units has been satisfactory after 2 to 5 years of service with the exception of a few instances of weld corrosion presumably due to carbon precipitation in the weld.

Wet collectors exhausting natural uranium metal-working operations have given satisfactory performance. During the last eight months, daily stack samples from three such units averaged less than 10 alpha dis/min/m<sup>3</sup> (7 µg/m<sup>3</sup>) and did not exceed 125 alpha dis/min/m<sup>3</sup>, (83 µg/m<sup>3</sup>). Daily samples from a fourth unit were slightly higher, averaging less than 20 alpha dis/min/m<sup>3</sup> (13 µg/m<sup>3</sup>) with a maximum of approximately 400 alpha dis/min/m<sup>3</sup> (270 µg/m<sup>3</sup>). This higher stack effluent concentration from the fourth unit has been attributed to the small particle size uranium dust and fume produced by the automatic cut-off wheel which is exhausted by this system.

As would be expected, the wet collectors are not effective for the removal of oxides of nitrogen from nitric acid pickling operations. However, they are satisfactory for removing acid mists and water soluble acid gases.

Daily inspections of the units are made to assure proper operation of the automatic liquid level control. The failure of electrical components of the liquid level control results in a low water level in the collector with loss of efficiency or water overflow from the collector which, in the case of radioactively contaminated liquids, places an unnecessary load on the liquid waste processing facilities. Caustic is added as required to control the acidity of the water and inhibit corrosion. Radioactively contaminated water is drained directly to the liquid waste processing facilities eliminating personnel exposures and area contamination such as could result from handling highly contaminated dry filters.

The highest levels of airborne radioactive contamination occur in the Hot Laboratory (high level radiation laboratory) where physical and chemical examinations are performed on multicurie radioactive samples. The exhaust air from the original cell block, which has been in use for 6 years, is cleaned by two-stage systems consisting of a wet collector of the type previously mentioned followed by a Westinghouse Precipitron as the final cleaner. The average daily concentration of radioactivity in the effluent from these systems over a period of several

years has been 150 to 200 beta-gamma dis/min/m<sup>3</sup>. Peak concentrations up to 50,000 beta-gamma dis/min/m<sup>3</sup> have been observed when certain operations were performed on particularly hot samples, notably, when these hot samples were sectioned by an underwater cut-off wheel. To accommodate the increased work load and the higher levels of radiation, a new cell block was put into service approximately a year ago. The dust collecting systems for these new shielded cells were designed to provide adequate cleaning of the more highly contaminated air which would be produced. They are three-stage systems consisting of a wet collector, an electrostatic precipitator, and a Mine Safety Appliances or Cambridge high-efficiency dry filter as the final cleaner. Average daily concentrations of radioactivity in the effluent from these systems have been less than 15 beta-gamma dis/min/m<sup>3</sup> and have not exceeded 2000 beta-gamma dis/min/m<sup>3</sup> in spite of the fact that those operations on hot samples which produce the most airborne contamination are performed in the new cells.

Maintenance problems on the electrostatic precipitators consist of replacing broken ionizing wires and defective power pack tubes and periodic cleaning of the collecting plates by the built-in water spray. The plates are sprayed with a water soluble adhesive which retains the collected material and aids in cleaning. The input voltage must be maintained at approximately 120 volts to obtain an ionizing voltage of 13,000 to 14,000 volts which is required for satisfactory cleaning.

The high efficiency filters in these systems have a life of approximately six months. They are changed when the pressure drop across them reaches approximately twice the initial value as indicated by a draft gauge.

High efficiency filters are also used in portable unit dust collectors where they are preceded by two layers of a fiber glass filter media (American Air Filter FG-50 filter media). These units are used for exhausting some uranium dioxide (UO<sub>2</sub>) powder metallurgy operations and have given satisfactory performance. The life of the high efficiency filters has been greater than one year. The FG-50 prefilters are changed every 1 to 4 weeks depending upon dust loading conditions. Draft gauges on the units indicate the need for filter change.

Day dust collectors of the Hersey reverse-jet type, are used for the local exhaust ventilation of production scale powder metallurgy operations. The uranium dioxide dust loadings have been light requiring infrequent manual operation of the reverse jet. One smaller unit of this type is used as part of a pulverizing process for reducing the particle size of uranium dioxide for powder metallurgy operations. Air velocities through the wool felt bag are 12 to 15 ft/min for a total volume of 300 to 375 cfm. At dust loadings of 20 to 25 grains/cu ft, the pressure drop across the bag is about 4 in. Hg. The unit collects 60 to 80 lb/hr of uranium dioxide having a mean particle size approaching 1  $\mu$  diameter. This unit discharges into the larger collecting system along with the exhaust air from other processes. Tests on this unit have indicated that it has a collection efficiency in excess of 99 per cent for this particular application.

There have been no serious maintenance problems on these reverse-jet type bag collectors. Some difficulty was experienced from water collecting in one of these units which is located outdoors. Some of this water was from leakage through deteriorated gaskets at the joints and doors. Condensation could be a contributing factor in cold weather.

In general, the factors which were taken into consideration in designing these air cleaning systems were (1) the required collecting efficiency, (2) nature of the material to be collected, (3) maintenance problems, and (4) cost.

# AIR CLEANING EXPERIENCE AT THE NAVAL REACTOR FACILITY

J. R. Horan

*SIW Industrial Hygiene Group, Westinghouse Electric Corporation*

## 1 INTRODUCTION

The SIW plant is a prototype nuclear power plant similar to the USS Nautilus which utilizes a pressurized water reactor as a heat source to supply steam to turbines, generating equipment, and similar components found in a conventional steam plant. This power plant has been operated successfully for over four years. During this time no employee has received any significant exposure as the result of inhalation of radioactive material. Since the feasibility of a submarine thermal reactor has been proven, the SIW plant has been transformed from a prototype operation to that of a test facility to supply important information for future water cooled reactors. The operations building contains a hot-cell and canal area, as well as chemistry laboratories for the testing, sampling, and analysis of highly radioactive materials.

Radioactive air contamination may result from primary coolant leakage in the power plant by a direct release to the atmosphere or by leakage into the steam system. The sampling or analyzing of radioactive material in the fuel handling area or chemistry laboratories is another source of air contamination.

## 2 CONTROL OF AIRBORNE RADIOACTIVE CONTAMINATION

### 2.1 Primary System Leakage

To remove air activity resulting from direct primary coolant leakage, we originally utilized a 600-cfm fan to exhaust air from the area into the following cleaning system before stack discharge: (1) dry cyclone, (2) air mat arrestor composed of cloth-cellulose fibers.

Two and a half years of operating experience demonstrated that this air cleaning equipment was unnecessary; therefore, discharge is now made directly to the stack without cleaning.

### 2.2 Secondary System Leakage

Primary heat exchangers of the type used at SIW, even though designed and built for high integrity, will develop primary to secondary leakage. With leak rates as low as 5 to 10 gal/hr a certain amount of contaminated steam will be released in the engine room area. This problem is of such a low order of magnitude that air cleaning equipment is not a feasible solution. Instead the problem is solved by dilution, using one or more of six available emergency exhaust fans, each fan having a capacity of 36,000 cfm.

We would like to find an inexpensive compact high efficiency air cleaner capable of removing contaminants from 300 cfm of radioactive steam.

### 2.3 Hot-Cell and Chemistry Laboratories Exhausts

Only low-level activity has been discharged to our air cleaning systems which consist of Roto-clone type N scrubbers, and two-stage electrostatic precipitators. Our main problem is to dry the air sufficiently by heaters to prevent electrical breakdown of the precipitator by high-moisture content of the air. Damage to the Roto-clone has been confined to heater damage caused by water minerals.

## 3 OPERATIONAL EXPERIENCE

### 3.1 Argon ( $Ar^{41}$ ) Study

Less than 50 curies of  $Ar^{41}$  have been discharged to the atmosphere. This quantity resulted for a test specifically designed to evaluate the hazard from  $Ar^{41}$  in a confined space. To

perform this test, several standard cubic feet of Ar<sup>40</sup> were injected into the primary coolant and allowed to reach radioactive equilibrium. The Ar<sup>41</sup> activity reached a maximum concentration of  $2.6 \times 10^{-7}$   $\mu\text{c}/\text{cc}$ . Except for this test our total discharge of radioactive material to the atmosphere would be less than 1 curie. Fallout trays downwind of our project have never indicated the release of particulate radioactivity from our stacks.

### 3.2 Secondary System Leakage

The leakage of primary coolant indirectly to the atmosphere through the secondary system has not resulted in any hazard under normal operating conditions. With a primary to secondary heat exchanger leak of up to 100 gal/hr, levels of air contamination in the occupied areas increased to a maximum of  $10^{-9}$   $\mu\text{c}/\text{cc}$  of beta-gamma activity. Since the major activity of biological significance is Fe<sup>59</sup>, this concentration is less than 0.06 per cent of the maximum permissible concentration based on National Bureau of Standards Handbook #52.

With fission products present in the primary coolant, air contamination of from  $3 \times 10^{-8}$  to  $4 \times 10^{-7}$   $\mu\text{c}/\text{cc}$  have been experienced in the engine room area during special tests.

The unusual feature is that although iodine is the major fission product present in the coolant, no iodine has been detected in the air contamination by either filtration, scrubbing, or biological techniques. The predominant activity is 30 min Cs<sup>138</sup>. Five coolers in the air-conditioning system proved very effective in removing a significant percentage of the air contamination through condensation.

### 3.3 Unusual Techniques

In confined areas, we have been successful in filtering low-level air contamination by the operation of one or more staplex air samplers with an all dust type filter (BM2133) recirculating the air at 30 cfm.

In unoccupied areas we have found that levels of contaminated air activity can be reduced by increasing the relative humidity to 100 per cent. This causes the radioactive particulates to rain out of the air, thus reducing the capacity of the atmosphere for radioactive materials.

## AIR CLEANING ACTIVITIES AT GE-ANP IDAHO TEST STATION

R. M. Chatters

*Technical Laboratories, General Electric Company, Idaho Falls*

In view of the increasing interest in fallout and other potential sources of radiation damage to human populations, the General Electric Company has accelerated its existing investigational program dealing with radiation hazards.

The General Electric Company's situation at its Idaho Falls Aircraft Nuclear Propulsion Test Station is a rather paradoxical one. The very meteorological and physiographic conditions which make the Upper Snake River Plain so desirable as a reactor site often militate against the operation of the reactors due to their effects upon the dispersal of stack effluents.

For the benefit of those who may not be familiar with the Idaho Test Station site, I will take a few moments to describe the area. The installation is part of the National Reactor Testing Station which includes Phillips Materials Testing Reactor, Engineering Test Reactor, Chemical Processing Plant, Argonne's Experimental Breeder Reactor, and the Naval Reactor Facility. It now occupies about 460,000 acres of the vast Upper Snake River Plain west of the city of Idaho Falls, the closest heavily populated town. The plain which is about 60 miles wide and more than twice as long is surrounded by mountains, some of which on the west are as high as 11,000 feet; and on the northeast the Grand Tetons reach altitudes in excess of 13,000 feet. It

becomes readily apparent that with the wide disparity in physical conditions between the warm, arid, and relatively flat desert floor to the snow covered peaks of the Tetons, many variable weather conditions can and do occur at the reactor site.

Because of the location of the Idaho Test Station of the General Electric Company relative to other reactor sites on the Snake River Plain, the operation of the reactors is limited to those times when the wind currents are from the southwest—which, fortunately, is the direction of prevailing winds.

Among the vagaries of nature which affect the operation of the General Electric facility are the occasional sudden changes in wind direction caused by the movement of winds down one of the nearby mountain passes. Winds which may be blowing from the southwest over the effluent stack at the Initial Engine Test facility, permitting reactor operation, will suddenly shift to come from the northwest, thus requiring cessation of reactor operations until southwesterly winds are again re-established. This may require several hours. These same northerly winds continue down the valley and encounter southerly winds blowing from the Materials Reactor Testing site 20 miles away. The nature of the shearing of the two directional air masses is not yet fully known.

From the foregoing, it is obvious that a solution for the problem of air pollution becomes more complex as reactors increase in number on the Snake River Plain, and that a better understanding of the paths taken by stack effluents and their contained constituents warrant detailed study.

In order that the General Electric Company can cope with this situation, tests and observations are now under way to acquire a more detailed knowledge of the movements of our stack effluents and of their composition.

Recently, the U. S. Weather Bureau offices at Idaho Falls proposed to investigate the shearing of the simultaneous north-south winds along the floor of the plain by means of smoke plumes. The U. S. Air Force was to provide aerial photographic assistance and the G.E. Idaho Test Station was to send up a smoke plume from a 167-ft stack for comparison with ground level activity. Perversely enough, the looked-for phenomenon did not occur before warmer weather set in; hence, the tests have been postponed until fall when weather conditions will more frequently again be favorable for the propagation of the two-way winds over the test area.

An independent series of smoke plume studies have been started by us in Idaho and are intended to provide information on the movement of smoke from the 150-ft stack at the Initial Engine Test facility. Of special interest is the determination of the effective stack height because of its value in diffusion of the effluents.

As the General Electric Company develops its study of an air-cooled direct cycle reactor, it is our intent to continue the smoke plume investigations under varied weather conditions both summer and winter until we feel that significant data have been obtained.

The smoke plumes which are being studied have been produced by oil and water smoke generators, smoke bombs, and titanium tetrachloride and ammonia. Examination of the plumes is being aided by the use of infrared detectors such as the sniper-scope and recorded permanently on movie film, and by black and white plus infrared photography. The photographs will provide us with information on the structure of the plumes as well as their paths of movement.

To provide a clearer concept of the amount of radioactive effluent which might be released from the Aircraft Nuclear Propulsion area, a program for the development of filtering devices has been in operation for some time past.

These investigations include the testing of filtering systems and adsorbents using in-pile loops at the Phillips Petroleum Company's Materials Testing Reactor site, out-of-pile test loops within effluent ducts at the Initial Engine Test pad, withdrawing and monitoring of air from the IET stack, and the employment of electrostatic precipitators.

A testing program has been initiated at the Materials Testing Laboratory which will investigate in detail the feasibility of using a multiphase filtering system in which several adsorbents specific for individual components in the stack effluents will be examined. Likewise, the program calls for testing the comparative efficiencies of various solid adsorbents, some of which will be conventional types and others which will no doubt be classed as exotic, if not bizarre.

We have been fortunate in having the assistance of the Harvard Air Cleaning Laboratory personnel and a number of other persons on this investigation, but will welcome further help from others in order that we may reach a satisfactory and speedy solution to stack effluent dispersal problem at the GE-ANP Idaho Test Station.

## AIR CLEANING OPERATIONS AT KAPL

W. H. Truran  
*Knolls Atomic Power Laboratory*

### 1 INTRODUCTION

Air cleaning operations at the Knolls Atomic Power Laboratory continue to receive deserved attention after seven years of operation to maintain their optimum effectiveness in promoting employee and public health. Through accumulated operating experience, and revisions in laboratory functions and facilities, air cleaning maintenance has been programmed, air cleaning services have been reduced, and new air cleaning facilities are improve 1.

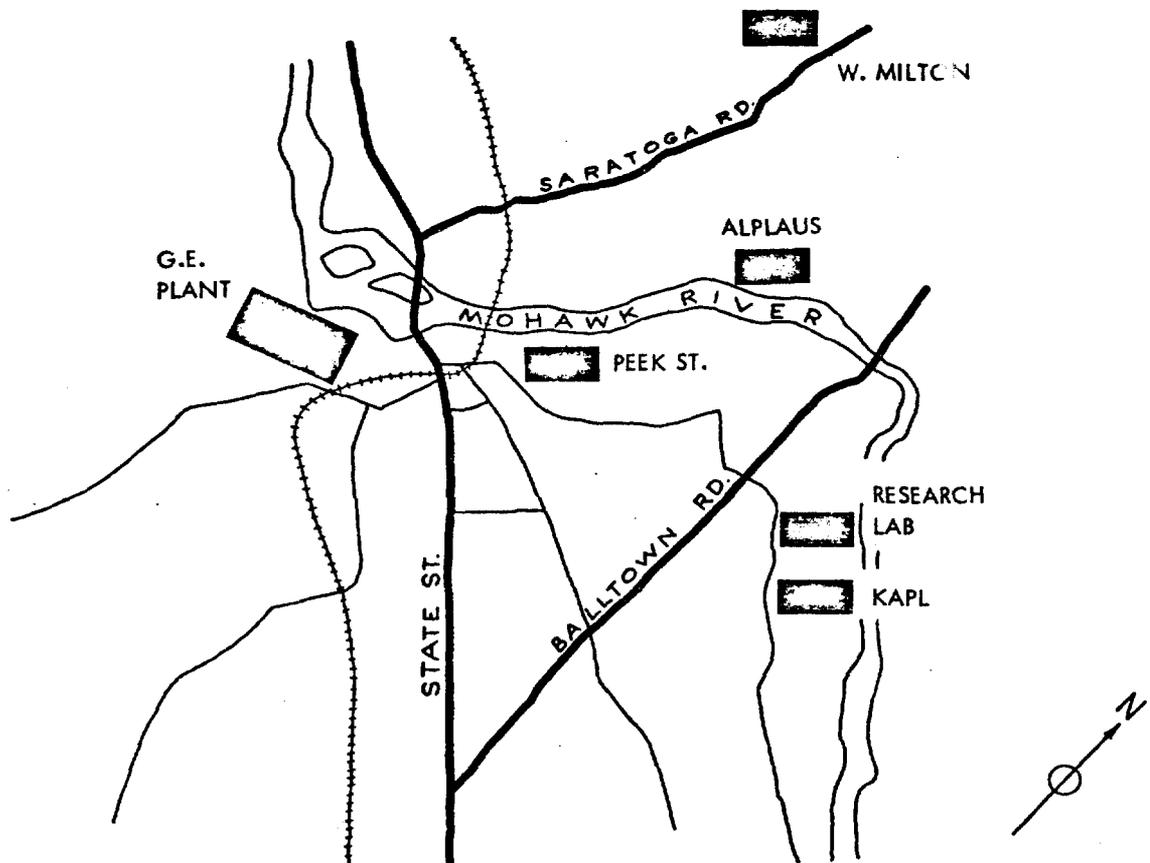


Fig. 1—Location of Knolls and West Milton KAPL sites.

## 2 THE LABORATORY

The Knolls Atomic Power Laboratory is engaged in the development of naval propulsion reactors. Its facilities occupy two sites. The Knolls Site is approximately five miles east of the center of Schenectady. The West Milton Site is approximately eighteen miles to the north. Their locations are shown in Fig. 1 together with the locations of the neighboring General Electric Research Laboratory and the General Electric Main Plant in Schenectady, New York.

The Knolls Site facilities (Fig. 2) requiring air cleaning services include physics, chemistry, and metallurgy laboratories; shielded cells for the examination of irradiated reactor components; a fuel element and reactor fabrication area; two critical assembly buildings; liquid and solid radioactive waste processing areas; and a laundry for laboratory clothing.

The West Milton Site (Fig. 3) facilities include nuclear power plant buildings and fuel service buildings. Investigations with the prototype for the nuclear power plant installed in the submarine, Seawolf, have been completed. The prototype for an advanced nuclear power plant to power the submarine, Triton, is under construction.

The personnel compliment of the Laboratory is approximately two thousand. Eighteen hundred are employed at the Knolls Site.

## 3 AIR CLEANING SYSTEMS

Air cleaning systems are either single-pass or partially recirculating systems. Ventilation air is not recirculated when ventilation is relied upon to control personnel exposure to airborne contaminants during established operations. Such systems service chemical laboratory hoods, glove boxes, shielded cells, and a special materials machine shop where uranium is machined. The ventilation air is partially recirculated in areas where air cleaning would be required only as a result of an unusual incident such as the failure of glove box ventilation or in a critical assembly area where personnel are not involved during operations.

Whether single-pass or partially recirculating, if the expected contaminant is significant amounts of plutonium, enriched uranium, or fission products, cleaning of exhaust air is performed by a Cambridge Absolute Filter, preceded by a Dust Stop Fiberglass Filter (Fig. 4). If the possible contaminant is limited to natural uranium or beryllium, an American Air Mat Filter is the air cleaner. It is preceded by a cyclone separator for machining operations. Exhaust systems for nuclear power plant buildings are complicated with condensers, compressers, and isolation valves to satisfy reactor safeguards requirements.

Where absolute filtration of single-pass exhaust air is provided, supply air is precleaned with self-cleaning oil filters and electrostatic precipitators. This helps to minimize the dust loading of exhaust filters. Make-up air for partially recirculating systems is filtered with Dust Stop filters. Shop supply air is not precleaned.

## 4 OPERATING EXPERIENCE

Experience has indicated the need for a monthly preventative maintenance inspection of all air moving equipment. The condition of motor and fan bearings, belts, and fan blades are determined. Maintenance is required on the average of once a year. Substantial replacement is anticipated after 5 to 10 years of continuous operation. Air cleaning equipment is also inspected at least once each month. Special cases may be inspected as often as once each week.

In supply air systems, self-cleaning oil filters are steam cleaned every six months. Electrostatic precipitator wires and insulators are scheduled for cleaning every three months, although cleaning is presently required every two months because of construction in the neighborhood. The frequency of changing Dust Stop filters in make-up air systems has jumped from every 2 months to 2 weeks because of construction.

In single-pass systems requiring absolute filtration of exhaust air, Dust Stop prefilters may require changing in periods ranging from three months to a year. In partially recirculating systems with Absolute filters, the Dust Stop filters generally last a year.

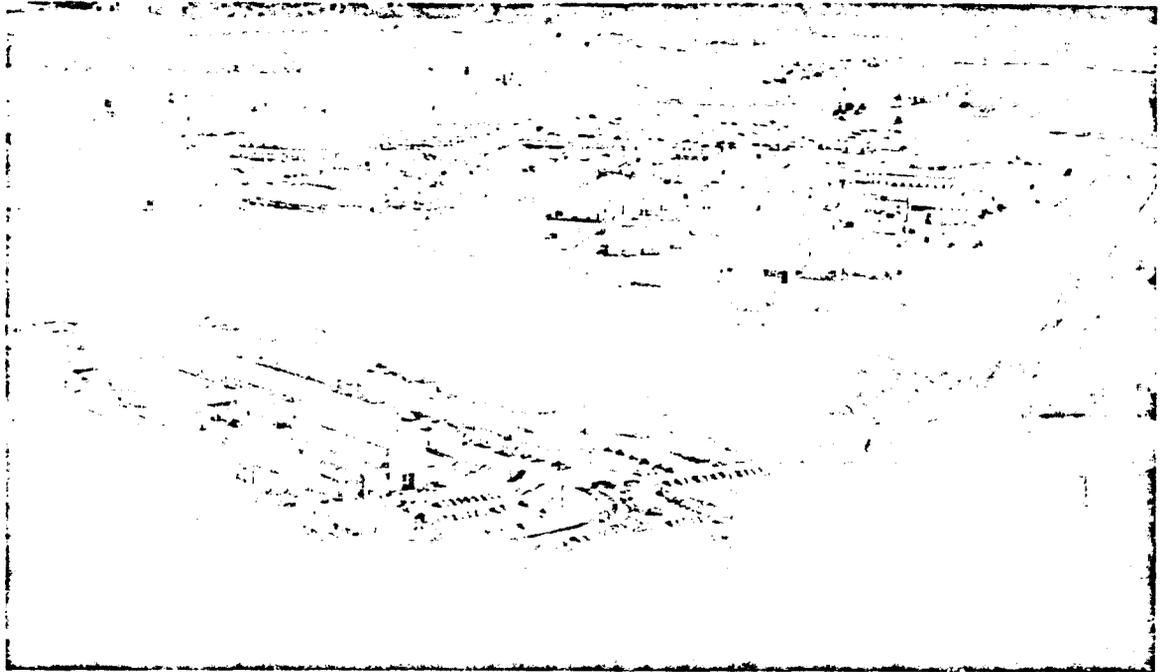


Fig. 2—Knolls site.



Fig. 3—West Milton site.

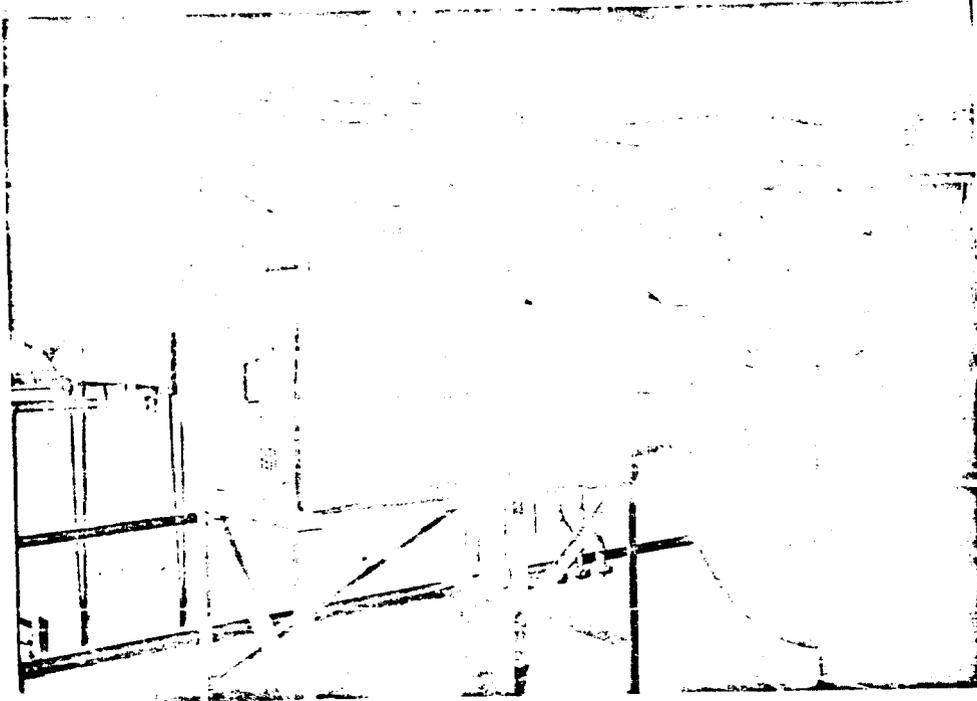


Fig. 4—Filtering system.

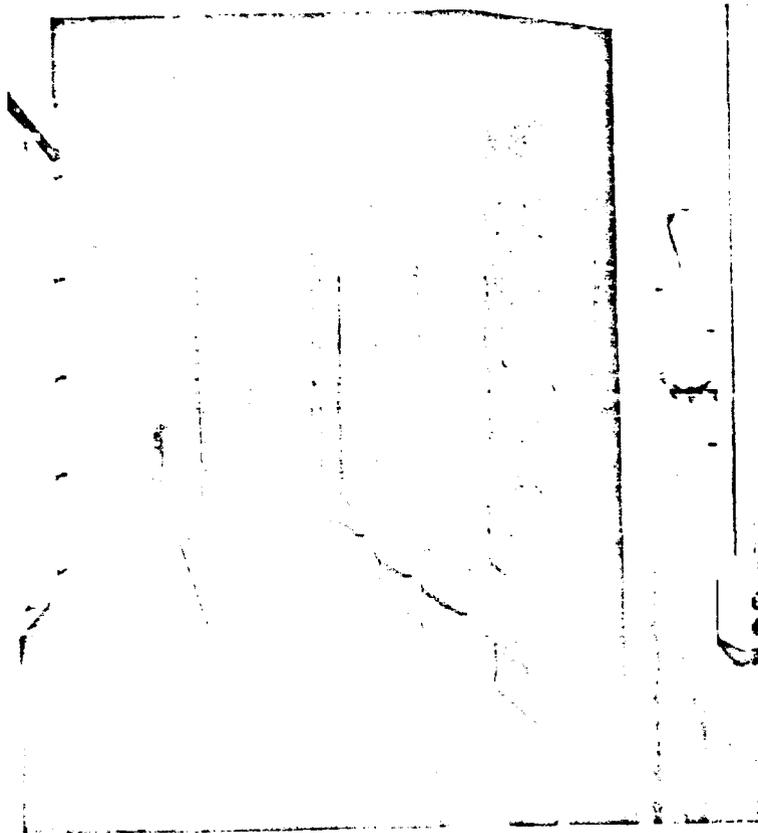


Fig. 5—System to reduce precipitator load.

Dust Stop filter changes are indicated by reduced exhaust velocity and increased pressure drop across the filter. Absolute filter changes are required by build-up in levels of radiation rather than dust loading. Some Absolute filters have been in use seven years.

The cyclone separator in the special materials machine shop is cleaned in periods of from 1 to 3 months, depending on the level of work load in the shop.

The air cleaning equipment for shop exhaust air originally included an electrostatic precipitator which processed air exhausted directly from machine tools following its passage through a cyclone separator. Due to the dust load created by machining operations, the precipitator required cleaning and maintenance once a month to keep ahead of short circuited and broken collecting wires. In order not to interfere with shop operations, maintenance was performed on off shifts. To ensure proper operation the following day, the man-hours required were so costly and inconvenient as to suggest the need for a better way. An American Air Mat Filter was installed preceding the electrostatic precipitator to reduce the precipitator load (Fig. 5). Investigation of contamination concentrations in exhaust air following the glass mat filtering, with the precipitator inoperative, indicated no need for the electrostatic precipitator with existing shop operations. This has continued to be the case for three years and no future need for the precipitator is anticipated. The mat filter is inspected visually and replaced every 2 weeks to 2 months, depending on shop workload.

A ventilation system being constructed for a critical assembly at the Knolls Atomic Power Laboratory is a partially recirculating, conditioned, and filtered system for the critical assembly area, separate from the control room and all adjacent areas. The filters are the series of rough and Absolute filters.

In the original systems provided for such operations at the Laboratory, experience and economy suggested a common air-conditioning unit in two parallel ventilation systems, one for the critical assembly area and one for the adjacent fuel storage, sub-component assembly, and reactor control room area. The two parallel systems were provided with dampers to shut down one in the event that toxic contaminants were picked up in the other but no filters were included. No problem arose in five years of operations. Revisions in last year's operations resulted in two minor incidents, one of which could be considered accidental, the other a part of revised operating conditions which were to continue. In the accidental case, radioactivity in the form of surface contamination was spread throughout the ventilation duct work of both the critical assembly rooms and the adjacent areas before the ventilation system was shut down. In the latter case, a nuisance level of short-lived radioactivity was detected by air samples in personnel-occupied areas which could only partially be corrected by dampening or shutting down all air circulating equipment.

Although in neither case did personnel exposure give cause for concern, the conditions inconvenienced reactor operations and pointed to a condition which could be intolerable in the event of a supercritical reactor incident. For these reasons in recent designs the ventilation system for a critical assembly area is completely isolated from all adjacent operating areas. The exhaust air is filtered to promptly reduce concentrations of particulate material. The air is recirculated to permit short-lived gaseous fission products to decay and be absorbed on filters and filterable material. The system is convertible to a single-pass system.

The program to evaluate the radioactivity content of atmospheres in operating areas, in exhaust ventilation, and in the environment of KAPL sites continues to demonstrate adequate cleaning of exhaust air. Occasional situations call for the wearing of respiratory protective devices temporarily in operating areas, such as an emergency spill of radioactive liquid, planned maintenance of radioactive waste processing equipment, or modifications within shielded cells. In only two cases are respiratory protective devices a part of routine operating conditions: unventilated critical assembly areas are entered following assembly operations and prior to the decay of short-lived airborne contaminants; the exhaust ventilation applied to baling of compressible radioactive waste, though generally adequate, is not sufficient to eliminate the need of respiratory protective devices in all cases. These operations are of short duration and respiratory protection requirements have not been objectionable. No significant exposure of Laboratory personnel has resulted from the inhalation of airborne contaminants as

indicated by air sample and biosample analyses. Exhaust ventilation and environmental monitors continue to indicate no influence on levels of environmental contamination attributable to Laboratory exhaust ventilation.

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## AIR CLEANING ACTIVITIES AT ATOMICS INTERNATIONAL

A. A. Jarrett

*Atomics International*

The prevailing practices at Atomics International, a Division of North American Aviation, Inc., to prevent environmental contamination by radioactive materials have been to use controlled air flow patterns in the laboratory from colder to hotter areas, to use prefilters followed by high efficient filters before discharge, and to collect radioactive gases in tanks prior to controlled discharge to the environment after decay.

In the main research laboratories at Canoga Park, a plenum containing twenty 20- by 20-in. Dust-Stop prefilters 4 in. thick and an array of 20 high efficiency final filters cleans approximately 15,000 cfm of air from laboratory operations. Influent air is cleaned electrostatically. Prefilters have been changed semiannually and final filters once a year when the combined pressure drop exceeds 2.5 in. water. Filter changes are determined by lowered air flow velocity across the face of laboratory hoods resulting from decreased efficiency of the blower rather than pressure drop across the filters. Under these circumstances the flow is approximately  $10^8$  ft of air between yearly changes of the final filtering media.

More emphasis must be placed on the instrumentation needed for evaluating the performance of installed air cleaning systems and the need for practical methods of control of radioactive gaseous effluents.

# AIR CLEANING ACTIVITIES AND ASSOCIATED STUDIES AT GOODYEAR ATOMIC CORPORATION

Ben Kalmon  
*Goodyear Atomic Corporation*

## 1 AIR CLEANING

Air cleaning at Goodyear Atomic Corporation may be grouped into two classifications: (1) air being discharged from various processes into the atmosphere outside the building to prevent possible air pollution within the buildings, and (2) local exhaust ventilation around various operations to keep the air contaminants in the worker's breathing zone well below the maximum allowable concentration (MAC) of chemical contaminants or below the maximum permissible limit (MPL) of radioactive uranium compounds.

The principal airborne contaminants resulting from plant operations are uranium and fluorine in various chemical forms, including fluorine itself, hydrogen fluoride, and chlorine trifluoride. Recently, other metals, fumes, and gaseous materials have been encountered among which are mercury (as used in the instrument maintenance facilities), nickel, iron oxide, welding fumes, and cadmium.

In locations where process gas is vented to the atmosphere, special chemical and/or mechanical traps are installed to collect the uranium before the process gas is vented. Although special traps are used for the elimination of hydrogen fluoride, we presently have no suitable method for the elimination of fluorine and, therefore, we have a potential fluorine air pollution problem. As a result, extensive background studies are made to determine whether fluorine air pollution is occurring.

Approximately one year ago, considerable difficulty was experienced with condenser corrosion. To check the corrosion, the method of water treatment was changed. This method of water treatment required the use of hexavalent chromates and sulfur dioxide; as a consequence, mists containing chromates issued from our cooling towers and it became necessary to conduct extensive surveys for chromate as well as sulfur dioxide. The surveys revealed no appreciable concentrations of either contaminant.

In regard to "air cleaning" the workers' breathing zone, the following is a brief summary:

1. *Welding Fumes.* Welding operations are of extreme importance at a gaseous diffusion plant. Wherever welding is performed in fixed locations, local exhaust ventilation is supplied to control the fume hazard. However, there are times when welding has to be done where local exhaust ventilation is not available. At these times, respiratory protection is worn by the welder.

2. *Metal Dusts.* Certain operations, particularly buffing and grinding, are dust producers and sometimes require high velocity local exhaust ventilation. Iron oxide fumes present a new problem during extensive burning operations. The concentrations have been as high as 26.6 mg/m<sup>3</sup> (MAC, 15). A local exhaust system has been approved for installation for three exhaust locations.

3. *Degreasers.* Organic solvent degreasers very often require a lateral slot exhaust type ventilation to permit the vapors from escaping into the surrounding area. We have five trichloroethylene and one Freon vapor phase degreasers. All degreasers have adequate exhaust ventilation, the amount depending upon the size and type of degreaser.

4. *Mercury.* The area where mercury is reclaimed is also provided with good local exhaust ventilation to prevent the accumulation of mercury vapors in the breathing zone of the workers.

In these operations the exhaust air is vented directly from the roof or the side of the building involved with no filtration or scrubbing. The amount of material involved in each case is relatively small from an air pollution viewpoint so that direct discharge with the associated dilution is considered adequate.

To determine whether local exhaust ventilation is needed or is adequate, routine air samples are taken around various processes for such metals as zinc, uranium, cadmium, nickel, and mercury and gases as trichloroethylene, nitrogen dioxide, fluorine, hydrogen fluoride, and carbon monoxide.

An evaluation is being made of an inert gas welding operation for the necessity of local exhaust ventilation. Preliminary results indicate that additional ventilation will be required.

### 1.1 Special Problems

One area of particular concern has been in a sampling facility where samples of product are withdrawn for analysis. Because of the level of  $U^{235}$  assay, the alpha activity is high. In this type of operation, uranium hexafluoride is withdrawn from cylinders by heating and valve systems are used extensively. Due to repeated usage, the valves eventually develop minute leaks.

The average airborne activity may be in excess of the MPL in as many as 20 per cent of the routine samples collected. As a result of this activity additional hoods and filter systems are being installed.

This system will be of an enclosed hood type over two adjacent work areas with separate exhaust fan and filtration system. It has been observed that considerable airborne concentration of hydrolyzed uranium hexafluoride can be traced to loose floor contamination due to the mechanical action of employees walking around. A stainless steel floor is being installed in this area so that the area can be more efficiently decontaminated as compared to concrete floors. A few cases have been reported of hydrogen fluoride skin burns due to the reaction of the process gas with perspiration.

## 2 EXTERNAL ATMOSPHERIC CONTAMINANTS

The major atmospheric contaminants as previously mentioned are fluorides. Since the threshold of odor is low, any fluorides vented to the atmosphere are readily detected. Considerable time and effort are directed to an extensive routine air sampling program. Air samples for fluorides and uranium are collected on a monthly basis within a radius of approximately five miles. The maximum average airborne fluoride concentration is 0.03 ppm. It has been observed that the average vegetation uptake is in the range of 25 to 30 ppm, up to five miles. It has also been noted that no definite correlation exists with wind direction or distance. The maximum values are generally found within a distance of 2 to 3 miles.

Plans are being made to recover the fluorides by returning the vent gases to a new feed manufacturing facility using a return line approximately one mile long. The recovery of the fluorides will serve two obviously desirable purposes: (1) the economic value of the recovered fluorides, and (2) the reduced airborne concentration.

### 2.1 Special On-Site Clover Damage Study

Early in November 1955, an area of clover on plant site became discolored and was found to be severely injured. Samples were collected to determine the fluoride uptake. This area was to the northeast of the top vent and parallel to the prevailing wind direction. Ten samples were collected at various distances up to an estimated 3000 ft from the vent. Of the ten samples, four collected from 825 to 1500 ft were severely injured. In the range from 1650 to 2000 ft, three specimens were moderately injured. At distances from 2300 to 2800 ft the clover exhibited slight injury. Samples taken at distances of 3000 ft or more indicated no injury.

The laboratory results were correlated with the degree of injury and the following general conclusions were made: 100 ppm, no injury; 110 to 175 ppm, slight injury; 225 to 350 ppm, moderate injury; and in excess of 490 ppm, severe injury.

In the spring of 1956, the newly grown crop of clover again exhibited the same pattern and a plot of the uptake vs distance indicated the same slope for both sets of data.

A plot was made on log-log paper of fluoride uptake vs distance from the top vent. The results indicated that uptake followed an inverse square relationship for the range covered. The points on the curve fall well within the limits of experimental error.

## 2.2 Extended Background Survey

In late summer of 1956, an extensive background survey was conducted to establish the normal background levels of fluorides in the Scioto River, in various species of vegetation, soil, and milk, and fluorides and sulfur dioxide in the atmosphere. This survey was desirable to determine background data in evaluating routine monthly surveys and to provide a means of detecting any build-up of contaminants. Samples of grass, clover, corn, pine needles, and soil were collected and analyzed for fluorides at 32 selected locations. A sample of each available species was collected at each location and isolated from the other species. The area covered was approximately 1385 sq miles with locations as far as 22 miles from the center of the plant activity. The locations were selected on a rectangular grid pattern and on the basis of prevailing wind and accessibility.

Continuous 24-hr air samples were collected to determine the airborne concentrations of fluorides and sulfur dioxide. The samples were collected simultaneously at locations from 7 to 25 miles from the plant in north, east, and south direction.

Eleven milk samples were collected and analyzed to determine the fluoride content of milk from dairy cows in the vicinity of the plant as compared to that from cows remote to the plant. Samples were taken as far as 34 miles from the plant. Four samples were collected from 2 to 6.7 miles surrounding the plant.

To evaluate the contamination in the Scioto River that could be attributed to plant operations, the river was surveyed from Chillicothe (25 miles north) to Portsmouth (22 miles south) at 12 locations. The time of collection at each sample point was scheduled to coincide with the river flow rate. This was done by following a float carried downstream by the river current. Samples were collected in each instance just upstream from the confluence of each major tributary. Chemical and radiological analyses were made for uranium, fluorides, hexavalent and total chromates, pH, and beta activity.

There were no indications that the contaminant concentrations in the milk, air, or Scioto River samples were different at points in the vicinity of the plant or at remote locations.

The average fluoride uptake in vegetation among the various species was statistically different at the 95 per cent confidence level. In general, the clover uptake was the highest; hence, future surveys can be limited to clover as this was the most sensitive indicator. The average uptake in pine needles was the lowest of the species analyzed.

The effect of prevailing winds is not evident. Based on the prevailing wind direction, it was expected that the northeast quadrant averages would be the highest. The highest values were found in the southeast and northwest quadrants.

The statistical analyses by quadrants and distance indicated no clear pattern and very little, if any, correlation.

The concentrations found in soil were erratic and random; for example, the highest value (350 ppm) and the lowest value (79 ppm) were found in approximately the same direction and the highest value was found at twice the distance from the plant site as the lowest value.

Because of the lack of correlation and erratic results, more surveying is being done. So far, it appears unlikely that plant operations have affected the vegetation fluoride concentration background at distances greater than five miles, and that the fluoride concentrations are random in nature. Although there is some evidence of increased fluoride uptake within a five-mile radius of the exhaust stack, no indication of off-site vegetation damage has been detected. Based on the clover study previously discussed, it is apparent that vegetation beyond five miles would be unaffected by plant operations.

# DEVELOPMENTS IN HIGH EFFICIENCY AIR FILTRATION

Paul M. Engle  
*Cambridge Filter Corp.*

I would like to extend two invitations. First, we have on display a considerable number of new and special Absolute and Aerosolve Filters. We will be at the hotel this evening and will be very happy to discuss filters of any type and questions involving their application with you there or even here immediately after this meeting. Bill Baldwin who is the engineer in charge of our manufacturing department is here and since development is my field, I believe we are well equipped to handle questions of every nature. I spent eight years on AEC contract work with Monsanto and feel that I understand a lot of your special problems.

The second invitation is to visit our plant in Syracuse. This invitation is always open. We'll be very happy to have you tour our manufacturing operations and discuss your particular problems. A number of our good customers have done this and we always find it mutually helpful.

I will touch briefly on some of our development programs and hope to continue the discussion with you at our display. One of our more recent developments is an adhesiveless Absolute filter. These filters are very useful where organic materials are taboo such as in contact with perchloric acid. This approach is also recommended when a fireproof filter is required.

Absolute filters with plastic separators have been developed for certain applications where corrosion resistance is important.

Cylindrical filters have been constructed for several customers. These are particularly useful where the filters are to be installed in pressure containers. As you might imagine the production problems which were solved to make this item possible were considerable. We are proud of the improvements in manufacturing made over the years which enable us to sell filters at less than their price six years ago, in spite of constantly increasing material and labor costs. I doubt if there are many articles you buy which can equal this saving. The price reductions now taking place in the glass media Absolute filters are particularly noteworthy. These will make fire-resistant filters more economical.

Since fire resistance is an important point of discussion at this seminar, let me mention our conclusions on this subject. We have found that as long as the media and separators are fireproof it is extremely difficult, if not impossible, to start a fire in the frames and adhesive even with a blow torch. The filters on which these tests were run employed ordinary plywood frames and rubber-based adhesive. We feel that further modification is probably unnecessary and may lead to a sacrifice of other properties, but, if it is required, we'll be glad to make it.

In general, I am sure you gentlemen understand the design and manufacture of standard Absolute filters, but there might be some details regarding their construction which would be interesting.

1. There are 200 or more square feet of filtering area in each 24- by 24- by 11½-in. filter. This means that at rated capacity the approaching air is spread out and slowed down by a factor of 50 before being filtered. This explains to a large extent how the filters can be so extremely efficient and still have reasonable pressure drop. This tremendous filtering area also explains why the life and dirt-holding capacity of the filters are so great.

2. Another important factor in the manufacture of Absolute filters is that there are no "seconds." After a filter is assembled if it does not meet the DOP smoke test, there is nothing that can be done. It is then scrapped. Fortunately over the last seven years we've had the same personnel building these filters and they've developed enough skill that we now lose very few filters.

3. The third point I want to emphasize is that in spite of increasing volume we've been able to keep our manufacturing flexible enough to accommodate special filters of almost any size or type conceivable. We have been supplying increasing numbers of Absolute and other high efficiency filters to industry for a number of years. These customers have a wide range of special problems such as corrosion, fire resistance, and steam sterilization. We have built

at least 20 different types of Absolute filters in the last year alone, not to mention the number of standard and special sizes. This experience is available in assisting you to solve your special problems.

Before closing I would like to mention briefly our other important development in the high efficiency air filtration field—our Aerosolve Filters. These filters are a two-piece unit consisting of replaceable cartridge and a special metal permanent support frame. They do not approach Absolute filters in efficiency, but rather were developed primarily for commercial applications covering a range of efficiencies up to and slightly above that provided by electrostatic precipitators. Aerosolve filters are frequently used as prefilters to Absolute filters.

Because of the lower efficiency, we certainly do not recommend that you replace your Absolute filters on highly radioactive exhaust systems with Aerosolves. We do feel, however, that there are less critical air cleaning problems at many of your plants where the efficiency and positive strainer-type action of the Aerosolve filters would be very valuable.

One good example is on supply systems where the exhaust will eventually become contaminated. It is certainly more economical and less trouble to remove ordinary atmospheric dust with efficient filters on the supply system, than to have this dust add to the load on the contaminated exhaust filters.

Aerosolve filters are also useful on certain exhaust applications. In fact, one of the AEC sites purchased a considerable number of our Aerosolve 95's soon after they were introduced over two years ago. On the basis of results obtained with these original installations, they are now installing these filters in additional systems.

Aerosolve 95 filters have a considerably lower pressure drop than Absolute filters and the replacement cartridges are less expensive. They are listed by Underwriters Laboratories. In closing, let me again invite you to visit us.

## DEVELOPMENTS IN THE MANUFACTURE OF ABSOLUTE FILTERS

A. R. Allan, Jr.  
*Flanders Mill, Inc.*

We are not yet able to offer for sale a filter made without cement such as our competitor claims to offer. However, we are sure that the subsequent savings in material in such a filter will be passed on to the consumer by our competitor.

Our latest development is an all ceramic filter that can be used, without injury to the filter, in temperatures up to 2300°F. I would like to pass this around while I continue my talk. The ceramic fibers disintegrate at 3200°F, and the filter may be used for a short duration of perhaps one hour at 3000°F. As the filter is of a homogeneous construction, it will withstand heat shock very well. Our units have been DOP tested and sent to the Buffalo Forge Company for heat testing. The filters were taken from room temperature and placed in an oven heated to 1500°F; they remained in the oven for approximately one hour and were withdrawn immediately to room temperature. The filters, after having been returned to us, were again DOP tested and no change in smoke penetration was noted. If anyone can tell us how we can DOP test these filters at a temperature of 2300°F, we would greatly appreciate it.

Unfortunately, the efficiency of the filter medium is not as good as that obtained with CWS or fiber glass media. It is 99.50 per cent at the rated capacity of the filters. However, the resistance is only about 60 per cent of the other filter media. The cause of the lesser efficiency is not inherent in the ceramic filters, but is due to the diameter of the ceramic fibers used in the media. No ceramic fiber exists, as yet, of sufficiently small diameter to increase the efficiency. Possibly, a greater demand for this small diameter fiber will result in its manufacture. These ceramic filters are made in all the standard sizes with the exception of the 24- by

30- by 11½-in. size. There are two different frame designs, one having a flange cast into the frame on one side, and the other having a uniform frame ½ in. thick all around the filter medium. The filter having the flange has a greater resistance at the same flow than the one without the flange. This is due to the space lost in providing a flange with the same over-all dimensions as the body of the other frame type.

The most recent development in glass media is a sheet 20 mils thick. We believe this to be quite important to filter users, as its efficiency is greater than the CWS and its resistance less by 10 per cent. We are willing to guarantee a smoke penetration of no more than 0.03 per cent and a resistance of not more than 0.9 in. wg at rated flows for filters made with this medium.

It is not affected by moisture and its fire resistant qualities are naturally superior to that of the CWS. We believe the strength of this new medium to be superior to that of the CWS. Static pressure tests were made across one of these units which was a reject. The smoke penetration of the unit was 0.07 per cent. Pressure was built up to 13 in. wg, and the filter was given a DOP test. It checked out at 0.07 per cent. The filter was again subjected to the static pressure test and was run up to 25 in. wg, the limit of our fan. It was again DOP tested and the results were 0.07 per cent penetration. No buckling or sagging of the frame was observed during this test. A similar test given to a filter made with CWS medium resulted in rupture of the medium at 16 in. wg. It is not our contention that the results of this test should be used as a criterion of filter strength, as we do not think that exactly the same stresses are put on a filter in operation as this filter was subjected to. We used cardboard to block off the face of the filter and this is quite different than dust-loading it. However, we do feel that it is an indication of the comparative strength of the filter papers. Mr. Walker, Dow Chemical Company, has shown some concern about the dust-loading capacity of glass media. We are not able to make tests to evaluate this as our only equipment is a DOP machine. However, we do feel that a filter with a greater efficiency and a greater strength should be able to catch and hold more dirt than a less efficient and weaker one. We do not think that filter paper thickness is a contributing factor to dust-holding capacity.

I learned before coming here that one of the AEC sites is considering the installation of a DOP machine. I know that one other site considered this at one time. We would certainly welcome such a development at all the sites. The sites are entitled to know what they are buying in the way of filter efficiency. Filters which are suspected of having been damaged in transit could be retested and filters which have been cleaned at the sites could be checked to determine if the cleaning process had damaged them.

# DEVELOPMENTS IN THE MANUFACTURE OF ULTRA-AIRE SPACE FILTERS

Robert A. Bub  
*Mine Safety Appliances Company*

Mine Safety Appliances Company has been in the Ultra-Aire space filter business since the U. S. Chemical Corps decided to stop manufacturing these units for government and allied uses. We worked very closely with the Chemical Corps, Arthur D. Little, Inc., and Hollingsworth and Vose to produce the standard space filter commercially.

This unit originally consisted of CC-6 filter media, corrugated kraft paper separators, rubber cement, and sponge rubber gaskets. It is interesting to note, in light of present discussions, that one of the sales features of this design is that it can be conveniently reduced to ashes by incineration for simple disposal. These units with all-glass filter web in place of CC-6 are available in sizes for 35, 50, 500, and 1000 cfm at a maximum initial resistance of 0.9 in. water. Special sizes can be fabricated if desired. This filter is shown in Fig. 1.

Very shortly after this item was placed on the market, several AEC sites indicated that there were installations requiring filtration equivalent to the standard Ultra-Aire space filter but at operating temperatures approaching 1000°F.

Mine Safety Appliances Company contracted with the Hurlbut Paper Company to develop filter media jointly capable of meeting the performance requirements outlined by the sites. This work resulted in a series of webs capable of filtering at elevated temperatures. Our No. 25310 or 1106-B glass filter web proved to be most practical for this application; in fact, it has less resistance and greater efficiency than CC-6.

Considerable time and money was spent to incorporate the material into a useful product. Long and involved tests were conducted with an endless series of high-temperature ceramic cements and adhesives that never proved completely satisfactory to our company.

Problems of compatibility, aging, humidity, weathering, chemical resistance, expansion and contraction, handling, shipping, and storage were encountered.

These obstacles were overcome by devising a new patented folding procedure and using a high-temperature metallic binder. The resultant filter slug was installed in a mineral wool fiber housing for gasketing and installation purposes.

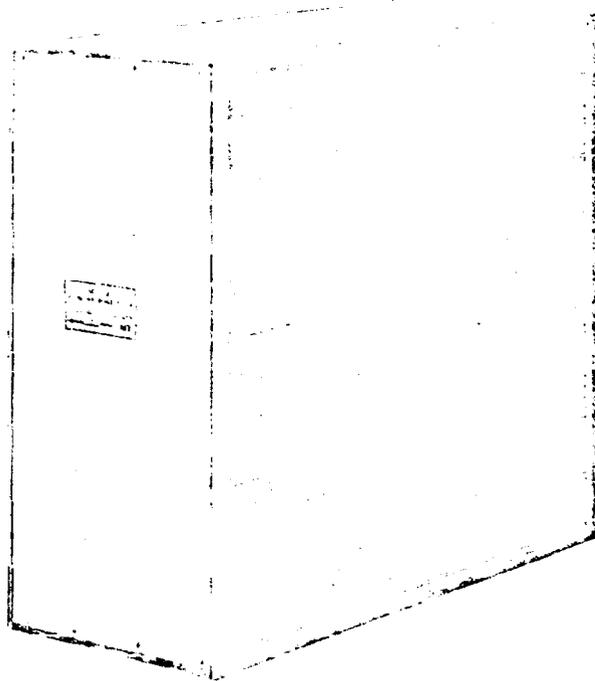
This filter is sold in a 50 cfm model (Fig. 2) that can easily be substituted for the standard units. It will operate at 1000°F and can be steam sterilized without damage. When tested with 0.3  $\mu$  DOP smoke, an initial efficiency of 99.97 per cent is guaranteed with a maximum pressure drop of 0.9 in. water. A survey of the potential market did not reveal sufficient activity to warrant development of larger production sizes.

As you all know, there is never a clean break between projects. During the development program on the high-temperature model, it was decided that the major need of the sites was a filter that would not contribute to a fire or explosion in an operating system or hood.

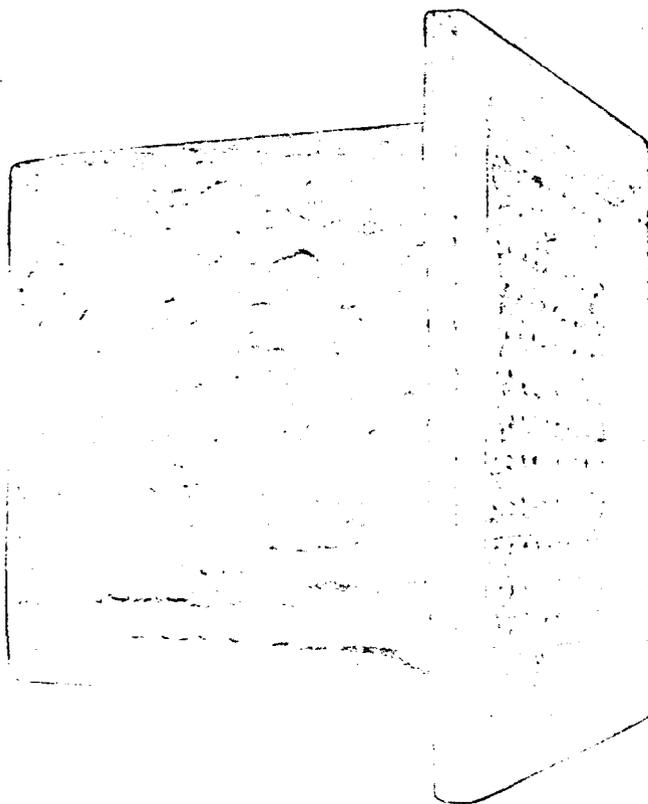
In case of fire, this filter should hold the material accumulated to date and prevent distribution of collected harmful particulate matter throughout the duct system or into the atmosphere. The filter would be replaced after the emergency has been brought under control.

With this new goal before us, substitutions were made in the original filter design to accomplish the desired item:

1. Fire resistant plywood manufactured in accordance with applicable military specifications was used for commercial fir.
2. Glass web with but 5 per cent organic material was used in place of CC-6 that has 85 per cent organic. In actual weight, the full content was reduced from 10 lb to 0.2 lb because of difference in total weight of media.
3. Mineral fiber separators were used instead of wholly combustible kraft paper.
4. Ceramic fiber gaskets were used in place of sponge rubber.
5. A more fire-resistant adhesive was used in place of the original material. We are still working to improve the fire-resistance of the adhesive used.



**Fig. 1—Ultra-Aire space filter.**



**Fig. 2—High-temperature filter.**

Results of tests conducted by MSA and AEC people are indeed encouraging. Data will probably be revealed in later papers on this program. These units, shown in Fig. 3, are available in 35, 50, 500, and 1000 cfm models as well as special sizes.

Figure 4 is a graph of pressure drop in inches of water vs cfm free air for all Ultra-Aire space filters in the sizes listed.

We have a continuous development program to improve performance of our Ultra-Aire space filters. Work along this line is being concentrated on reduced cost, increased efficiency, lower resistance, better sealants, and extension of filter life.

Along with Ultra-Aire space filter work MSA is designing, developing, and marketing special filters for particulate, gaseous, and liquid filtration. We have a series of catalytic filters for removal of gaseous contaminants, several liquid filters, and a long list of filter media for particulate problems.

The limited presentation time has made it necessary to give you a condensed version of our work in the filter development section of Mine Safety Appliances Company. This work is varied and very interesting to our company. It is hoped that the information presented was sufficiently useful to the extent that we will have an opportunity to discuss your specific filtration problems in the future.

## FIRE-RESISTIVE FILTER PROGRESS AT HAFORD

Don J. Keigher  
*Hanford Operations Office*

Since the early days of the atomic energy program, safety and fire protection engineers have had increasing concern for the fire hazards of the highly combustible type high efficiency filter, particularly when used in large contiguous banks. Since 1951 the Hanford Works—the General Electric Co. and the AEC's Hanford Operation Office—have actively pursued a program of filter studies and testing, and have promoted the development of a less hazardous filter at every opportunity.

In this panel we will report on progress or experience gained at Hanford since the last Air Cleaning Seminar. This report will be given on three aspects of the problem; operating and ventilation, industrial hygiene, and fire protection. Mr. James H. Palmer, of the Air Balance Unit, Chemical Processing Department, General Electric Company, will report on the moisture and fire tests made in the last eighteen months. Mr. Frank E. Adley of the Industrial Hygiene Group, Hanford Laboratories Operation, General Electric Company, will report on a significant fire that occurred in his operation. I will give a review of our criteria for a fire-safe filter. I would like to add, before we start, that the cooperation of the various groups of G.E. and AEC and particularly of the three of us represented on the panel has been excellent, and what progress we have made can largely be credited to that spirit of common effort.

I was fortunate to participate in the Fourth Air Cleaning Seminar held at Argonne National Laboratory in 1955. At that time we attempted to review the broad field of Fire Considerations in Filter Design. We reviewed the design growth of high efficiency filters, as well as ventilation systems in general, from a fire protection and fire safety viewpoint.

We noted and it is still remarkably true that no major fires have developed in filter banks using the old and still most common cellulose-asbestos type units we usually refer to as the CWS-6 type. We reviewed some seven fires that had occurred and were documented through investigation reports, and although we said at the time none had occurred during the war years under the Manhattan Engineering District, we have found that is not true. I cannot stress too strongly the importance of investigation and documentation of even seemingly minor incidents such as filter fires when a solution for such a problem is being sought. These fires occurred at

varying sites, under various AEC contractors, and under varying conditions, pointing up a serious universal fire problem in filters that needs serious attention.

I think it important that we stress the need for good fire protection engineering design throughout ventilation systems before we get into the fire aspects of the filters themselves. An excellent guide for the over-all firesafe design of ventilation systems is the National Fire Protection Association's Code No. 90A, "Standards for the Installation of Air Conditioning and Ventilation Systems for Other than Residence Type." Most of you are familiar with the red-jacketed National Fire Codes and have used them before. I cite this particular code, and cannot overemphasize its general usefulness in design, because it would be folly to spend many thousands of dollars for fire-resistive filters and have them installed in systems that have light plywood plenum chambers, easily shattered duct work, lack of fire dampers, and all the other deficiencies that all too often prevail in these systems.

At the 1955 meeting we presented in our opinion what was the ideal criteria for a firesafe high efficiency or absolute filter for use at our AEC installations or at any installation where similar filtration is necessary.

We have revised our criteria with subsequent test experience and actual fires that have occurred. I also acknowledge the work done by Humphrey Gilbert of our Washington Safety and Fire Protection Branch who has devoted considerable time to this filter fire problem, has visited most of your facilities compiling information on the subject, and has worked closely with the manufacturers in recent months.

These criteria for a firesafe filter are premised on preventing the two fundamental effects fires in filters can produce. (1) The release of highly radioactive materials into vital buildings and areas, with subsequent decontamination costs and time delays. (2) Equally serious and sometimes overlooked is the rapid release of tremendous heat energy in confined spaces which results in wholesale fire destruction to contents and the structure itself.

Using our previous criteria as a guide we must note some fundamental corrections. We were striving, and hoping for a fully noncombustible filter. We still are, but we will use the more correct term fire-resistive filter when referring to this unit, since for the present at least we are willing to accept some combustible materials into our ideal. We also must point out that there are very high-temperature units available that can withstand temperatures in the range of 1500°F to 2000°F. We are not talking of such a filter although there is a need for such a filter. We are talking of what might be called an intermediate high-temperature filter say in the range of 500°F to 1000°F, and we will not ask for an oven test of the entire unit. Only certain components need to be oven tested.

We do ask that this filter remain substantially intact when subjected to vigorous fire and even though its filtration abilities break down that it continue to act as a barrier and not contribute to the fire.

It is our opinion that the practical criteria for a firesafe filter should be:

1. *Frame.* The frame itself should be  $\frac{3}{4}$ -in. plywood, preferably exterior grade of an impregnated fire retardant type. This type plywood is generally available and quality controlled by a federal specification and/or the U.L. labelled type. For best stability we recommend corner butt joints and screws, or rabbetted joints with double nails.

Although fire tests and actual fires indicate the wood frame was not a prime fuel, it is hoped that an acceptable noncombustible frame will be found some day that is comparable in price.

We feel the added cost of the fire retardant, and this is the impregnated not surface-painted type plywood, is justified because this is the bulk of the burnable material left in the improved unit.

2. *Filter Media.* The all-glass fiber generally used by all the manufacturers is satisfactory from a fire point. It must be capable of withstanding at least 75 per cent humidity, 10-in. water pressure differential, and have an initial capacity of 10 sq ft of contact area at 0.85-in. water gauge pressure drop. A maximum of 7 per cent binder is recommended.

Although not recently tested we believe the type A glass-asbestos paper, the type A. D. Little Co. developed for AEC in the early 1950's, will also be adequate firewise, but we have had very little experience with it.

3. *Loading, Capacity, and Efficiency.* The loading characteristics must be comparable to or better than CWS-6 media. We expect a minimum efficiency of 99.95 per cent with the standard DOP penetration of 0.05 per cent for 0.3- $\mu$  diameter homogenous particles. This would be in service in 75 per cent relative humidity air. Mr. Palmer has made some successful moisture tests with some specially made filters.

4. *Separators.* We strongly feel separators should only be of noncombustible, nonmetallic materials. Flame treated paper readily loses its fire resistance even in dry atmospheres. The thin aluminum type rapidly deteriorates in acid and wet chemistry atmospheres causing rapid loading of the filter media by the aluminum salts. Also the aluminum dividers (melting point, 1218°F.) literally collapsed in our fire tests. The mineral wool (asbestos) type separators have given very good performance firewise, also the fiber glass type, and we are confident the ceramic will be very good too. Our tests also show that in mounting the filters they should be placed so the separators are vertical, not horizontal.

Now we get to the two components that need further work and study but we have made arbitrary recommendation to expedite replacement.

5. *Adhesives.* We recommend an adhesive, that when cured shall resist a minimum temperature of 250°F for eight hours (this is a separate oven test, not as part of whole filter). If ignitable above this temperature, it must be self-extinguishing and shall meet all general operating conditions without change in physical properties and without loss of seal.

There are numerous compounds proposed and some used such as polyester resin that ignites in the range of 400°F to 600°F and when it does it burns violently. A chlorinated resin shows promise and a nitril rubber adhesive gave acceptable performance in our fire tests. A whole family of other adhesives are still to be studied.

6. *Gasket.* We have decided that the neoprene sponge rubber  $\frac{1}{4}$  in. thick is satisfactory at present mostly because of the angle iron framework in which Hanford filters are placed. A noncombustible gasket is available and quite satisfactory if competitive costwise. Naturally this gasket must cover the front and rear edges with tight butted joints at the corners.

In summary of this brief review of our criteria for a firesafe filter I might report that a purchase of over 1000 units of essentially this fire-resistive filter is now in the making. We hope to report at the next Air Cleaning Seminar our field experience with this type and its possible successes or deficiencies.

In closing I am moved to remark that I feel that my job, as a fire protection engineer, is about completed in this filter fire problem. The numerous references to fire incidents and concern for fire hazards associated with the air cleaning operation at many AEC facilities that have been made in papers presented here indicate that our first mission to promote concern for the fire problem is fulfilled. Also many of you are working on the solution to these problems. And with availability of the fire-resistive filter we mentioned as a standard commercial item almost at hand, the large filter bank fire should be a problem of the past.

# MOISTURE AND BURNING TESTS OF SPACE FILTERS

J. H. Palmer

*General Electric Company, Hanford, Wash.*

Many tests have been conducted at the Hanford Plant in an effort to obtain an all-purpose moisture- and fire-resistant space filter, capable of extremely high collection efficiency in removal of submicron particles from exhaust gases and systems.

Frequent reports of fire incidents occurring at various AEC installations, in which space filters are involved, and minor incidents occurring in our own plant, have made the need for the fire-resistant filter urgent.

Fire-resistant filters are available, but in our experience, they have broken down during the moisture tests. Some have deteriorated in actual use by "weathering" under normal atmospheric conditions. Then again, the best fire-resistant filters do not meet our high efficiency demand.

The existing fire-resistant filters contain a heavier or thicker filter medium, thus reducing the number of folds, or filtering area, per filter. This, in turn, will reduce the life of holding capacity of the filter.

Cost is another consideration. Completely fireproof filters no doubt could be fabricated but the cost per unit would be prohibitive. This is a big factor where hundreds of filters are in use.

Life or holding capacity is another big factor, as replacement of filters is a costly procedure involving many man-hours, sometimes under extremely low time limits. Extreme care must also be used when changing these filters because of endangering personnel and facilities with exposure and possible spread of contamination.

In our tests various manufacturers' products were used, the first object being to determine the available filter with the highest moisture resistance quality consistent with the high filtration qualities required. Flow capacity, construction, original pressure drop, and filtering area, were also taken into consideration.

One filter withstood our moisture tests in an outstanding manner. It met all requirements demanded of this type filter.

This resulted in our requesting the manufacturing company to modify their standard filter to the extent that the wood frame be fire resistant according to federal specifications and that the separators be of noncombustible material. Corrugated aluminum separators were disqualified.

As a result of previous tests of various manufacturers' products, this company's filter was chosen for development because of its better over-all moisture-resistant qualities, in addition to its equal or better filtering quality and construction.

This specially constructed filter is the best moisture-proof and fire-resistant filter so far tested by us. Tests to which this filter have been subjected are admittedly severe, but we feel were justified by the results obtained.

## 1 MOISTURE TEST APPARATUS

The test apparatus consists of a stainless-steel chamber, similar to a regular fan casing, with intake and discharge ducts. A rack is provided to hold filters up to and including a 24- by 24- by 11½-in. size. Test ports are installed in the intake and discharge ducts and also at various locations in the chamber for purposes of measuring static pressures, drops, and flows. Wet steam is admitted at the intake where it is mixed with the incoming air to the filter or filters being tested. The apparatus is connected to an Aladdin Heating Co. type E.X. fan, with a rated capacity of 2000 cfm at 4 in. wg standard pressure (see Figs. 1 and 2).

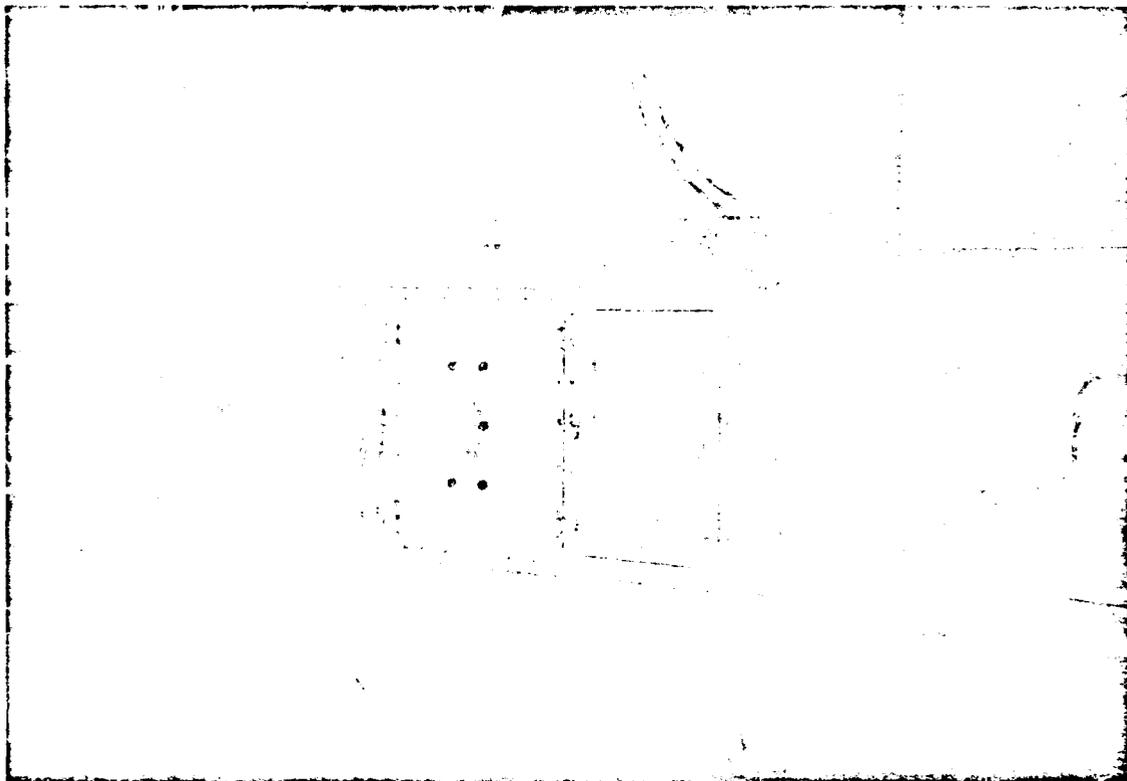


Fig. 1 — Moisture and capacity test apparatus.

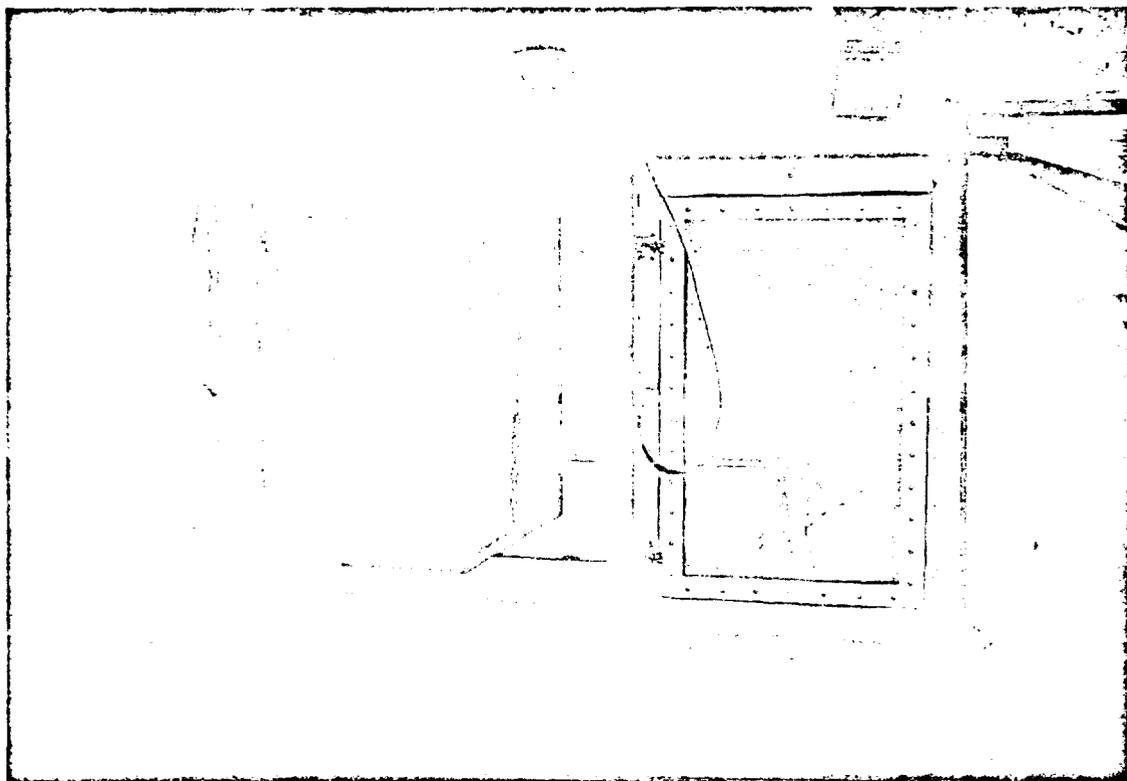


Fig. 2 — Moisture and capacity test apparatus, showing filter in position for testing.

## 2 BURNING TEST APPARATUS

This simple apparatus consists of a 1-ft 2-in. by 20-ft tube with transition from a 2-ft by 2-ft by 1-ft 8-in. open end box for holding the filter under test, fabricated in black iron. A damper to control flow quantity and a test port for static pressure and flow measurement are provided.

The tube is attached to a Lamb air mover, manufactured by the Lamb Mine Safety Appliance Company. The mover is a venturi, No. SE-63. The motive power is supplied by a large 90-lb air compressor.

A loose, fire-brick furnace was erected at the filter box intake. Excelsior and shredded paper were used as combustion material. The air flow passing through the filter was controlled at 1050 cfm, with a velocity of 260 fpm. Six thermocouples were installed at various locations on the filter, so that temperature readings could be taken during the course of the tests (see Fig. 3).

Photographs were taken at various stages of the tests and are included in this report.

Combustion tests of the components of two manufacturers' filters were conducted by the Industrial Hygiene group, under the direction of F. E. Adley, the results of which corroborate our findings.

## 3 MOISTURE TEST

To speed the test and to hasten possible breakdown of the components, the filter was alternately exposed to completely saturated air for periods of 48 hr and drying periods of 24 hr, with a continuous flow passing through the filter for the duration of the test. The wetting and drying cycles were repeated twice.

At the start of the test, with a dry filter, an air flow of 1200 cfm was obtained with a pressure drop across the filter of 1.10 in. wg. The gradual saturation of the filter reduced the flow to 107 cfm and increased the pressure drop to 4.5 in. wg.

At the end of each drying cycle the pressure drop would automatically return to the original 1.10 in. wg with its corresponding flow quantity.

During and at the end of the test the filter was carefully inspected for breakdown and deformation. The only effect noted was a slight compression of medium where it folded over the separators on the intake side of the filter.

This filter, after passing through the above test, and being thoroughly dried out, was later used in a preliminary burning test, the results of which are described in this report (see Figs. 4 and 5).

The other filter tested completely failed on the first wetting cycle.

## 4 BURNING TESTS

### 4.1 Test 1, Preliminary

A preliminary test was conducted, using the filter which had passed through the moisture tests, to test out the apparatus and to perfect the test procedure.

This 24- by 24- by 11½-in. filter, one of the originally modified filters, was constructed as requested. The frame was composed of plywood which had been externally treated with fire-protective coating. (Since receiving this filter, this manufacturer has further improved the filter by constructing the frame of impregnated plywood.)

As this was a preliminary test, extreme and minimum firing was tried. Small handfuls of excelsior were placed against the filter and fired with little or no result. The amount of combustibles were finally increased so as to cover approximately three-fifths of the filter as shown in Fig. 6.

The firing material in this test was placed directly against the filter and fired. Within seconds the temperature at a point approximately 8 in. from the bottom center of the filter was

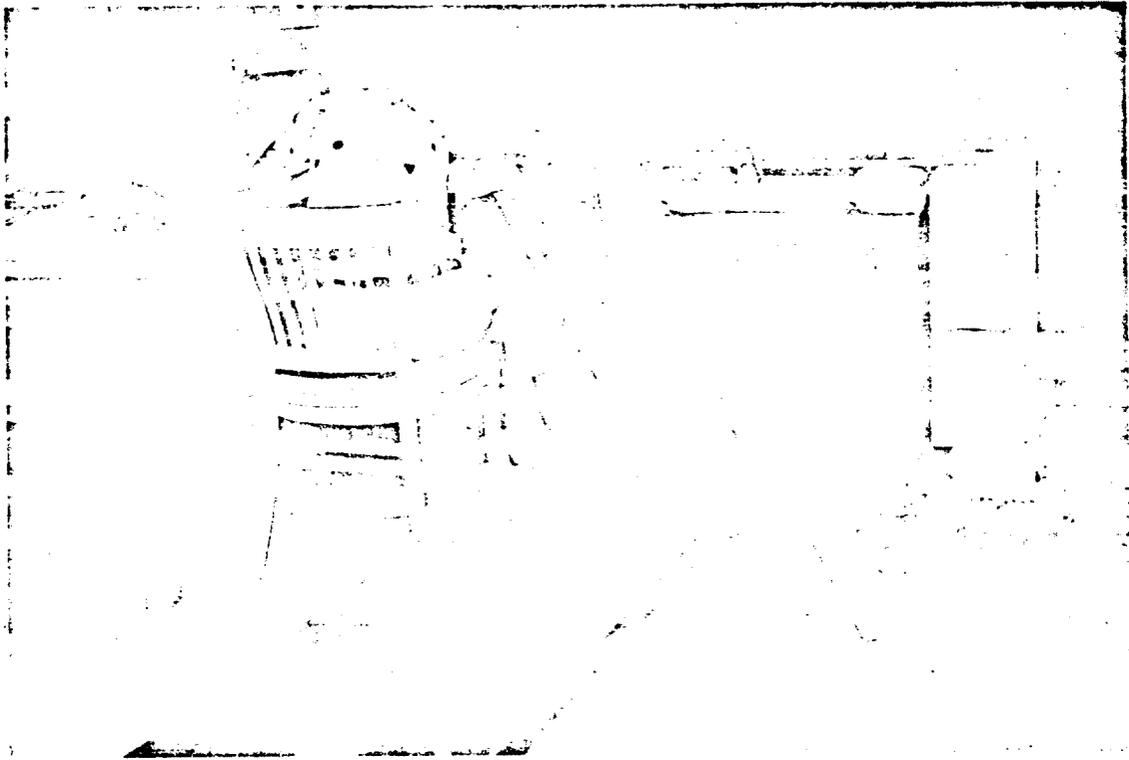


Fig. 3—Downstream side of burning test apparatus, showing multiple temperature recorder.

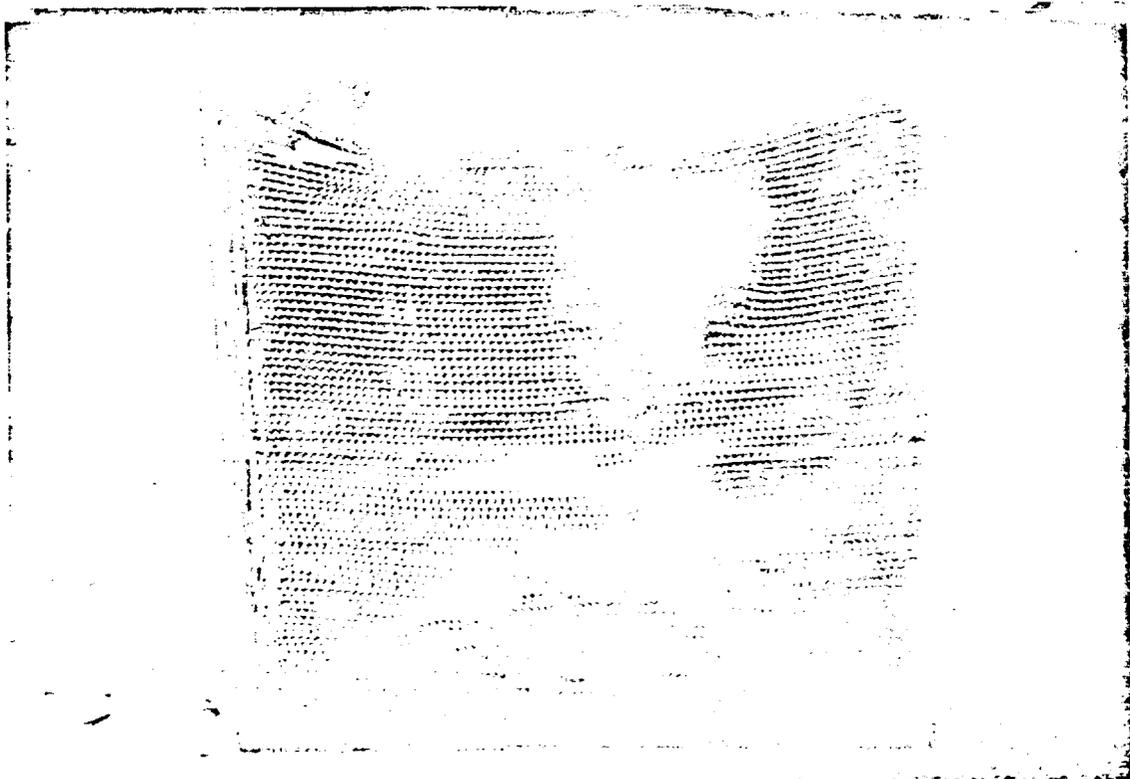


Fig. 4—Result of fire test on specially modified filter. Side exposed to fire. Filter was constructed of externally fire treated wood frame and passed through two burning tests in addition to moisture tests.

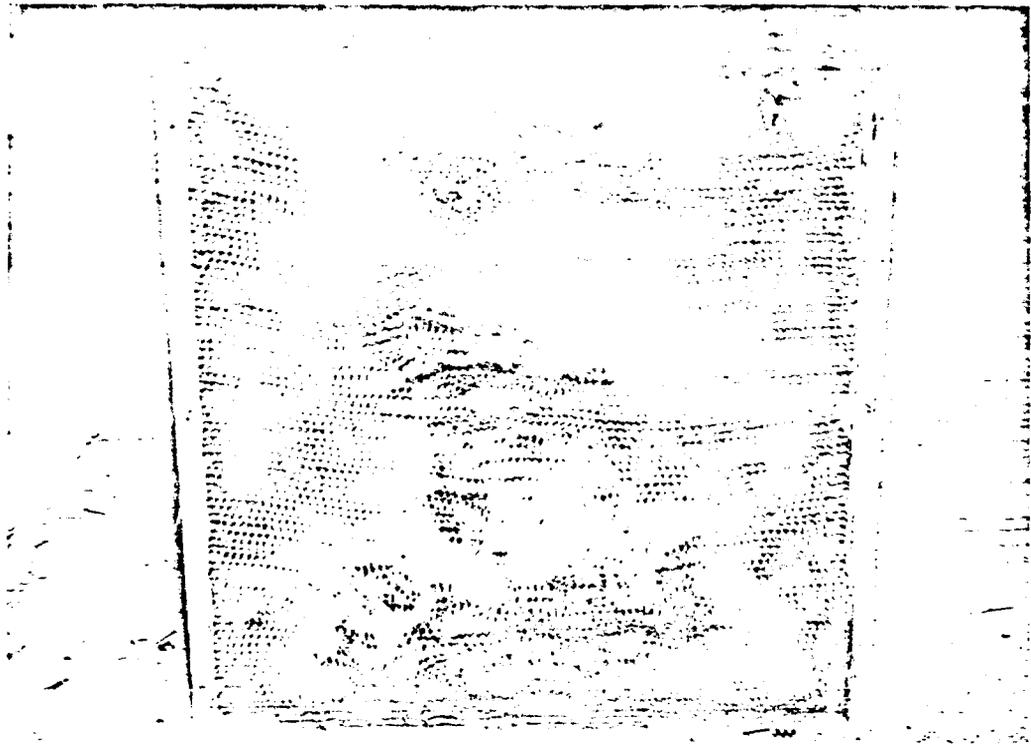


Fig. 5—Same filter as in Fig. 4, showing downstream side of filter.

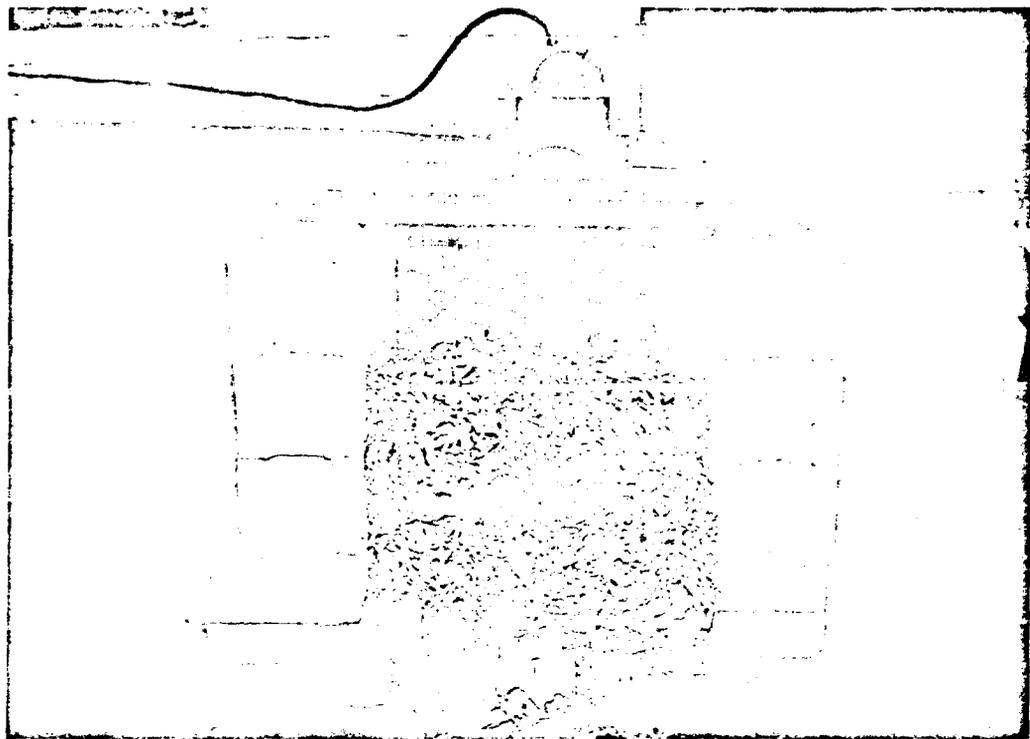


Fig. 6—Impregnated wood frame filter immediately before firing. Chicken wire screen, 4-in. mesh, not present in previous tests.

read at 950°C, as sensed by the thermocouple located at this point (see Fig. 7). The next highest temperature, 600°C, was reached at a point approximately 8 in. from the top center of the filter. The temperature of the wood frame at the bottom of the filter was recorded at 150°C. The temperature of the adhesive was measured at 185°C and started to smoke at this temperature. Other point temperatures were insignificant.

It will be noted (see Figs. 4 and 5) that the wood frame at the bottom and center of the filter has been completely burned through and that the filter medium is badly charred at the extreme burning point. Also it can be noted that the side frame is charred but not burned through. This was no doubt due to angle irons being placed on the sides of the filter just barely covering the gasket.

To further perfect the test, this same filter was turned 180° and refired. This time a piece of masonite was placed in front of the gasket material at the bottom of the filter (top of filter in previous test). The exhibits show that this prevented the frame from burning through even though it was subjected to the same temperature and conditions as in the previous tests.

Note that the top of the filter in Figs. 4 and 5 was the bottom of the filter in the first burn test.

We feel that this preliminary test was of considerable value, inasmuch as it demonstrated the significant comparison between fire-treated wood frames and impregnated wood frames, as shown in the tests which followed.

#### 4.2 Burning Test No. 2

The filter used in this test was constructed of the same materials as the filter in the previous tests, except that the frame was constructed of impregnated wood.

This test was nearly identical to the first test, the exceptions being: a 4-in. chicken wire screen was placed approximately 6 in. from the face of the filter and angle irons were placed at top and bottom of the filter as well as at the sides.

The chicken wire screen kept the bulk of the firing material from actual contact with the filter, but not the flames or burning fragments. The placing of the angle irons around the filter closely corresponds to actual installation.

Thermocouple sensing lines were installed as in previous tests, except that No. 3 was placed approximately 3 ft downstream from the filter. Combustibles containing shredded paper and excelsior were placed in the firing chamber as in the previous tests (see Fig. 4) and fired. Figures 8 and 9 were taken during this test.

As in the previous test, the highest temperature (760°C) recorded was at point No. 1, approximately 8 in. from the bottom of the filter, and the next highest (650°C) at point No. 2, approximately 8 in. from the top of the filter. Temperature of the downstream air was read at 410°C at maximum. Point No. 5 indicating temperature of the adhesive showed 185°C, and the wood frame at the bottom of the filter reached a temperature of 260°C.

The accuracy of the temperature readings is not positive as the multiple recorder was hand operated. It is quite possible that higher temperatures were attained at the various points, but were not detected.

This filter withstood the test in an excellent manner as shown in Figs. 10, 11, and 12. Figure 12 shows the main points of break-through. A flash bulb held behind the filter intensifies the holes caused by charring and air velocity.

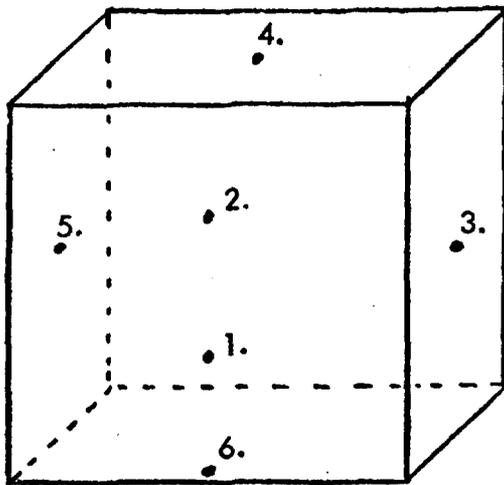
The impregnated wood frame did not break into flame. Also, it held its shape and dimensions. The rubber gasket was shriveled at the edges, but where covered by the angle irons showed little effect. The adhesive bubbled, but did not flow or flame. The adhesive did show signs of charring where exposed to extreme temperatures.

#### 4.3 Burning Test No. 3

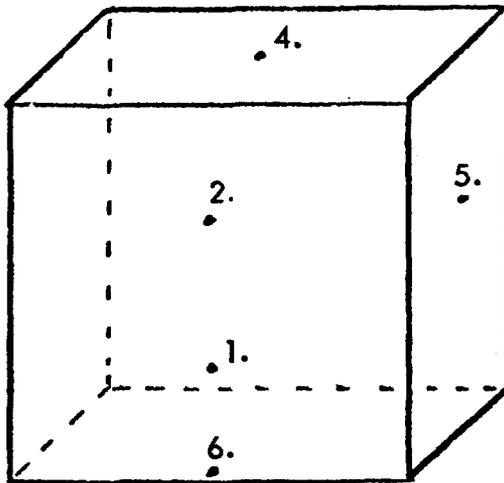
This test was conducted to compare the effects on the modified filter with that on a filter which has been accepted as being fireproof.

Figures 13 and 14 graphically show the comparison.

(Text continues on page 65.)



Thermocouple Locations—1st Test.



Thermocouple Locations—2nd Test.  
Point No. 3 Placed In Downstream Duct

Fig. 7—Thermocouple locations.

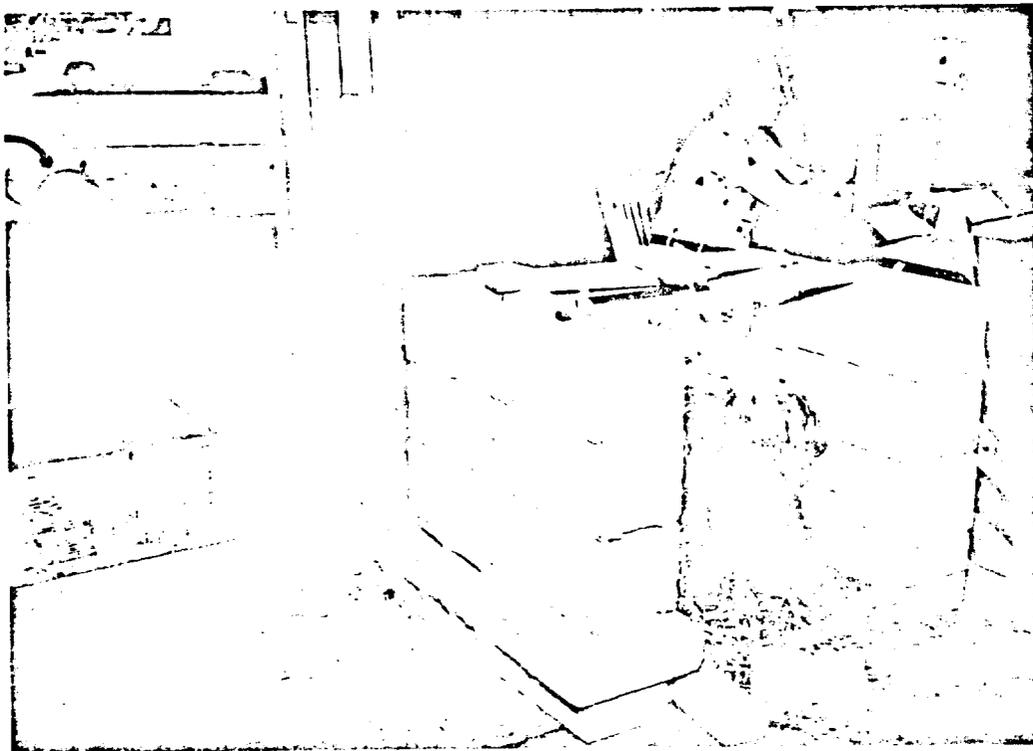


Fig. 8— Same filter as in Fig. 6 with fire started.

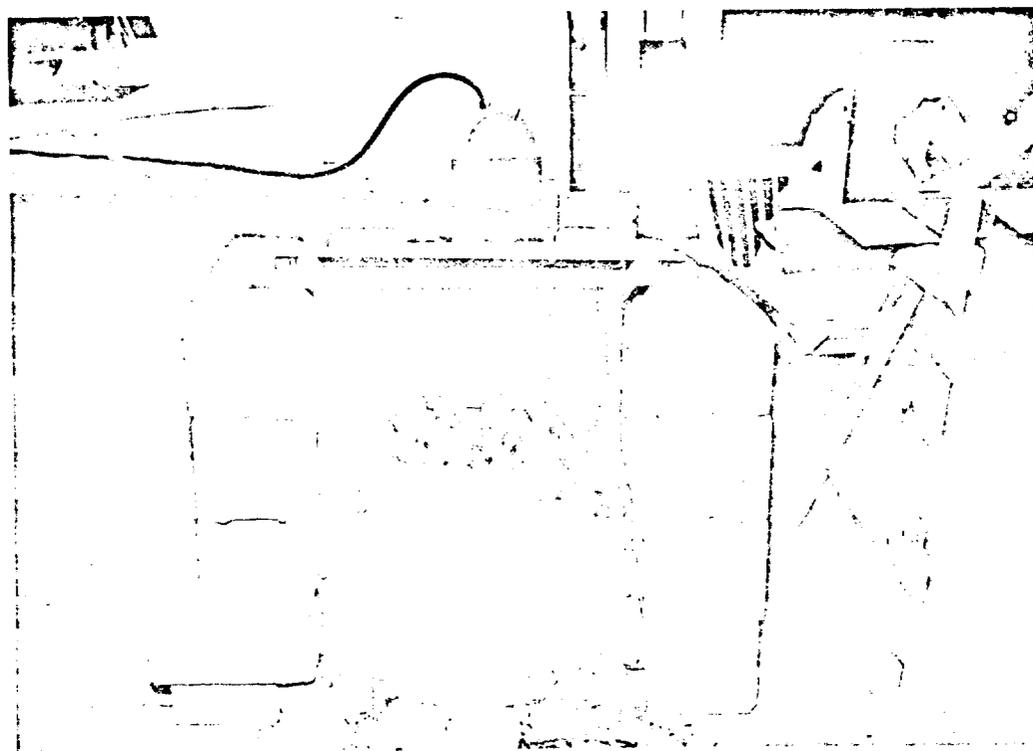


Fig. 9— Same filter as in Fig. 6 with fire half burned out.

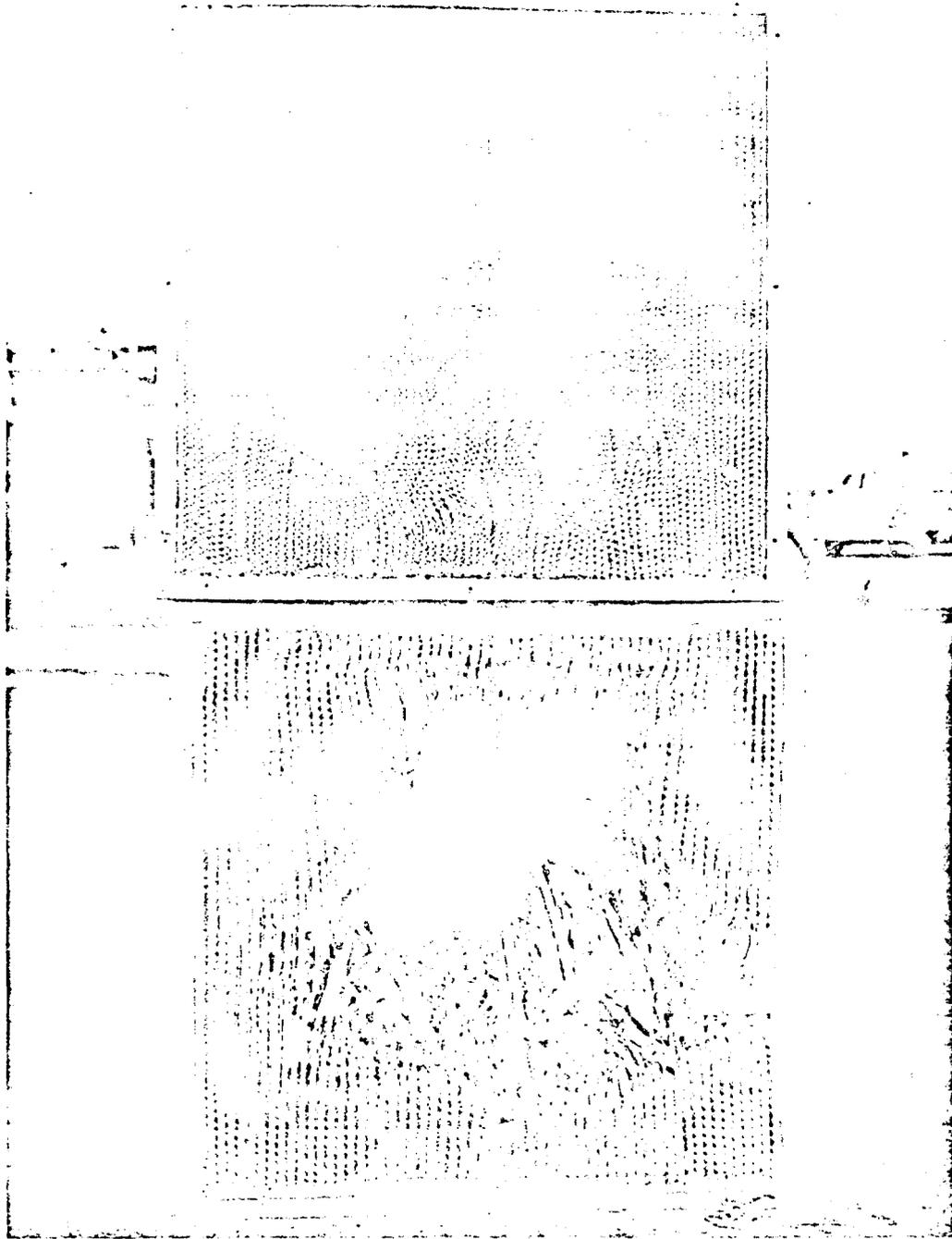


Fig. 10 — Comparison of filters after test. Top, modified filter; bottom, accepted fireproof filter. Sides exposed to fire, accepted fireproof filter upside down to position in test. Gaskets on both filters show little or no effect from burning test.

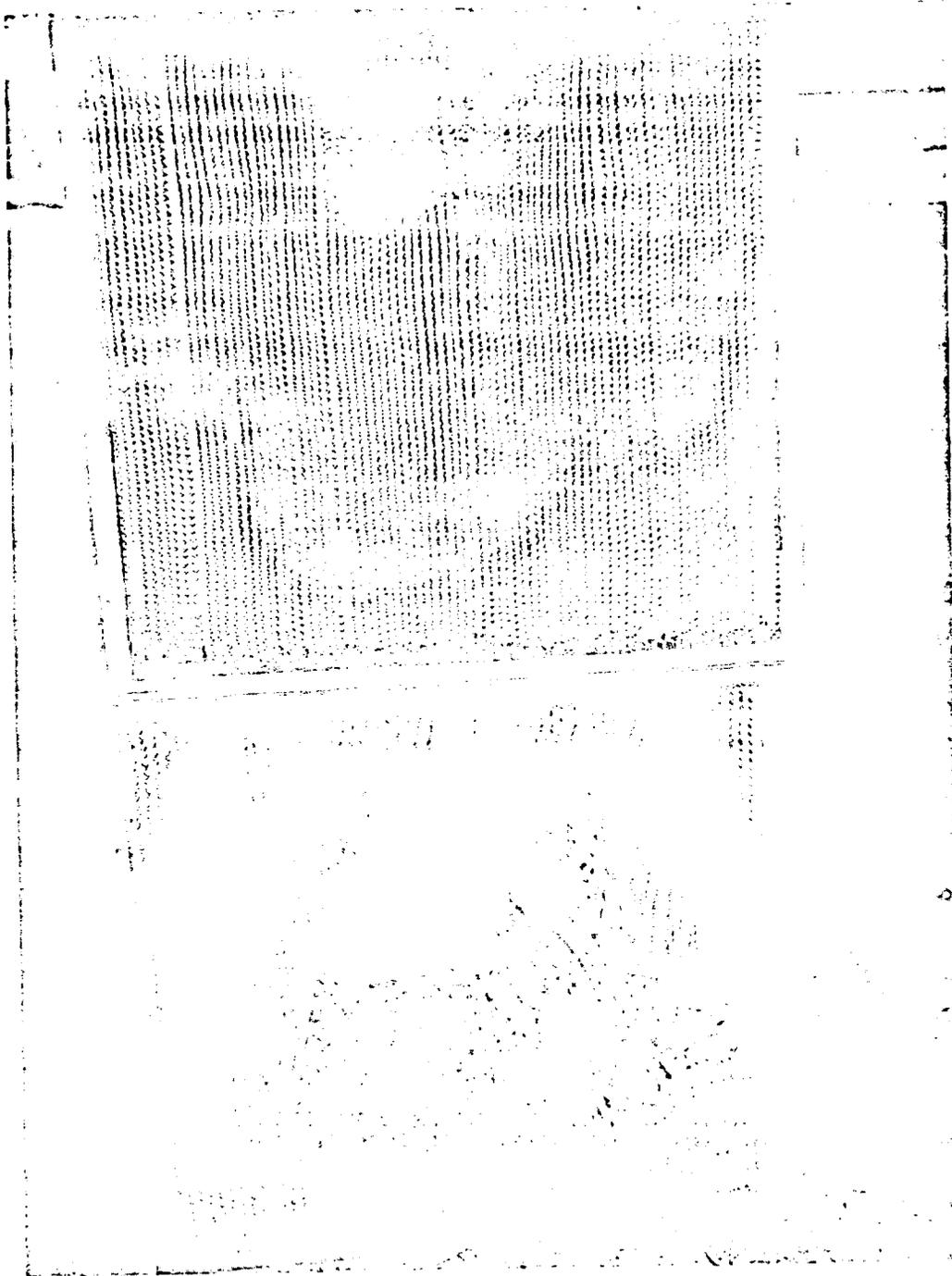


Fig. 11— Comparison of same filters as in Fig. 10, showing downstream side of filters. Both filters are upside down to positions in test. Gasket is gone on modified filter where exposed to extreme heat; no effect on other gasket.

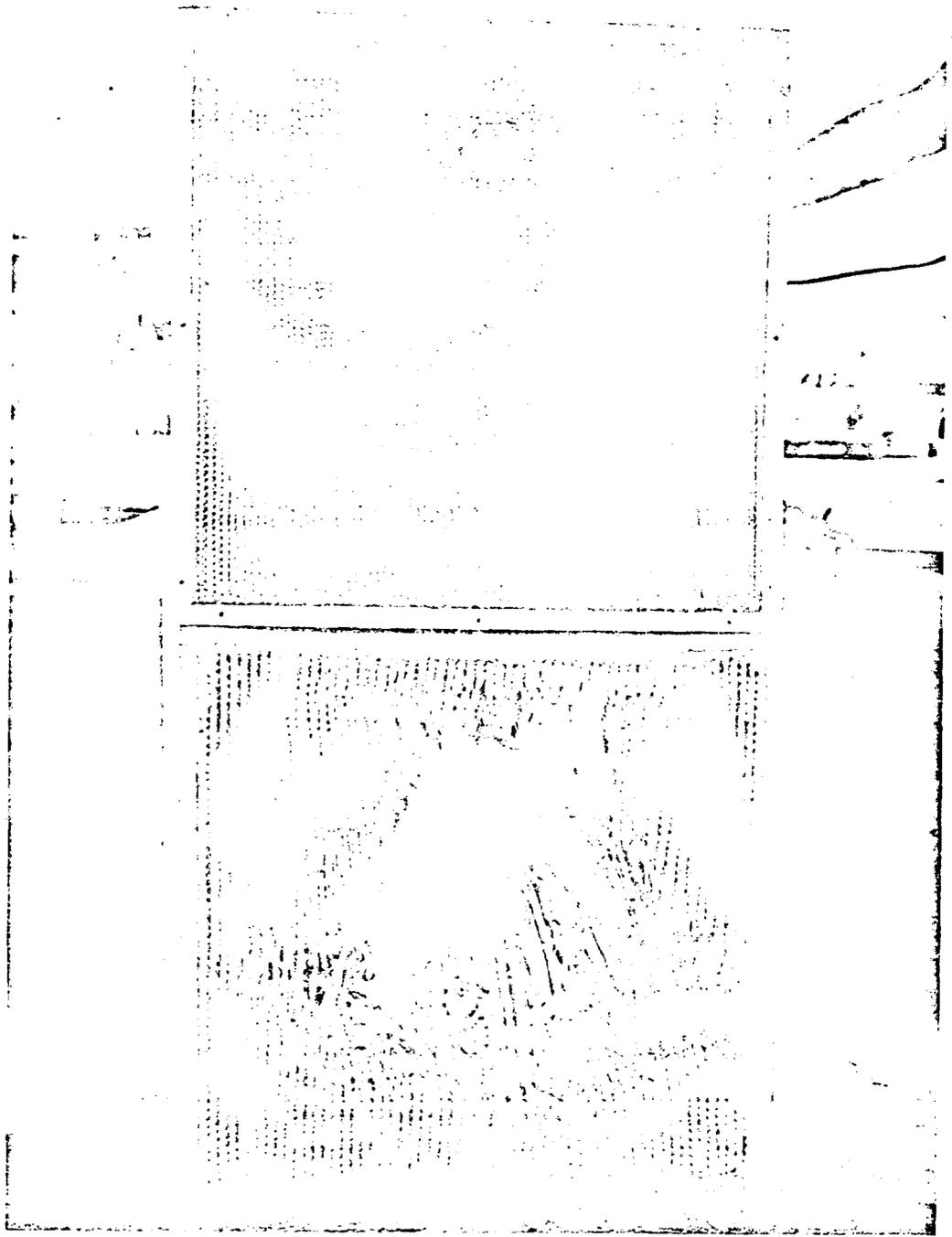


Fig. 12 — Same filters as in Fig. 10 with flash bulb held at back of modified filter to make breakthrough more pronounced — two white spots.

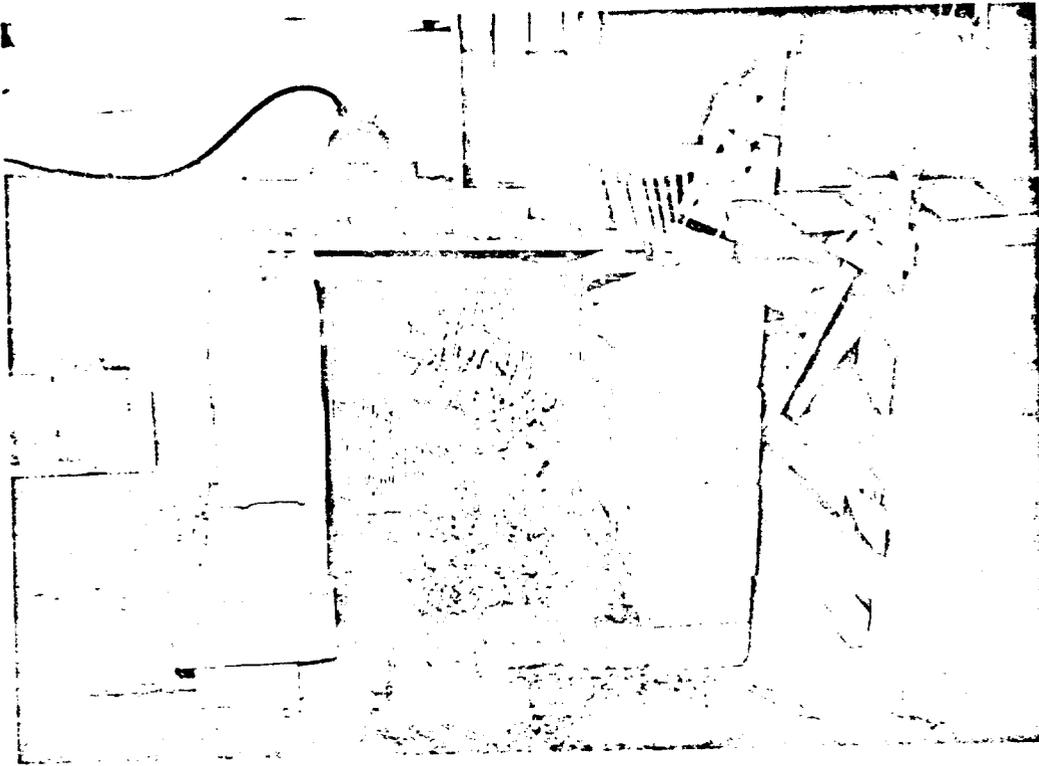


Fig. 13—Accepted fireproof filter under test with fire nearly burned out. Note hole in filter.

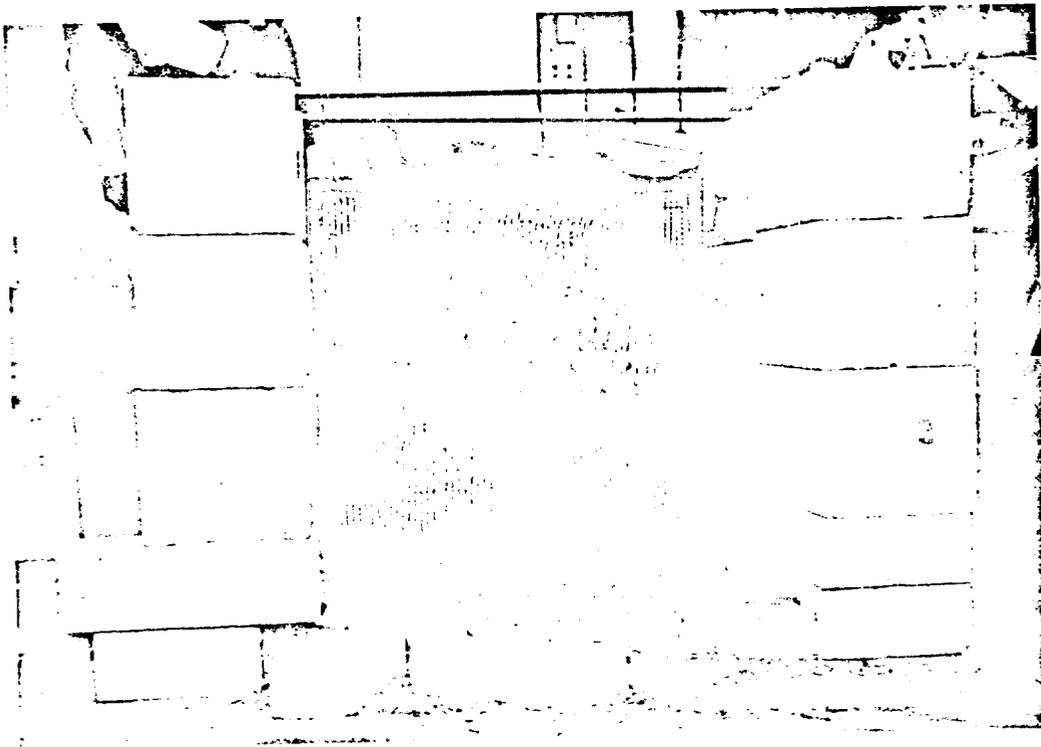


Fig. 14—Same filter as in Fig. 13 immediately after fire was out.

The accepted fireproof filter was subjected to as near as possible the same conditions as the previous filters under test. The same amount of combustibles was applied and the same air flow quantity maintained.

This filter decomposed so rapidly that very few temperature readings were taken. The aluminum separators melted within seconds and without the support of the separators the filter medium disintegrated. Wads of aluminum "wool" were found at the extreme end of the downstream duct, near the venturi tube.

## APPLICATION OF FIRE-RESISTANT AIR CLEANING FILTERS AT HAFPO

F. E. Adley

*Hanford Atomic Products Operation*

The need for fire-resistant filters for air cleaning at Atomic Energy Commission installations where radioactive air contamination is involved has been evident for many years. Excessive amounts of airborne radioactive substances, which may be present in ventilation air during a building or process fire, or from the normal accumulation or loading of radioactive substances on filter faces, indicate the necessity for these filters to remain intact during fires. The absence of such control provides a serious source of building and environmental contamination as well as potential exposures to humans. Combustible filters for cleaning ventilation air of radioactive particulates have periodically been the source of noteworthy environmental contamination, expense, and time loss.<sup>1,2</sup> Such filters, however, due to their acceptable air cleaning performance characteristics, have been and are still used widely for such applications.

At Hanford, Absolute filters are used in numerous installations at production and laboratory sites. These two applications differ notably, particularly with respect to the quality of the filter loadings encountered. At process facilities such filter systems are normally designed to remove fairly well identified contaminants. That is, identified to the extent that the particulates, for example, may be predictable fission products at known concentrations. This aspect was covered well by Mr. Palmer's presentation. The use of these same filters for research and development laboratories subjects them to a potential loading of almost any conceivable combination of pyrophoric, corrosive, or toxic chemicals in addition to the radioactive loading. Such loadings can produce any degree of fire hazard up to those of spontaneous ignition from substances such as perchlorates. Two instances of laboratory fires at Hanford exemplify this problem.

The first instance involved an experiment wherein 1 cc of anthracene was being heated in a glass flask by a Bunsen burner. During the course of this heating the vapors forced the stopper from the flask and some of the material apparently entered the air stream. This particular filter installation comprised a 2-ft by 2-ft by 11½-in. CWS filter unit preceded proximately by a glass fiber roughing filter. Very little time elapsed before the filters were burning and were extinguished with difficulty. This system is all stainless steel with the exception of the filters, consequently, the fire was confined to the hood assembly.

The second fire was in an identical hood and originated from the wet-ashing of vegetation in concentrated nitric acid. On reaching dryness for the third time, the rapid oxidation of the nitrated organics resulted in a flash fire. Once again the filter unit was quickly ignited and burned with such vigor that the stainless steel ducts in the attic space above were aglow for several feet. Considerable difficulty was encountered in extinguishing this filter fire although it was similarly confined to the hood assembly.

Several observations were apparent in these two instances with respect to the factor of flammability.

1. Filter units employed in ventilating systems should be constructed of nonflammable materials. This also applies to roughing filters.
2. It is imperative that all components of the exhaust ventilating system and all attachments thereto should be constructed of nonflammable materials.
3. If design permits, the Absolute and roughing filters should be separated by several feet since organic substances such as lint can accumulate on the roughing filter and are capable of being ignited.
4. The behavior or intensity of combustion in an airstream having a velocity of several hundred feet per minute is tremendously accelerated. This increases combustion temperatures, with attendant problems, and additionally increases the problem of extinguishing the fire.

These filters are being replaced as the development and supply of fire-resistant Absolute filters permits.

To understand better various applications of fire-resistant filters at Hanford, typical filter units were subjected to full-scale burning tests, as discussed by Mr. Palmer, and in addition, components were submitted to laboratory combustion tests by the Industrial Hygiene Operation in August 1956. Most of the tests were conducted in a muffle furnace in the presence of air unless noted otherwise. The findings from tests on two makes of filters are presented in Table 1.

Table 1—FINDINGS FROM TESTS OF TWO MAKES OF FILTERS

Filter	Component	Remarks
A	Impregnated wood frame	Charring commenced and smoking at 480°F. Started to turn to white ash at 1020°F. Complete ashing at 1440°F. Did not flame at any time.
	Fiberglas filter medium	Flamed briefly when ignited, probably due to binder. Darkened at 760°F, then turned white as carbonaceous material ashed. At 1470°F it shrank to about 50 per cent of its original size.
	Asbestos separator	Darkened to brown color in a Meeker burner flame. Became extremely brittle at 1700°F, but did not change its shape.
	White sponge rubber gasket	Material becomes tacky and smokes at 360°F. Melts at 540°F, hardens into a dark solid at 760°F, and turns to a white ash at 840°F.
	Adhesive	Becomes tacky and smokes at 360°F. Charred and bubbled at 630°F. Turns to dark, firm mass at 750°F, and to a white ash at 840°F.
B	Fiberglas filter medium	Darkened at 760°F, probably due to charring of binder. Turned white as temperature rose. At 1220°F it had shrunk about 50 per cent in size.
	Aluminum separator	Melted at about 1200°F.
	Black sponge rubber gasket	Shrinks under heat but does not smoke or liquify up to 1400°F, at which temperature it becomes a white ash.

Mr. Palmer's burning tests indicated that the core of these filter units was probably the area of the highest temperatures. This would mean that in most instances the filter media and separators would probably be subjected to the highest temperatures. The gaskets, in their semiprotected location, are apparently exposed to the least heat, while the frame and adhesive would be at some intermediate temperature. If this assumption is correct, the weakest component would be the adhesive which breaks down and loses its supportive quality and probably its sealing capacity at approximately 360°F.

Although fireproof Absolute filters of limited capacity are currently available, those having sufficient capacity for large-scale applications are impractical at this time, due primarily to the technological stage of development. Nevertheless, continued development and research will in time produce filters that are sufficiently fire-resistant to confine most ventilation system fires to the filter assembly with minimal loss or damage. This will permit a considerable saving to industry by minimizing fire losses and will be a noteworthy milestone, particularly, from the standpoint of air cleaning systems for radioactive substances.

## REFERENCES

1. The U. S. Atomic Energy Commission, Serious Accidents, Issue No. 110, Nov. 8, 1956.
2. The U. S. Atomic Energy Commission, Accident and Fire Prevention Information, Issue No. 6, Feb. 21, 1955.

# DESIGN AND CALIBRATION OF AN IMPROVED CASCADE IMPACTOR FOR SIZE ANALYSIS OF AEROSOLS

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## 1 INTRODUCTION

A rapid and reliable method for determining the particle-size distribution and concentration of aerosols is essential for general aerosol and air cleaning studies. Although the physical properties and effectiveness of sprays and aerosols are determined by their particle-size distribution, accurate data on size are seldom available. Some of the numerous experimental methods of determining size distributions of aerosols are: (1) microscopic examination of particles collected on slides or in cells, (2) freezing of drops in a spray followed by sieving, (3) direct photographic methods, (4) other optical methods based on the scattering or absorption of light, (5) electronic and radioautographic techniques, and (6) impaction methods. Each of these methods has its advantages and disadvantages and none is entirely satisfactory.

The most commonly used of the six above mentioned methods is the microscopic technique. A sample of an aerosol is collected by passing a slide through the aerosol. Each individual particle on the slide is then measured. Not only is this method tedious and time consuming, but it is also biased in favor of the larger particles because the smaller particles will tend to pass around the slide.

The purpose of this paper is to describe an improved cascade impactor for the size analysis of aerosols and the methods by which it was calibrated.

## 2 PRINCIPLE OF THE CASCADE IMPACTOR

A cascade impactor is a device which separates aerosols into various size classes. The impactor operates on the principle that particles in a moving air stream will impact upon a slide placed in their path provided that the inertia of the particles is sufficient to overcome the drag exerted by the air stream that must pass around the slide. One of the pioneers to use this principle to classify aerosols was K. R. May.<sup>1</sup>

Figure 1 is a schematic drawing showing how the cascade impactor classifies particles of different sizes. As the moving particles approach the slide in the impactor, the larger

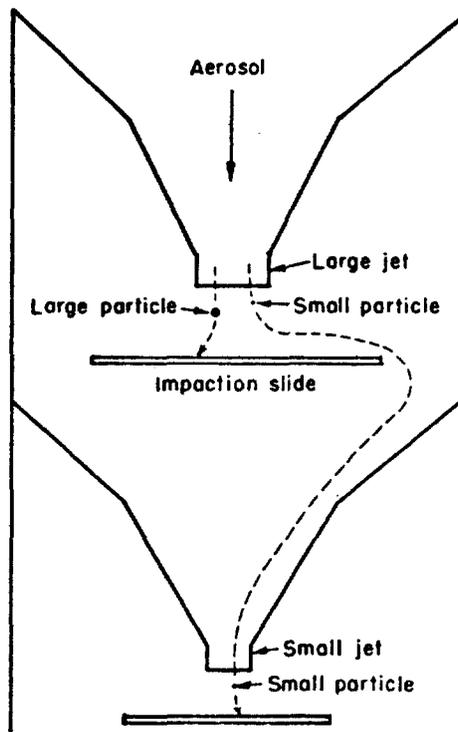


Fig. 1—Schematic diagram showing principle of the cascade impactor.

particles will impact on the slide while the smaller particles are carried around the slide by the drag force of the air stream. Since each jet is smaller than the preceding one, the velocity of the air stream is increased as the aerosol passes through various stages of the impactor. Consequently, smaller size fractions of particles are impacted on each successive slide, and a complete size classification of the particles is obtained.

### 3 IMPACTOR THEORY RELATING TO THE DESIGN

The design of the previous Battelle impactors was based on the assumption that the jet-to-slide clearance is infinite, and that impaction takes place on a slide of infinite extent. Moreover, it was assumed that gravitational and electrical effects are small compared with the inertia effects. Under these assumptions, the impaction process may be characterized by a single impaction parameter.

$$\psi = \frac{\rho_p V D_p^2}{18 \mu D_j}$$

where  $\rho_p$  denotes the density of the aerosol particle,  $V$  the velocity of the particle relative to the surrounding fluid,  $D_p$  the diameter of the particle,  $\mu$  the viscosity of the fluid, and  $D_j$  the diameter of the jet. The impaction parameter is easily derived by the techniques of dimensional analysis. Moreover, the derivation shows that the impaction process may be expected to be characterized by a single parameter only if the jet-to-slide clearance is infinite, and if the impaction slide is infinite in extent. Otherwise, the efficiency of impaction may be a function of the usual impaction parameter and an additional dimensionless ratio of lengths.

A theoretical study by Davies and Alyward<sup>2</sup> has shown that jet-to-slide clearance less than the jet diameter may be expected to yield a more desirable classification with a rectangular jet.

It was suggested that the design of new impactors should be based on a narrow jet-to-slide clearance to obtain better separation of sizes. As shown in a technical report for Fort Detrick prepared by Einbinder,<sup>3</sup> each stage of the impactor may be designed based upon the value of the impactor parameter corresponding to 50 per cent impaction. Ranz and Wong<sup>4</sup> found that the impaction parameter ( $\psi$ ), corresponding to 50 per cent impaction for round jets, was about 0.14. However, this value holds for a jet-to-slide clearance which is effectively infinite. For smaller jet-to-slide clearances, the value of the impaction parameter would be expected to decrease appreciably.

#### 4 EXPERIMENTAL DETERMINATION OF IMPACTION EFFICIENCIES

As a result of a study of the impaction theory, the effects of varying the jet-to-slide distance for round jets were studied. Round jets were used because of their ease of fabrication.

Figure 2 is a plot of the experimental impaction efficiencies,  $\eta$ , for round jets as a function of the impaction parameter,  $\psi^{1/2}$ . The figure shows how the sharpness of classification was improved by reducing the jet-to-slide clearance from approximately three to three-eighths of the jet diameter. These data for the small jet-to-slide clearance were obtained by microscopic count and by colorimetric analysis of the material collected on the slides. Essentially mono-dispersed aerosols were produced by the atomization of dyed dibutyl phthalate with a spinning disk operating at 80,000 rpm. The impaction parameter was varied by changing the volume flow rate while holding the other factors constant. Because of the low volume flow rate required to make the curve asymptotic with zero efficiency of impaction, it is believed that gravitational effects caused particles to impact on the slide for the low values of the impaction parameter.

The results of these tests indicated that it would be desirable to design an impactor with small jet-to-slide clearances. Because the wall losses for these tests were higher than desired, tests were run to determine the effects of wall-to-slide distance on wall loss.

#### 5 EFFECT OF WALL-TO-SLIDE DISTANCE

An aerosol particle that is slightly too small to impact on a slide and, consequently, passes around and near the edge of the slide, tends to strike the inner wall of the cascade impactor. This phenomenon, which is called aerodynamic wall loss, becomes more probable when the diameter of the impaction slide approaches the inside diameter of the cascade impactor. The distance between the inner wall of the impactor and edge of the slide is equal to the difference in the radii of the inner wall and of the slide, and is called the wall-to-slide distance,  $D_{ws}$ .

Figure 3 is a plot of the amount of aerodynamic wall loss as a function of the wall-to-slide distance. Circular jets and circular slides were used, and the sampling rate was 12.5 liters/min. The impactor was mounted in a vertical position during these tests to reduce the likelihood of fall-out on the walls by gravity. These tests were run with particles 12 and 16  $\mu$  in diameter, which is the suggested cutoff diameter,  $D_p$ , for the first stage of the small-scale impactor.

Figure 4 is a replot of the same data showing the relation between the efficiency of impaction on the walls,  $\eta_w$ , and the wall-to-slide distance. The term,  $\eta_w$ , is defined as that fraction of the total weight of particles of a given size which passes around a slide and deposits on the wall.

The following empirical equation was developed to fit the bulk of the data obtained in these experiments.

$$\eta_w = \left[ e^{-(0.00428 D_{ws} \times D_s^2 \times Q^{1/2})} \right] \left[ \frac{D_p^2 Q^2}{10800 D_j^3} \right]$$

where  $D_{ws}$  denotes the wall-to-slide distance in centimeters,  $D_s$  denotes slide diameter in centimeters,  $Q$  denotes the volume flow rate in liters per minute,  $D_p$  denotes the particle diameter in microns, and  $D_j$  denotes the jet diameter in centimeters.

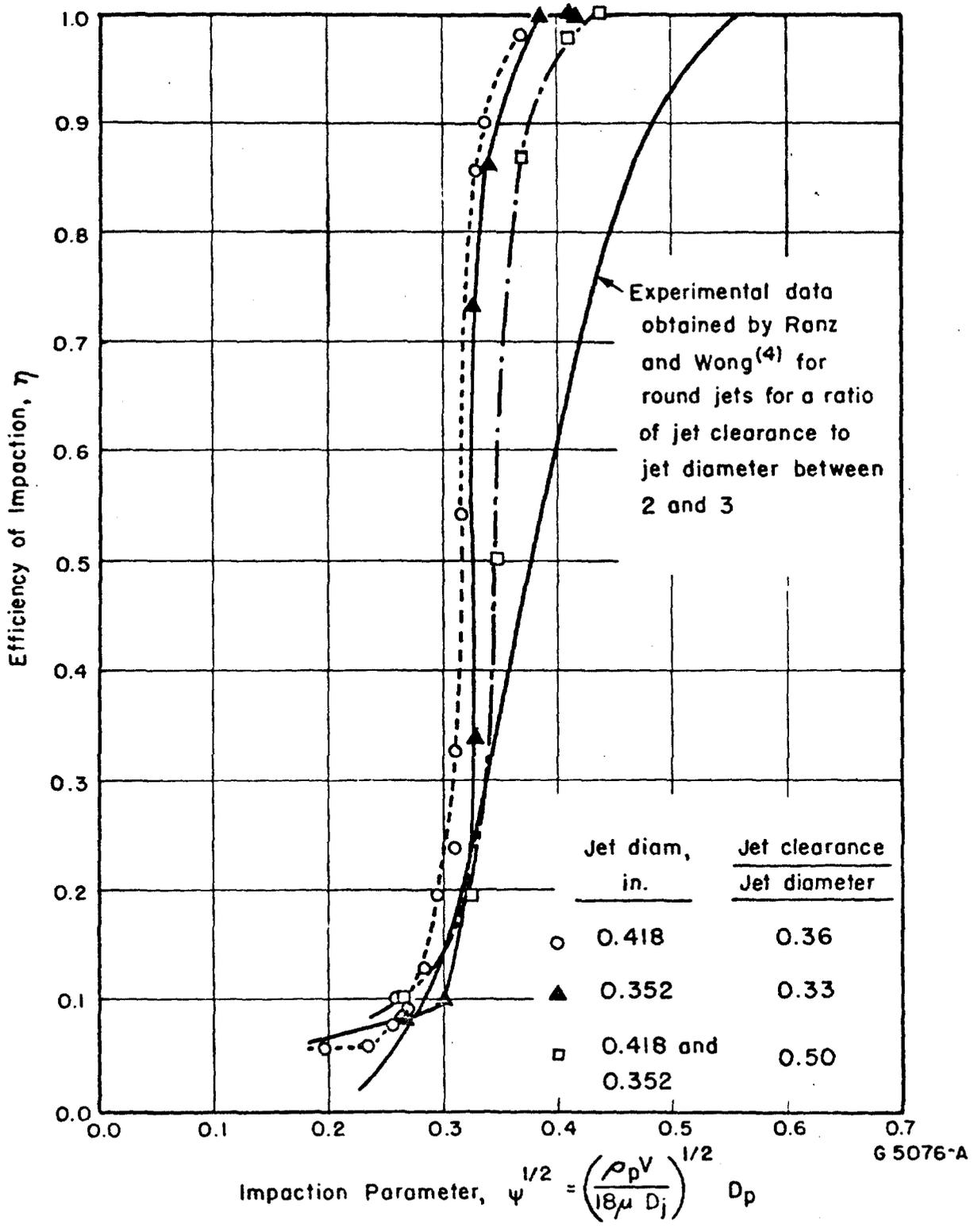


Fig. 2—Impaction efficiency as a function of the impaction parameter for circular aerosol jets impinging on flat 25 mm slides.

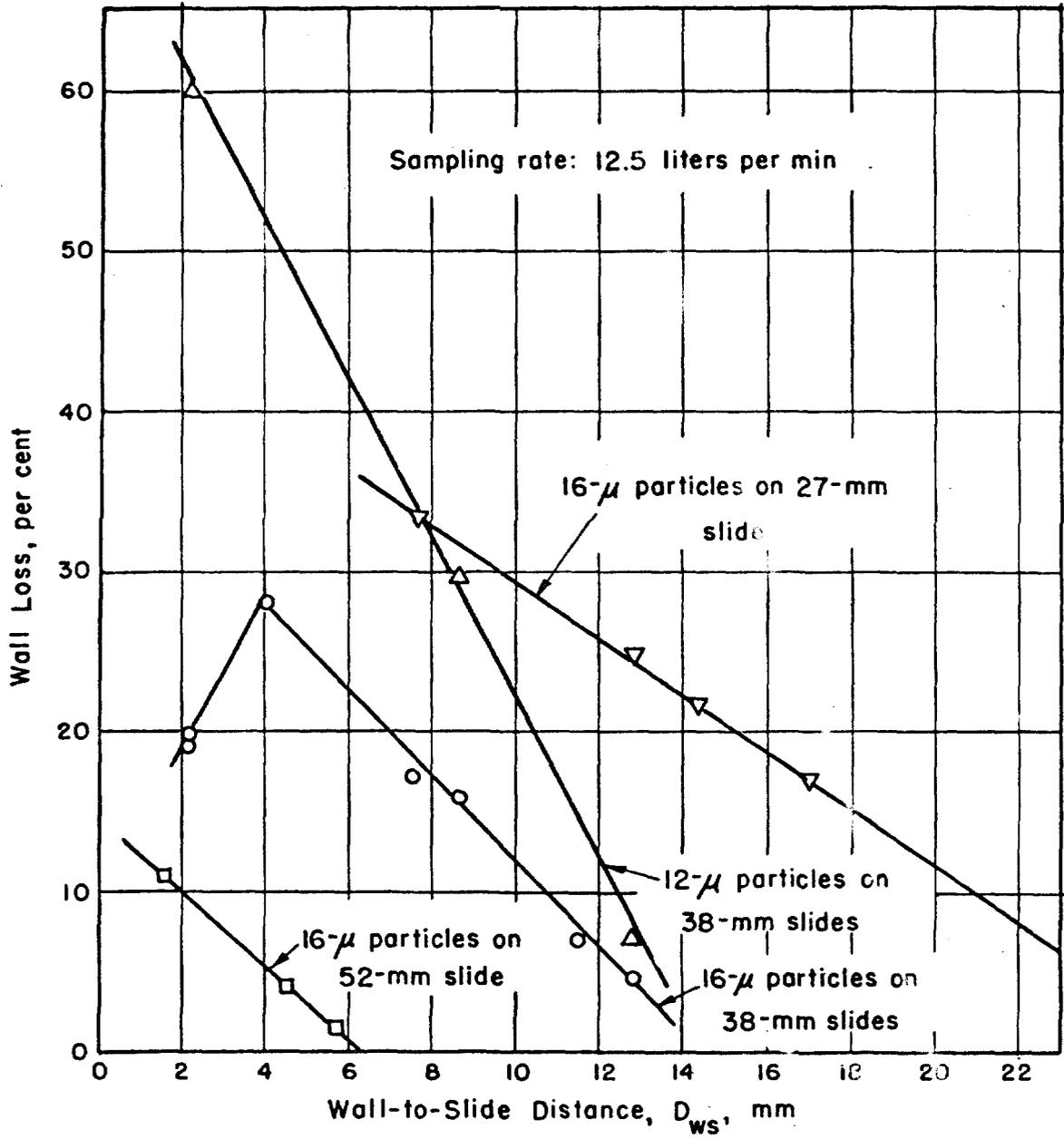


Fig. 3—Aerodynamic wall loss as a function of wall-to-slide distance ( $D_{ws}$ ) for circular jets.

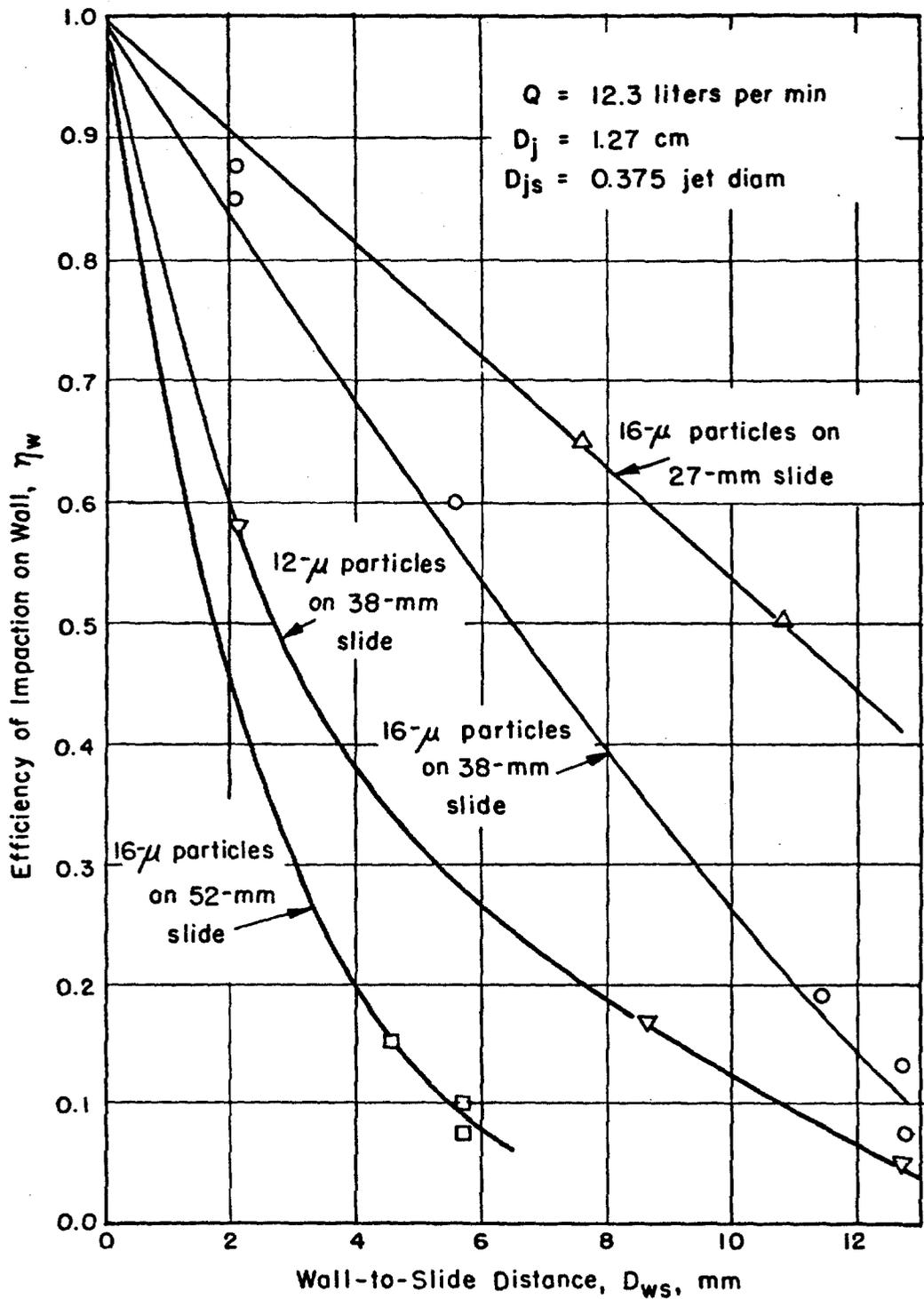


Fig. 4—Impaction efficiency on the wall as a function of wall-to-slide distance ( $D_{ws}$ ) for circular jets.

Table 1 is a comparison of observed and calculated values of the impaction efficiencies for the wall. The results of these tests indicate that the empirical equation holds well over the entire range studied.

Table 1—COMPARISON OF OBSERVED AND CALCULATED VALUES OF WALL-IMPACTION EFFICIENCIES

$\eta_w$ (observed)	$\eta_w$ (calculated)	$D_p$	$D_s$	$D_{ws}$	$D_j$	$Q$
0.05	0.06	12	3.8	1.27	1.27	12.3
0.16	0.16	12	3.8	0.86	1.27	12.3
0.60	0.63	12	3.8	0.21	1.27	12.3
0.10	0.11	16	5.2	0.56	1.27	12.3
0.15	0.19	16	5.2	0.45	1.27	12.3
0.22	0.18	16	2.7	1.70	1.27	12.3
0.65	0.64	16	2.7	0.76	1.27	12.3
0.12	0.09	16	3.8	1.27	1.27	12.3
0.70	0.80	12	2.5	0.67	1.06	12.3
0.31	0.26	12	2.5	0.67	1.06	8.3
0.08	0.08	12	2.5	0.67	1.06	4.0
0.21	0.21	12	2.5	0.67	1.06	7.2
0.29	0.33	12	2.5	0.67	1.43	12.3
0.11	0.15	12	2.5	0.67	1.43	7.2
0.02	0.05	12	2.5	0.67	1.27	4.0
0.28	0.29	12	3.8	0.56	1.27	12.3
0.23	0.20	10	3.8	0.56	1.27	12.3
0.15	0.14	8.4	3.8	0.56	1.27	12.3
0.03	0.04	10	3.8	1.27	1.27	12.3
0.45	0.46	14	3.8	0.56	1.27	12.3
0.77	0.75	18	3.8	0.56	1.27	12.3
0.07	0.08	14	3.8	1.27	1.27	12.3
0.14	0.13	18	3.8	1.27	1.27	12.3

## 6 IMPACTION EFFICIENCIES UNDER CONDITIONS FAVORABLE TO LOWER WALL LOSS

Because the wall loss was high for the data presented in Fig. 2, impaction-efficiency curves were obtained for an experimental two-stage impactor in which the slide diameter and wall-to-slide distance could be varied. The main object of these tests was to determine the optimum size of slide and to evaluate the effect of the increased wall-to-slide distance on the impaction-efficiency curve.

Figure 5 is a plot of the experimental impaction efficiency,  $\eta$ , for round jets as a function of the impaction parameter. These results show that both the jet-to-slide distance and the diameter of the slide affect the impaction efficiency. The aerosols for these tests were produced by the disk atomization of dyed dibutyl phthalate. The impaction parameter was varied by changing the sampling rate and the jet diameter.

These tests indicated that the first stage of the new impactor should have a slide of about 38 mm in diameter, a  $D_{js}$  of approximately three-eighths of the jet diameter, and a  $D_{ws}$  of 12.7 mm. A prototype impactor was made with an increased  $D_{ws}$  value of 22 mm.

## 7 CONSTRUCTION OF THE BATTELLE NO. 6 PROTOTYPE IMPACTOR

A transparent small-scale impactor having a volume flow rate of 12.5 liters/min was constructed to determine the over-all feasibility of such a design. The slides for this impactor are 38 mm in diameter, the jet-to-slide distance is 0.375 times the jet diameter, the length is 17 in., and the wall-to-slide distance is 22 mm.

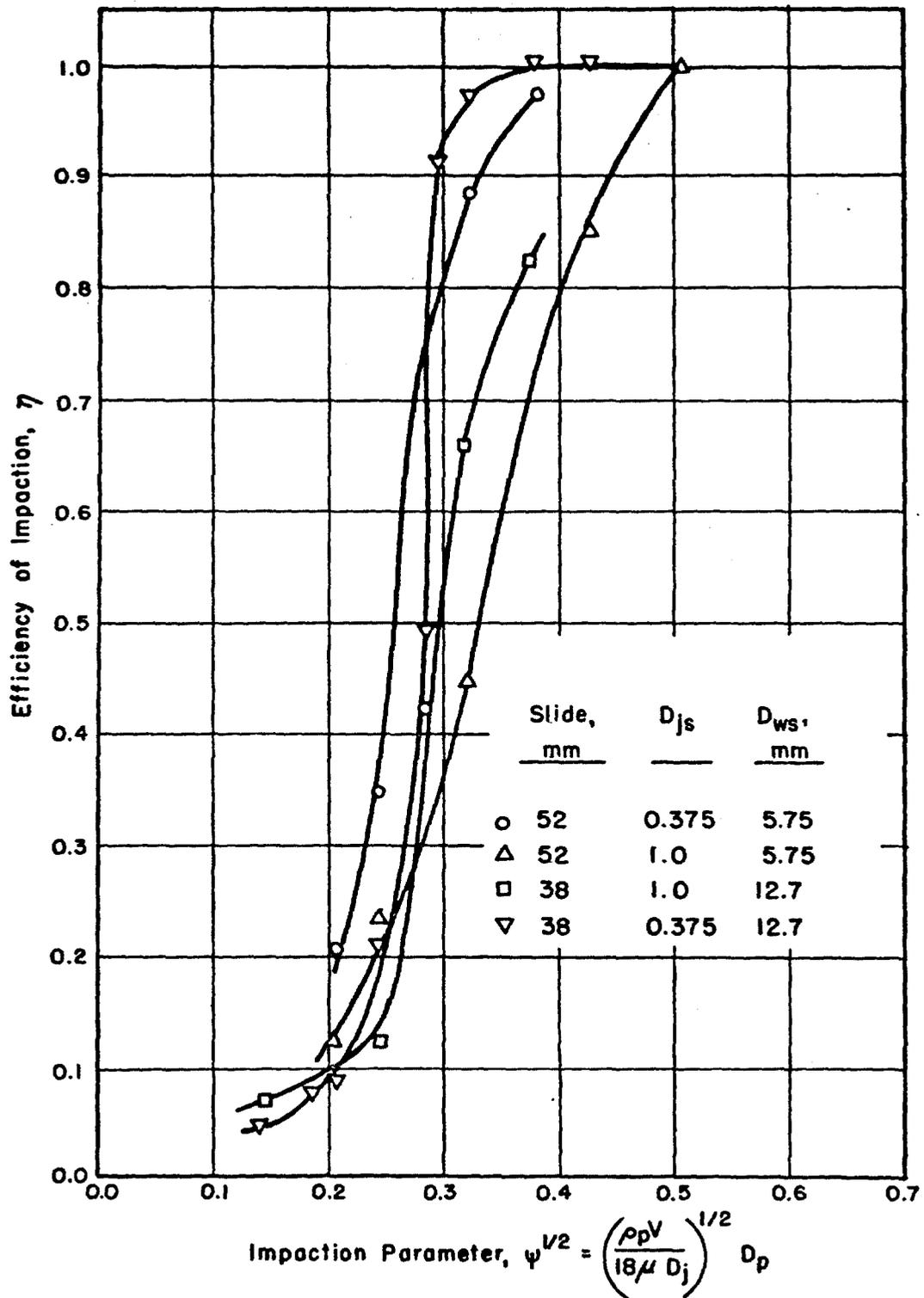


Fig. 5—Impaction efficiency as a function of the impaction parameter for circular aerosol jets impinging on flat circular slides.

Figure 6 is a photograph of the transparent impactor in which the slide supports and retaining springs are attached directly to the lucite jets. The walls are made of cylindrical sections of 87 mm glass tubing. Leaks are prevented by means of O-rings at each joint. Wall loss tests were run with this impactor and the results, which are reported in a later section, indicate that the wall loss was substantially eliminated.

Additional impaction-efficiency curves were run with this impactor to determine the effect of increasing the wall-to-slide distance from 12.7 to 22 mm. Since there was no appreciable change in the impaction efficiency curve, additional impactors were fabricated of metal.

## 8 CONSTRUCTION OF THE BATTELLE NO. 6 METAL IMPACTOR

Figure 7 is an assembly drawing of the Battelle No. 6 cascade impactor. The six jets of the impactor are made of monel metal and the cylindrical walls are made of Type 316 stainless steel to reduce corrosion. All joints are sealed with O-rings to prevent leakage. Three tie rods hold the stages together for operation in a vertical position.

The No. 6 cascade impactor was designed to sample aerosols composed of particles less than  $25 \mu$  in diameter; however, the largest size which impacts on the first stage depends on the maximum size present in the aerosol. The cutoff sizes for each of the six jet stages are approximately 16, 8, 4, 2, 1, and  $0.5 \mu$ . The seventh stage of the impactor consists of a filter which removes nearly all of the particles which fail to impact on the sixth stage.

Table 2 shows the jet diameter and the particle-size cutoff diameters,  $D_p^*$ , for each of the six stages. During fabrication the variation in jet diameters is confined to less than  $\pm 0.001$  in.

A critical-flow orifice, downstream from the filter, maintains a flow rate of 12.5 liters/min provided a sufficient vacuum is applied at the impactor outlet.

Slides which are 38 mm in diameter were used for all stages of the No. 6 impactor. The slides in the latter stages of the impactor could be made smaller in diameter; however, a uniform slide size was maintained for convenience and ease of handling.

Upon the completion of fabrication of the metal impactors they were calibrated.

## 9 CALIBRATION OF THE BATELLE NO. 6 CASCADE IMPACTOR

Before the cascade impactor can be used for rapid determination of the particle-size distribution of an aerosol, the various stages of the impactor must be calibrated. The Battelle No. 6 impactor was calibrated by the following methods.

1. The first method consisted of sampling aerosols of nearly uniformly sized particles and determining the distribution on the various stages by mass analysis.
2. The second method consisted of sampling uniformly sized particles and determining the size distribution by microscopic counting.
3. The third and most tedious method was to determine the particle-size distribution of a sampled heterogeneous aerosol by microscopic measurement of each particle.

### 9.1 Calibration of the Impactor by Mass Analysis

The most rapid method of calibration consists of sampling a nearly uniformly sized aerosol produced by means of a spinning disk. The impaction efficiency was determined by evaluating the mass fraction of the aerosol particles collected on two successive stages. Because of the difficulty of obtaining particles smaller than  $7.8 \mu$ , this technique could only be used to calibrate the cutoff sizes for Stages 1, 2, and 3 of the Battelle No. 6 impactor. To reduce to a minimum the effect of evaporation of the liquid droplets, dibutyl phthalate which had been dyed with 10 per cent DuPont oil yellow dye was chosen as the test liquid. The purpose of the dye was to provide a tracer so that the mass of the collected droplets could be determined colorimetrically. The collected droplets were washed from the slide with ethyl alcohol, and the amount of dye present was determined with a Beckman Model DU spectrophotometer.

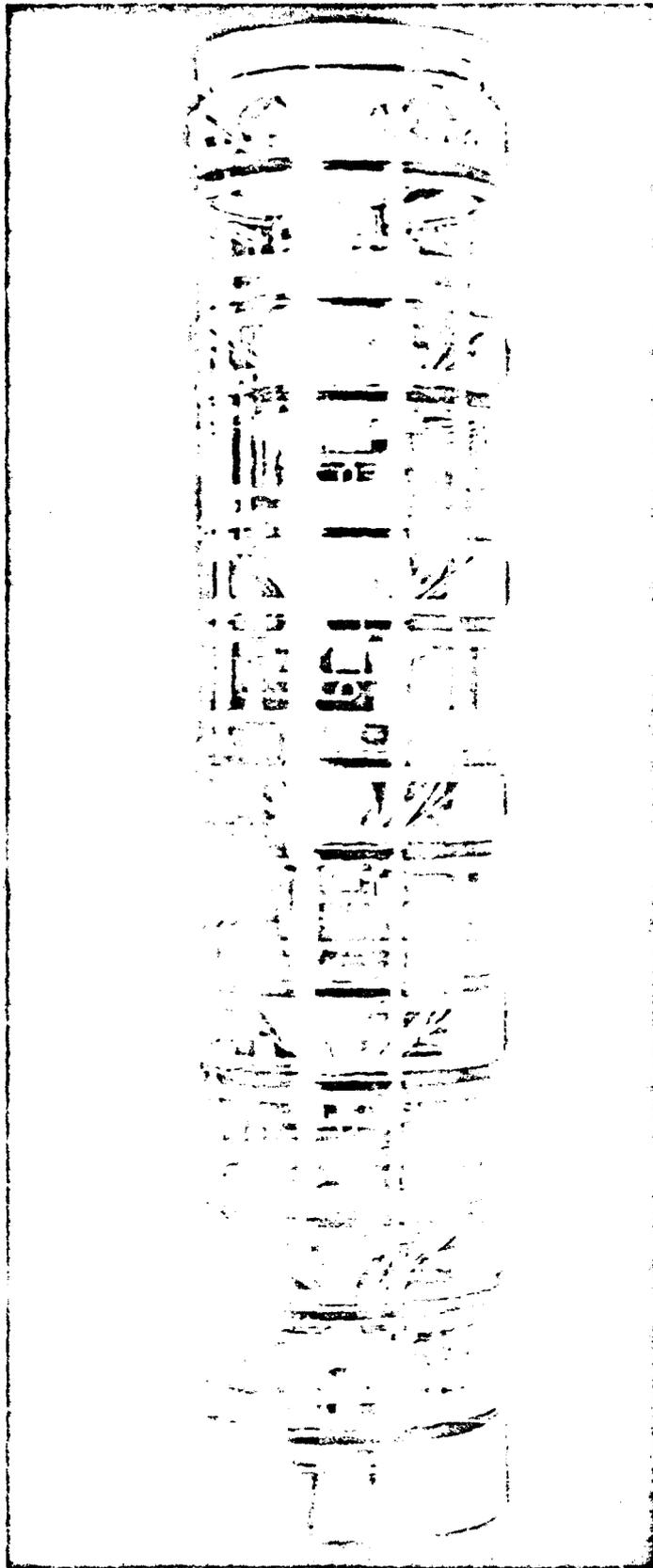


Fig. 6—Transparent small-scale impactor.

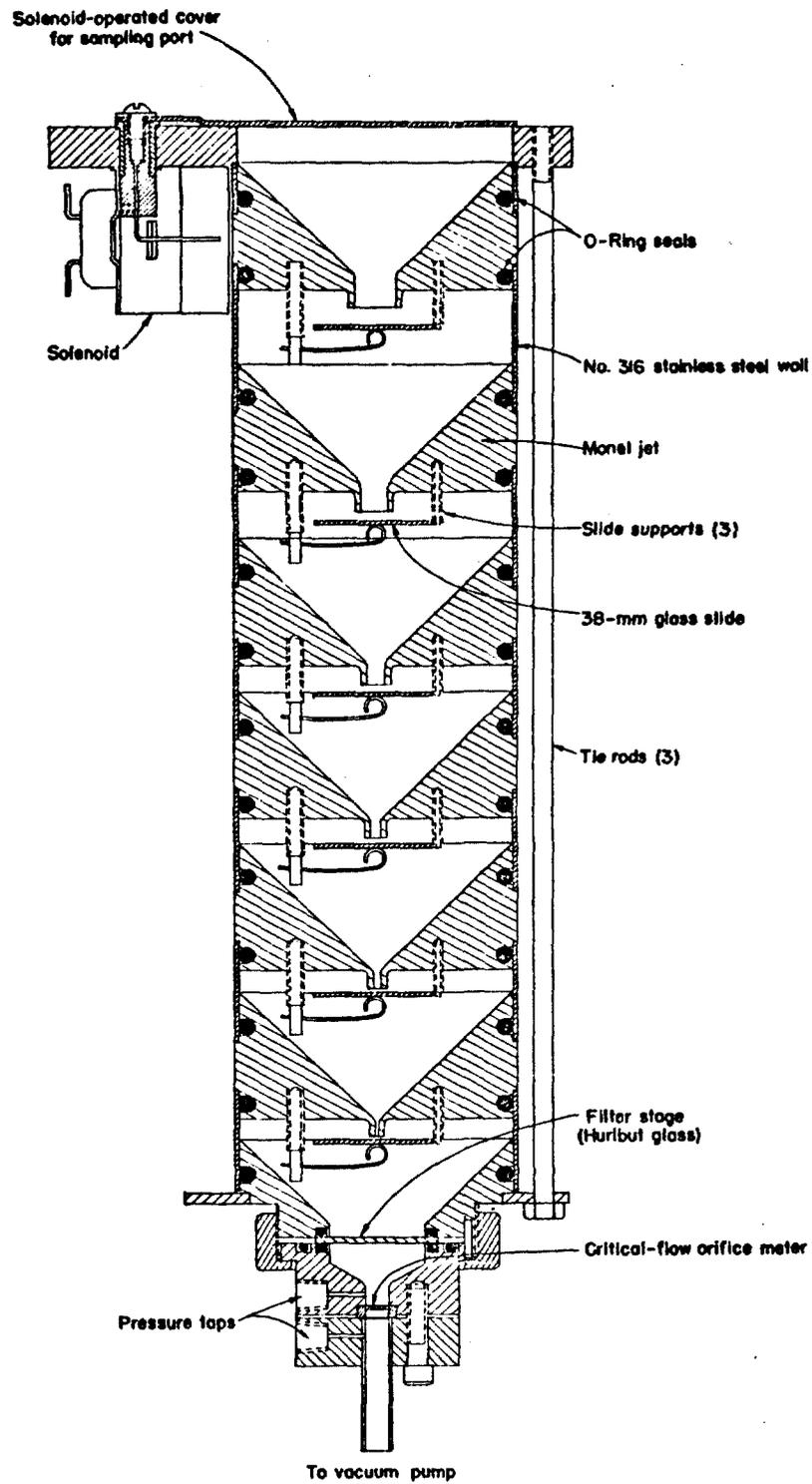


Fig. 7— Assembly drawing of the Battelle No. 6 cascade impactor.

Table 2—JET DIAMETER AND CUTOFF SIZES FOR THE BATTELLE  
NO. 6 CASCADE IMPACTOR WHEN SAMPLING AEROSOLS AT  
A RATE OF 12.5 LITERS/MIN

Stage No.	Jet diameter, mm	Cutoff size ( $D_p^*$ )† uncorrected, † $\mu$	Cutoff size ( $D_p^*$ ) corrected, § $\mu$
1	13.64	16	16
2	8.59	8	7.9
3	5.41	4	3.9
4	3.41	2	1.9
5	2.16	1	0.92
6	1.41	0.5	0.42

† $D_p^*$  is the diameter of spherical particles of unit density for which 50 per cent will impact on the given slide and 50 per cent will pass on to the succeeding slide.

† Uncorrected for Cunningham effect.

§ Corrected for Cunningham effect.

Figure 8 shows the impaction-efficiency curve obtained by sampling dibutyl phthalate aerosols composed of nearly uniform droplets having mean diameters of either 7.8 or 10.0  $\mu$ . The numerical value of the impaction parameter was varied by changing the volume flow rate of the aerosol through the impactor. The numerical value of the impaction parameter,  $\psi^{1/2}$ , which results in an impaction efficiency of 50 per cent is approximately 0.29. Knowing the viscosity of air, the density of the particles, the diameter of the jet, and the velocity of the air within the jet, the cutoff particle size for each jet can be calculated.

### 9.2 Calibration of the Impactor by Microscopic Counting of Uniformly Sized Particles

The last three stages of the impactors were partially calibrated by a method in which uniformly sized polystyrene beads, 1.172 and 1.73  $\mu$  in diameter, were collected in the cascade impactor and the efficiency of impaction determined by making a microscopic count. The aerosols were produced by ultrasonic atomization in a 1700-liter plastic capsule. Before atomization the polystyrene latexes, which were supplied by the Dow Chemical Company, were diluted by a factor of  $10^5$ .

After the suspending medium had evaporated completely, the aerosol was sampled on clean glass slides placed in the six stages of the cascade impactor. The impaction slides were then shadowed with gold in a vacuum evaporator so that the particles had a shadow length of six times their height. Errors resulting from the presence of extraneous particles on the slide were avoided by counting only those particles with shadows of the right length.

### 9.3 Calibration of the Impactor by Microscopic Measurement of Each Particle

One of the most tedious methods of calibrating an impactor is to measure each collected particle microscopically. This method of analysis was used to calibrate some of the stages of the cascade impactor.

The main disadvantages of microscopic measurement are the limitation of accuracy when measuring particles less than three microns in diameter, and the rapid evaporation of small liquid droplets.

Figure 9 is a size-frequency distribution curve of polystyrene beads collected on sticky slides in the first three stages of the transparent impactor. The sampled aerosol was produced by the aerosolization of heterogeneous polystyrene beads. A microscopic examination showed that the beads were spherical; however, some of the outer surfaces were covered with plate-shaped particles less than one micron in length. The plate-like material on the surface of some of the spherical particles was ignored when the diameter was measured.

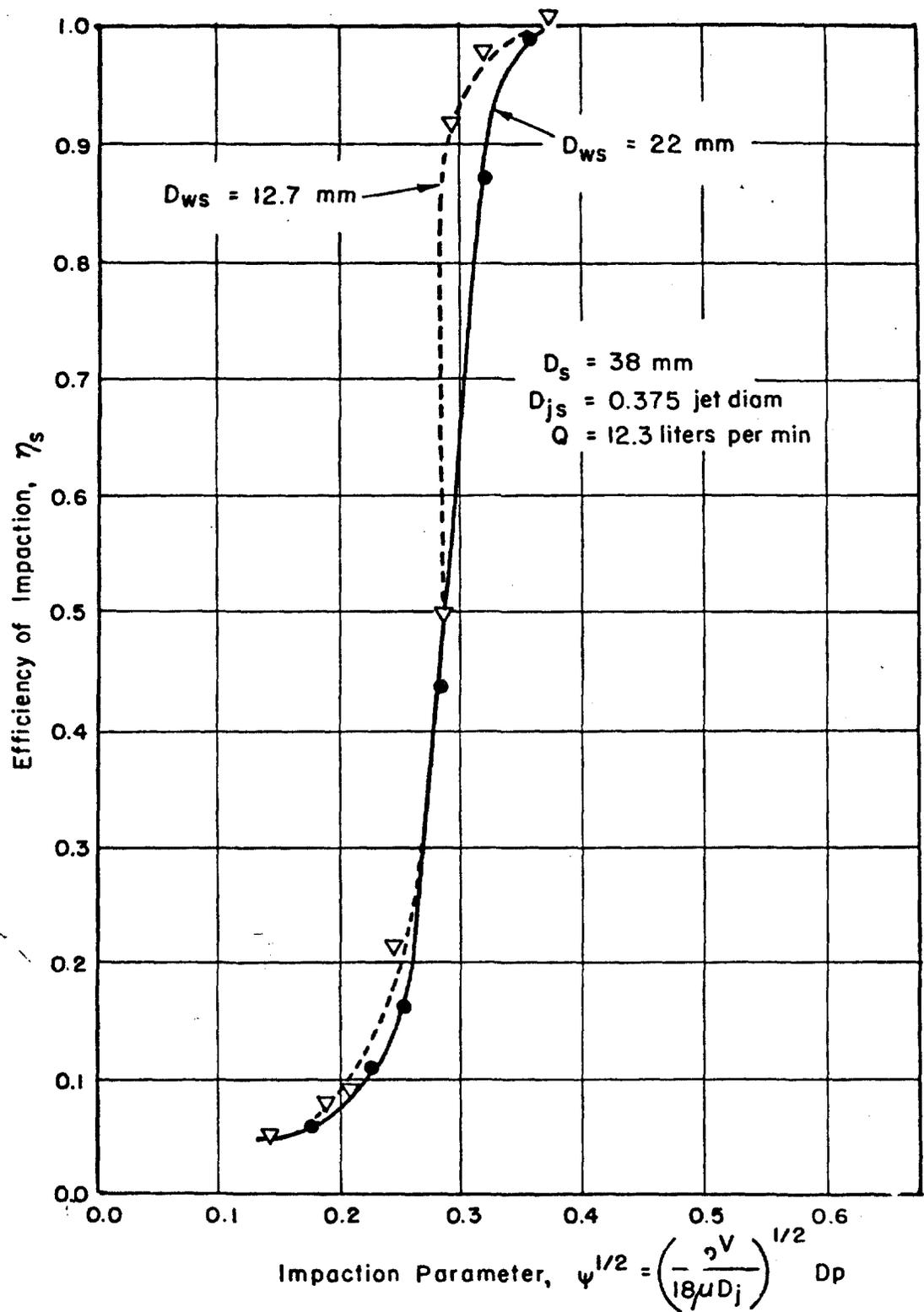


Fig. 8—Impaction efficiency as a function of the impaction parameter for circular aerosol jets impinging on flat circular slides.

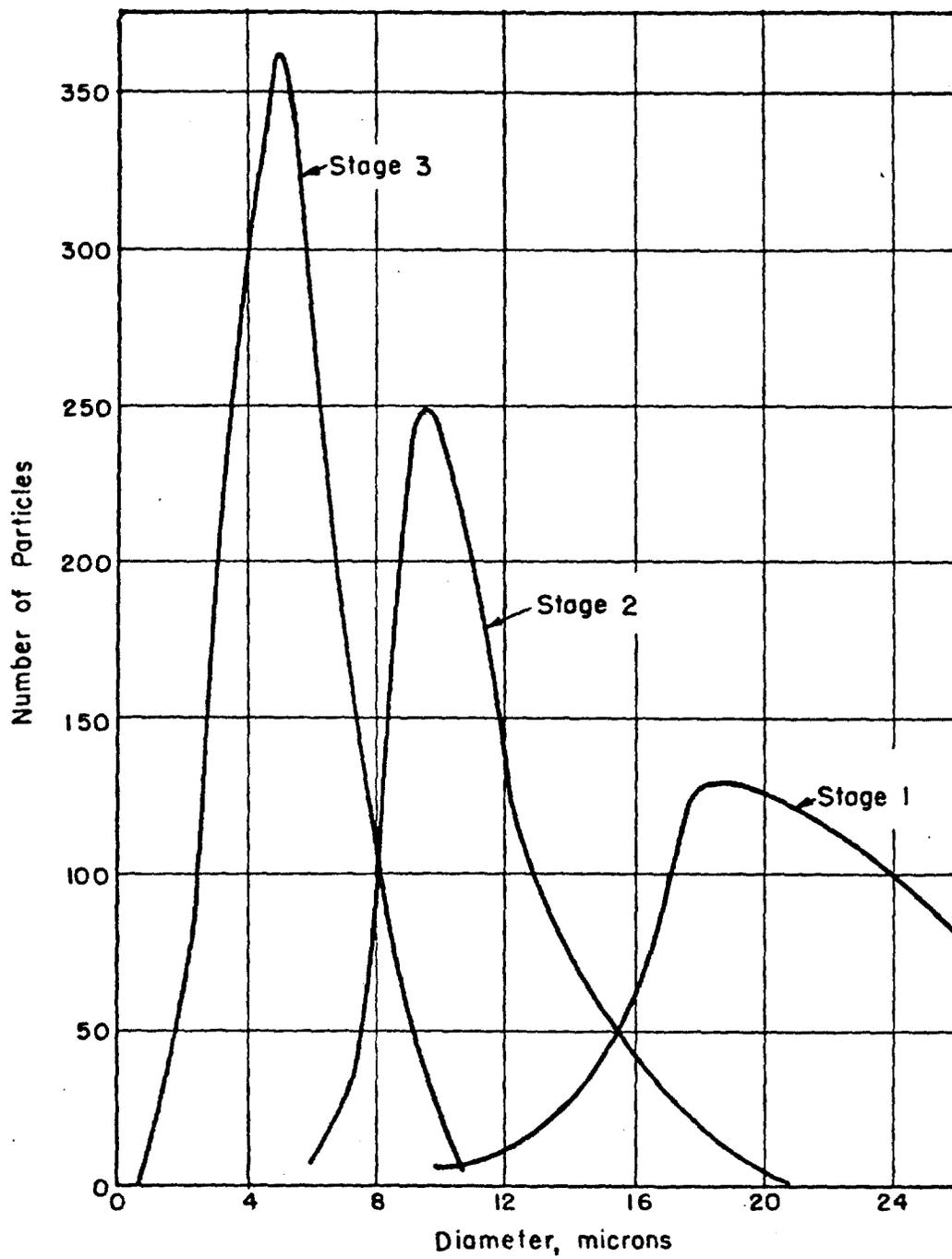


Fig. 9—Size distribution of polystyrene beads collected on three stages of the small-scale prototype cascade impactor.

The polystyrene particles were well classified according to size, and the cutoff sizes for Stages 1 and 2 were close to the calculated values of 16 and 8  $\mu$ , respectively. The cutoff size  $D_p^*$  for the first stage was about 1  $\mu$  lower than the designed size of 16  $\mu$ . A probable explanation is that the effective diameter of the particles covered with plates was slightly greater than the measured spherical diameter.

Figure 10 is a plot of the theoretical impaction efficiency curves as a function of particle size for each of the seven stages of the impactor. The points on the curves are experimental results obtained by all three methods of calibration.

The sharpness of cutoff of the impaction efficiency curve permits the impactor to be designed so that the cutoff size for each stage is approximately one half that of the preceding stage. Consequently, particles of a given size will not impact on more than two stages.

## 10 WALL LOSS STUDIES WITH THE BATTELLE NO. 6 CASCADE IMPACTORS

Several tests have been run with the Battelle No. 6 cascade impactor to determine the extent of wall loss. Because the wall loss on the latter impactor stages is usually below the limit of detection of most light measuring instruments, radiochemical methods of analysis were used. The aerosols sampled were produced by the atomization of biological slurries tagged with radioactive phosphorous-32, using a standard two-fluid nozzle, into a 1700-liter plastic capsule. For the first series of tests a glass "L" was used to transport the aerosol from the chamber to the transparent impactor. The slides of the impactor were porous metal moistened with a glycerin-water solution to make them sticky. For two of the three trials, the walls of the impactor were also treated with the same coating. The relative humidity was kept low to assure that the aerosol particles would be substantially dry.

Table 3 shows wall loss for each stage expressed as a percentage of the sum of the material collected on the wall and on the succeeding slides.

These results indicate that the wall loss is extremely small for this type of aerosol. Wall loss for the entire impactor for this series amounted to less than 1 per cent of the material sampled.

Recently a series of tests were run in which the wall loss of a metal impactor was compared with the wall loss of a transparent impactor. Although both impactors were of the series six design, the jet diameters were slightly different. The design of jet diameters of the metal impactor was adjusted for the particle-size deviation caused by the Cunningham effect.

The aerosols for this series of trials were identical to those of the previous series. However, both impactors were mounted inside the center of a 1700-liter plastic capsule. Porous slides which had been moistened with glycerine were used to collect the aerosol particles. The impacted particles were removed from the slides by passing a wash solution containing a wetting and chelating agent through the slides while held over the mouth of a filter flask. Material that collected on the walls was removed by scrubbing each wall with a brush using the same kind of wash solution.

Table 4 is a tabulation of the counts obtained on the walls and slides for two typical tests. These results indicate that the wall loss for Stages 4, 5, and 6 of the metal impactor is less than 1.5 per cent of the material which collects on the stage, and the wall loss for Stage 3 is less than 4 per cent. The particle size of the aerosol sampled at the high humidity was increased considerably by the addition of a large amount of glycerine before atomization, so that the amount of material which collected on Stage 2 would be significant. The results of this test indicated that the wall loss for Stage 2 is less than 15 per cent. An interesting point to note is that this wall loss apparently was not caused by aerodynamic factors which force particles to impact on the cylindrical portion of the stage, but by gravitational settling of the particles as they entered the second jet. The total wall loss for this particular test amounted to 6.5 per cent. In most of the tests in which wall loss was determined it was less than 2 per cent of the total aerosol sampled.

Radiochemical methods of determining wall loss have an advantage over light-measuring method in that a blank need not be run because most contaminants do not contain any radio-

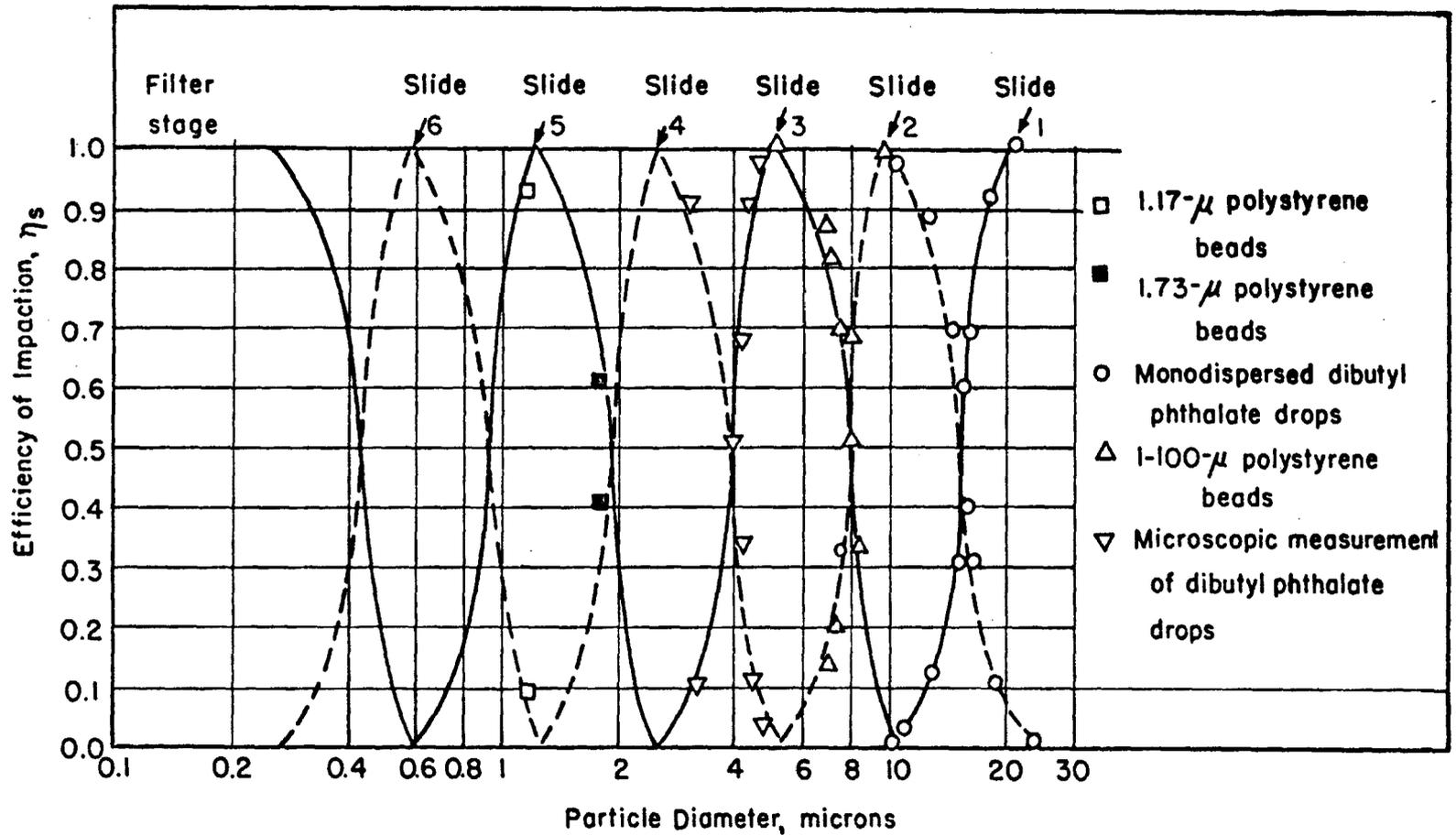


Fig. 10—Impaction efficiency as a function of particle size for each stage of No. 6 cascade impactor.

Table 3—WALL LOSS WHEN SAMPLING BACTERIAL AEROSOLS WITH THE TRANSPARENT IMPACTOR

Test No.	Temp, C	RH, per cent	Wall loss*				
			Wall 2	Wall 3	Wall 4	Wall 5	Wall 6
1	25	25	1.43	0.38	0.09	0.36	0.22
2	26	46	3.09	0.71	0.23	0.22	0.14
3†	28	30	3.18	0.78	0.18	0.30	2.63‡

\* Wall loss =  $\frac{\text{material impacted on wall}}{\text{material impacted on wall} + \text{material impacted on succeeding slide}}$ .

† The walls of the impactor were not treated with glycerine for Test No. 3.

‡ It is believed that the relatively high value of 2.63 per cent is correct and is due to electrostatics. The operator held the impactor by placing his hands on Stage No. 5 which may account for the higher wall loss.

Table 4—CASCADE IMPACTOR WALL-LOSS TESTS

Test	RH, %	Stage	Brass impactor			Transparent impactor			Remarks
			Counts on slide	Counts on wall	Wall loss, %	Counts on slide	Counts on wall	Wall loss, %	
3	40	1	18,528	750	*	372	2,077	*	Bacterial standard slurry
		2	2,514	727	22.44	752	2,091	73.54	
		3	9,573	652	6.37	12,281	1,417	10.34	
		4	190,085	1,002	0.52	129,326	1,644	1.25	
		5	241,780	564	0.23	310,487	2,267	0.72	
		6	172,669	418	0.24	181,947	2,941	1.59	
		7	72,138			42,695			
		Total	707,290	3,365	0.47	677,863	10,362	1.50	
7	98	1	15,201	16,946	*	11,436	19,957	*	Bacterial slurry containing 50 per cent glycerine
		2	73,583	12,875	14.89	64,019	12,333	16.15	
		3	92,642	3,578	3.72	92,786	4,363	4.49	
		4	47,004	730	1.53	48,844	531	1.07	
		5	14,289	28	0.19	18,469	17	0.12	
		6	4,994	0	0	2,417	0	0	
		7	756			222			
		Total	248,469	17,211	6.48	238,193	17,244	6.75	

\* By definition the material which settled on the inlet cone before the sample of aerosol entered the impactor is not considered as part of the sample. Consequently there is no wall loss for Stage 1.

activity. Unless extreme care is taken, the blank readings can amount to a high portion of a reading obtained on a light-measuring device, causing a large error in the final analysis.

## 11 CONCLUSIONS

The size distribution of an aerosol can be determined rapidly and accurately with the cascade impactor. After one instrument has been calibrated additional impactors with identical dimensions can be fabricated, and no further calibrations are required.

Because of its inherent versatility for the sampling of either solid or liquid particles over a wide range of conditions, the cascade impactor meets most of the requirements of an instrument for general studies of aerosols.

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## A MULTIBED LOW VELOCITY AIR CLEANER

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### 1 INTRODUCTION

It is estimated that the civilian power reactor program will have accumulated by 1970,  $10^7$  gallons of waste containing  $2 \times 10^{10}$  curies.<sup>1</sup> The disposal of this large volume of wastes, without danger to the public, presents a unique problem in industrial waste treatment. While the exact composition of these wastes will vary widely, an off-gas problem will always exist in their storage or ultimate disposal. The multibed air cleaner is designed to decontaminate the off-gases from one waste disposal method, the fixation of radioactive wastes in a sintered clinker.

### 2 DISPOSAL SCHEMES

Processes for the ultimate disposal of acid aluminum nitrate wastes fall into two broad categories based on temperature. Medium-temperature processes are defined as those which operate in the range of 400°C to 600°C. High-temperature processes are those which operate at temperatures greater than 800°C.

Examples of medium-temperature processes are the fluidized bed reactor<sup>2</sup> and the fused salt calciner.<sup>3</sup> The fluidized bed reactor utilizes a seed bed of alumina to form a product of alumina particles containing the fission products. These particles can be placed in containers for storage.

The fused salt calcination process uses sodium nitrate (produced by sodium hydroxide neutralization of acid aluminum nitrate waste) as a flux to produce a melt which can be cast into a convenient form for storage.

There are two different techniques of high-temperature fixation under development. In the first method acid aluminum nitrate wastes are calcined to give a granular product from which leachable fission products are removed by water or mild acid. The fission products are absorbed from the leachate by montmorillonite clay which is then fired in a kiln at 1000°C. This fixes all the fission products except ruthenium. The ruthenium is leached from the fired clay for separate disposal.<sup>2</sup>

A second method of high-temperature fixation is under development at the Oak Ridge National Laboratory. Raw acid aluminum nitrate waste is processed with Conasauga shale and fluxing agents at temperatures greater than 800°C to form a sintered clinker which immobilizes the fission products. The fluxing agents are limestone and sodium carbonate. The heat re-

quired for the sintering process may be obtained by (1) self-heating, heat of fission product decay, or (2) self-heating plus external heating.<sup>2</sup>

### 3 ANALYSIS OF OFF-GASES

The processes outlined above produce radioactive aerosols of several types. The fluidized bed and fused salt calcination will produce an aerosol of solid particles in a hot gas stream. The sintering process produces a complex of particulates ranging from approximately gas molecule size 1 A to 10  $\mu$ . The nature of the aerosol will vary with the changing temperature of the sintering material. As the sintering material heats, water vapor and water droplets are evolved. Radioactive materials begin to appear in the aerosol when the mass reaches 86°C (see Table 1). After the boiling temperature is reached, the aerosol contains water droplets carrying both dissolved and insoluble particles.

Table 1—ENTRAINMENT BY EVAPORATION-ENTRAINMENT WELL

Well			
Temp., °C	Count, counts/min/ml	Cond. count, counts/min/ml	Decontamination factor
90-100	856	1.340	$6.39 \times 10^2$
86	8514	1.35	$6.3 \times 10^3$
91	8514	2.47	$3.44 \times 10^3$
95	8514	63.	$1.35 \times 10^2$

The nature of the aerosol particulates evolved from the sintering material at temperatures greater than 100°C is not presently known. On the basis of experiments with sodium chloride it is expected that a copious number of crystalline particles of about 0.05  $\mu$  are evolved at temperatures greater than 300°C. The particle size of the NaCl aerosol increases as the temperature of the solid salt material increases to 800°C.<sup>4</sup> Particulates from the sintering material are expected to follow this pattern.

Reactive and nonreactive gases will be present throughout the sintering process. Of the reactive gases the first to be released is carbon dioxide, released during the mixing operation. Radioiodine will be present in the off-gases during the entire sintering operation, though the major part of the iodine will be volatilized below 200°C. Nitrate salts begin to decompose at 150°C, and oxides of nitrogen persist at 800°C.

The important nonreactive gases present in the waste solution are Kr<sup>85</sup> and Xe<sup>133</sup>. The more important of the two biologically is Kr<sup>85</sup> because of its long half life, 9.5 years.

### 4 EXPERIMENTAL EQUIPMENT AND DATA

It is recognized that no single filtering agent can effectively remove this multiplicity of contaminants. The variety of contaminants suggested a multibed air cleaner (see Fig. 1). The components of the multibed air cleaner are sand, soda lime, and activated carbon.

Dry sand is an effective filter for particulates. Figures 2 and 3 show that the efficiency of a sand filter depends upon (1) sand grain size and shape, (2) superficial air velocity (volumetric flow divided by filter cross sectional area), and (3) sand bed depth.

At a superficial gas velocity of 0.1 cm/sec (0.2 ft/min) the most penetrating aerosol particle size is in the 0.25 to 0.45  $\mu$  radius range.<sup>5</sup> The efficiency of a sand filter increases exponentially with depth of the sand bed. Thus, if a sand filter 4 in. in depth passes 2 per cent of an aerosol, a filter 8 in. deep will pass only 0.04 per cent of the same aerosol.

If very moist aerosols are passed through a sand filter, water condenses in the filter voids and clogs the filter. Figure 4 shows the build-up of pressure at the inlet to a sand filter as it

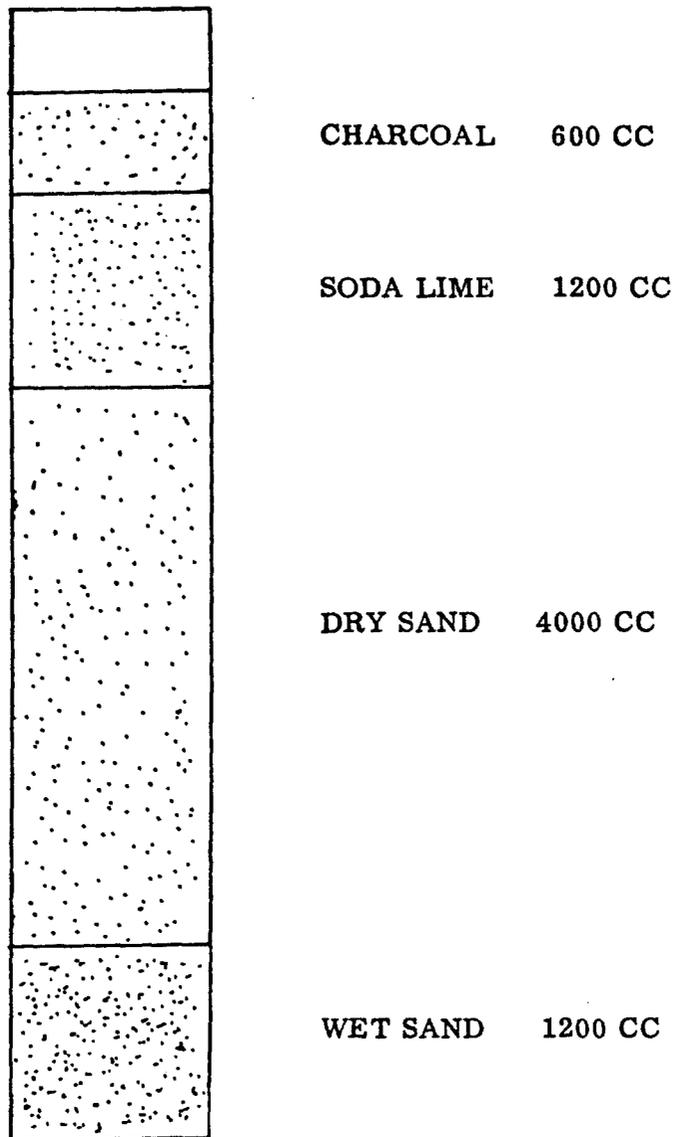


Fig. 1—Compound sand filter. Column diameter, 9 cm; flow rate, 500 cc/min.

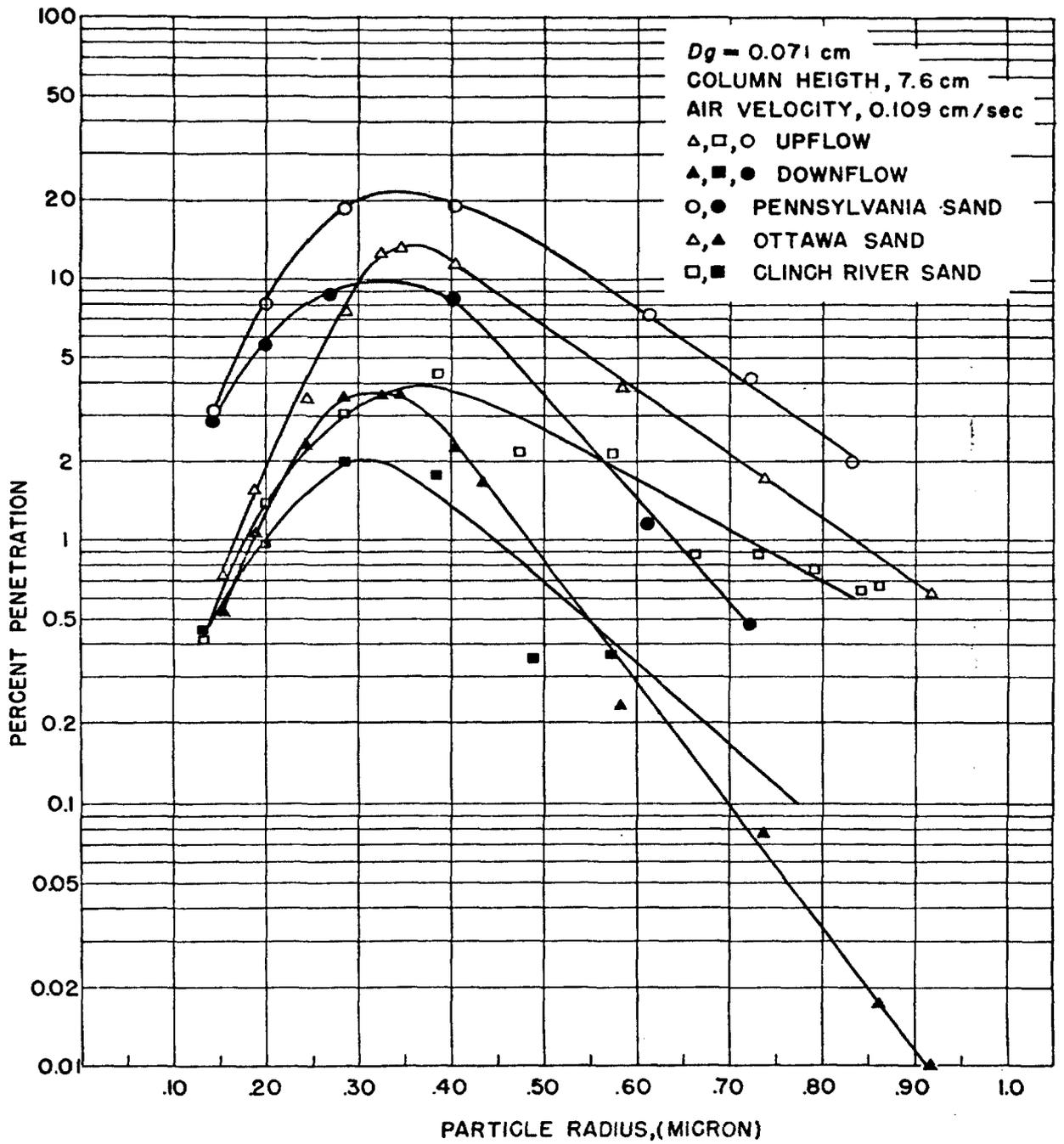


Fig. 2—Penetration in filters of Pennsylvania, Ottawa, and Clinch River sands.

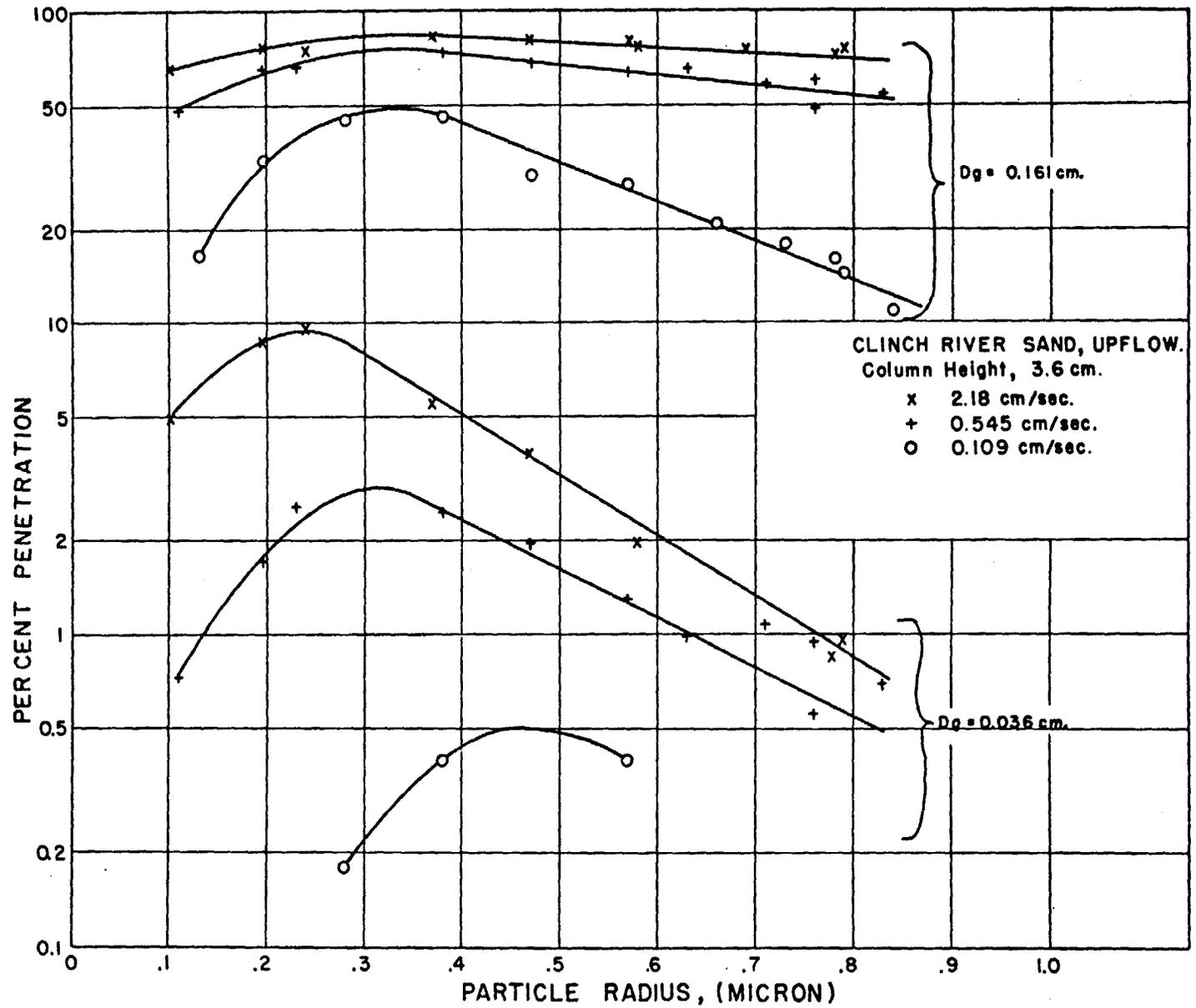


Fig. 3—Penetration in Clinch River sand filter.

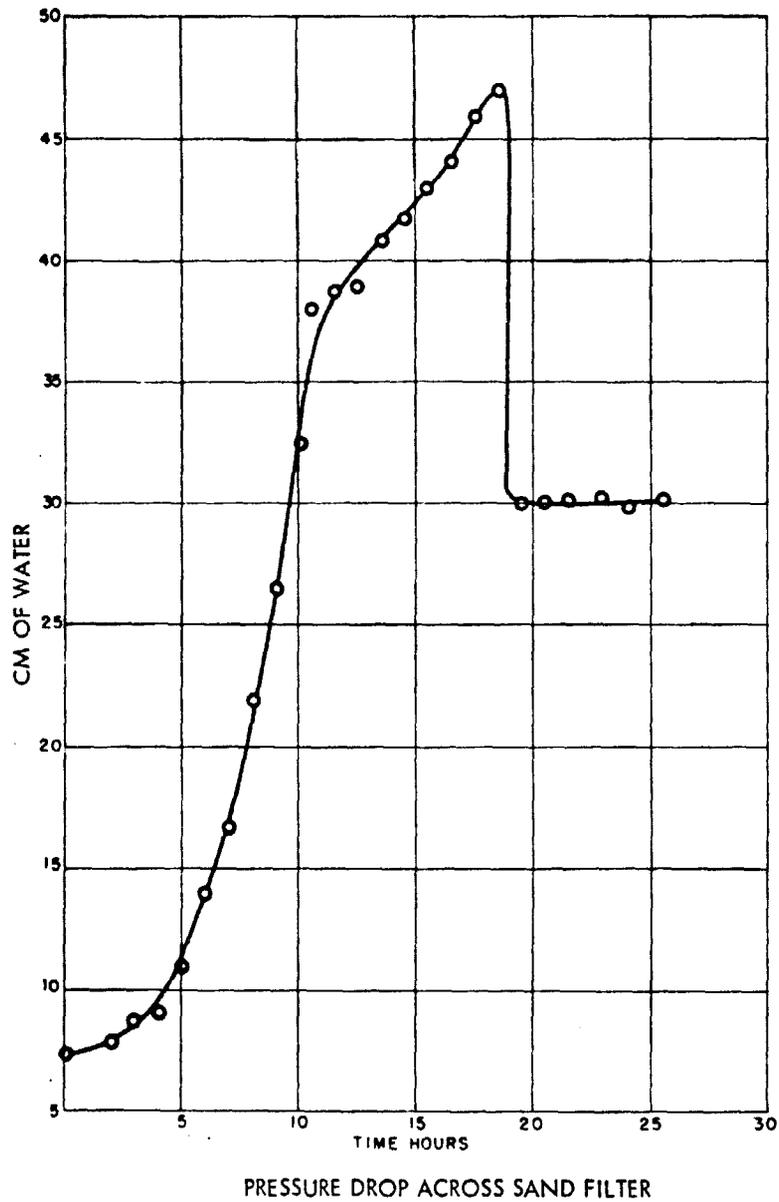


Fig. 4—Build-up of pressure in sand filter from saturation with water.

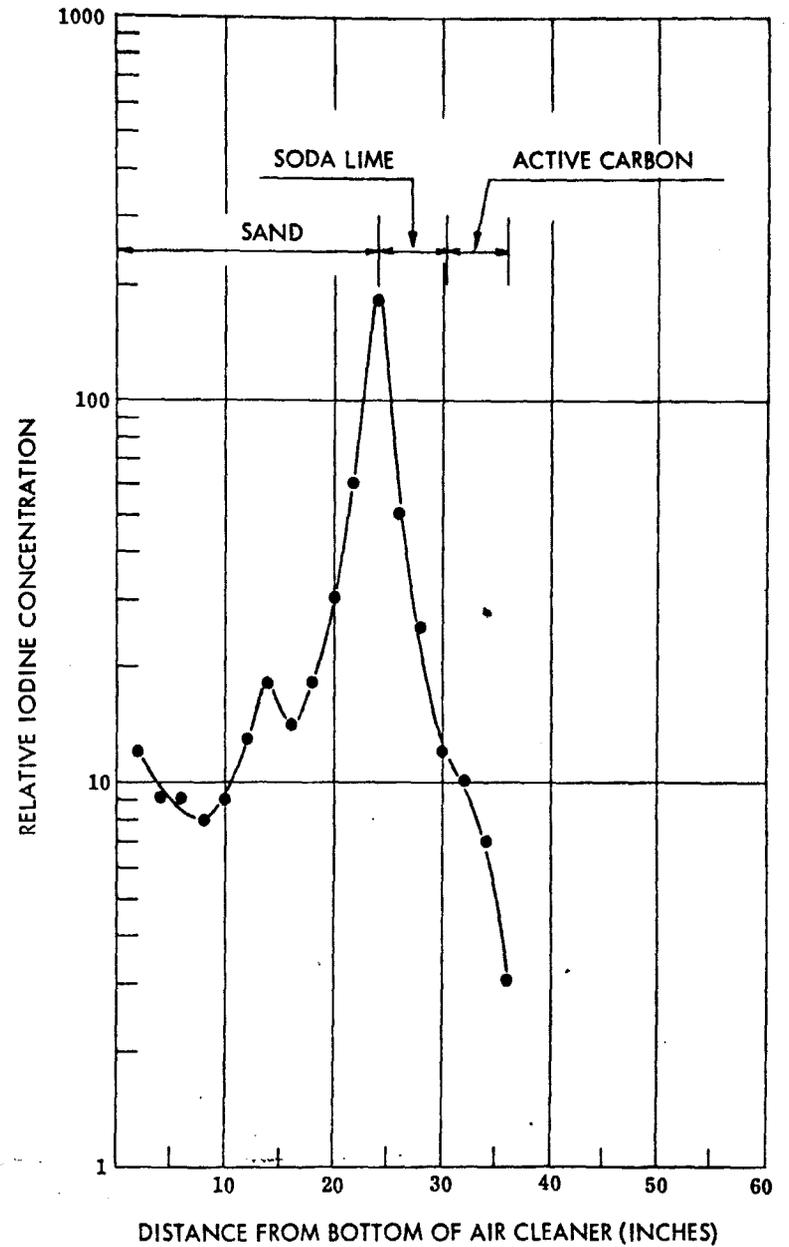


Fig. 5—Distribution of  $I^{131}$  within the multibed air cleaner.

becomes saturated with water. The sharp drop is indicative of channeling. The data show that for wet aerosols, sand is a poor filter but an effective condenser. By proper filter design the condensed water can be drained from the filter thus maintaining the sand in an unsaturated (and efficient) condition.

Laboratory sintering experiments using  $Ru^{106}$  tracer show that the sand filter functions as described above. Water condenses in the lower few inches of the filter and is drained to a sump beneath the filter. Most of the evolved ruthenium is found in the condensate and in the filter, although some is found plated on the surface of the tubing leading to the filter. No activity is found in the off-gas system after the filter. Table 2 presents the data for these experiments.

Table 2— FATE OF RUTHENIUM IN  
THE MULTIBED AIR CLEANER

	Activity, counts/min
Initial waste	$5.6 \times 10^7$
Final waste	$4.4 \times 10^7$
Condensate	$3.3 \times 10^6$
Ruthenium scrubber	0
Air cleaner	$5.8 \times 10^6$
Tubing	$2.9 \times 10^6$

Soda lime is known to be an effective agent for removal of nitrogen oxides from gas streams. A soda lime bed (8-mesh) placed on the sand filter reduced the oxides of nitrogen concentration (nitrite) to approximately 10 ppm as determined by bubbling through dimethyl-aniline. A 12-in. bed of soda lime was not measurably more effective than a 4-in. bed. The 4-in. bed of soda lime was one sixth the depth of the sand filter.

Radioiodine, when used as a tracer, condensed on the sand. As the sand was heated by the condensing water vapor, the iodine sublimed, moving slowly up the filter to the sand-soda lime interface where it remained. The distribution of iodine within the filter is shown in Fig. 5.

Activated carbon was included in the multibed air cleaner primarily to remove the initial surge of iodine and was placed immediately above the soda lime. Since the iodine did not reach the activated carbon, its inclusion for iodine removal was not justified. However, the activated carbon did reduce the nitrogen oxides passing the soda lime to less than 1 ppm nitrites. For this reason the activated carbon was included in the air cleaner.

It is known that noble gases are retained by activated carbon at low temperatures. Because their retention is low at room temperature, this factor has not been considered in the design of the air cleaner.

## 5 SUMMARY AND CONCLUSIONS

One solution to the air cleaning problems presented by the self-sintering method of reactor waste disposal is the multibed air cleaner. This air cleaner will remove greater than 99.995 per cent of the evolved particulates and all the fission product gases except xenon and krypton.

The air cleaner is applicable to the cleaning of off-gases from any similar operation. It must be remembered, however, that the superficial air velocity should not exceed 0.1 cm/sec.

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## AIR CLEANING OPERATIONS AT UCRL

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Air cleaning and other controls of radioisotopes to prevent their dispersion into the environment entrained in air continue to receive both operating and applied research attention.

In processing off-gases from chemical manipulation of reactor irradiated materials, containing multicuries of alpha emitters and associated fission products, increased emphasis on containment in physical systems of very low exhaust volume is noted. In such operations dependence on AEC type filters for cleanup has been abandoned; these now act as forefilters for Millipore filters handling the total exhaust, which lies in the 200 to 300 ml/min range. In the past, radioactive fission product gases passed to the stack from such equipment. We are now set up to capture this fraction nearly quantitatively from our so-called closed dissolver design reported at the 1957 Nuclear Congress in Philadelphia.

For the past several years considerable effort has been devoted by UCRL Berkeley to processing kilocuries of alpha emitters of classified interest for our Livermore laboratory. It is with considerable gratification we observe they are now eminently capable of staffing their own responsibility under Mr. Jack Murrow. This has made possible Berkeley's increasing attention to projects of foreseeable magnitude for the near future. Among these will be the development of equipment and techniques for the suppression and capture of aerosols arising in small-scale, but high-level activity, evaporations necessary as a preliminary to ion exchange separation processes.

Another problem of some interest will be the perfection of gas cleaning methods for circulating helium blankets in accelerator target systems.

Vacuum furnace operations involving vaporizing transuranics as well as certain fission products are posing increasing difficulty in decontaminating the pump effluent. This problem is aggravated by the oil mist commonly associated therewith.

Our room air sampling program continues to increase with laboratory expansion of programs, personnel, and work areas. We now routinely handle 1500 separate samples monthly, on the average less than two per month approach Handbook 52 concentrations. The major problem existing in this field is an old one, namely, finding a practical way to get early or immediate warning of above background alpha emitter pollutants dispersed in air or stack gases. A portion of our air sampling effort is devoted to periodic collaboration in assessing fallout from nuclear device tests.

On the increase is attention to individual stack emissions of very low level, as from fume hoods where local policy dictates handling maxima of less than 0.1  $\mu\text{c}$ .

Substantial but intermittent work has been performed on control of radioactive air pollutants arising from biological experimentation, both plant and animal. In the middle range view this will demand a perhaps disproportionate expenditure of time and expense per curie handled because of the often almost bizarre requirements superimposed on good air cleaning fundamentals by the objects worked on.

A hidden cost of continuous nature resides in the lack of trained available personnel. Perhaps 15 per cent, as a guess, of available trained man-hours is devoted to indoctrination and

training of those new to the ranks. Since costs of air cleaning and surveillance, after initial expenditures are made for capital equipment, are largely those for salaries, it would appear an AEC effort to support instruction of specialists in the professional and technical aspects of air cleaning might well be considered.

## ECONOMIC SURVEY OF AIR AND GAS CLEANING OPERATIONS WITHIN THE AEC

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At the request of the Division of Reactor Development, U. S. Atomic Energy Commission, the Harvard University Air Cleaning Laboratory is conducting an economic survey of air and gas cleaning operations within the AEC. The concept of such a program is not new, the basic purposes and requirements of the current survey having been outlined in a memorandum to AEC site management over two years ago. However, this laboratory and personnel responsible for handling air cleaning operations throughout the Commission have not yet succeeded in obtaining comparative data. The shortage of technical manpower and the increase in air cleaning problems and their complexities probably represent the best arguments for reviewing air and gas cleaning experience at the major AEC sites.

Certainly the most practical approach to engineering problems is immediate reference to a guide or manual which suggests reliable solutions in accordance with economic factors. In limited cases, the experience of individuals or a single facility may furnish the desired information. On the other hand, it may be necessary to perpetuate uneconomical methods of gas cleaning to meet production schedules.

It seems reasonable to assume that a detailed inspection of the several AEC sites would reveal (1) that each plant has developed gas cleaning procedures for certain operations which could well be adopted as "standard methods" and (2) that each plant has collector problems which are still unsolved. A composite of successful AEC plant experience on air cleaning methods and costs would provide a useful guide in approaching new problems and re-evaluating present techniques.

Compilation of representative data on the cost and performance of air and gas cleaning apparatus is a major objective of this survey. Since the hazards associated with the handling of fissionable materials demand emphasis first on proper control measures and second on the economics involved, the tremendous industry developed by the AEC is burdened with far greater air cleaning costs than those encountered outside the atomic energy field. The only possible way to assess these costs is to identify them, find out how much and what degree of air cleaning is represented by them, and what bookkeeping methods have led to the cost estimates.

Basically, these are straightforward questions whose answers should permit advancement of design and cost criteria which can provide more economical solutions to air and gas cleaning problems. However, it is recognized immediately that obtaining the necessary data from the various sites is going to require that several persons at each plant be contacted in person or by letter. It will be necessary to define precisely the reasons for the survey and the type of information wanted. If preliminary visits to several of the major AEC sites can be used as guideposts it will be discovered that the over-all handling of one air cleaning operation may involve several departments and individuals. Capital, freight, maintenance, repair, inspection, monitoring, replacement, and disposal charges may be dispersed through several departments with nearly as broad a spectra for equipment performance data, such as power requirements, efficiency, air handling capacity, pressure loss, and filter life. Obviously, considerable labor

will be required to ferret out the facts and many plants will be hard put to cooperate, man-power and budgetwise.

This laboratory and the Division of Reactor Development realize that the success of the economic survey depends in large part upon the response of the various AEC sites. The fact that several papers have been presented at the AEC Air Cleaning Seminars discussing specific site air cleaning methods and problems demonstrates a positive interest in the subject. Information furnished by Van Valzah<sup>1</sup> on filtration costs at the Argonne National Laboratory and by Harris and Mason<sup>2</sup> on bag filtering costs at the Mallinckrodt Chemical Company represents a substantial contribution to the economic survey. References to these papers and others have helped to determine what factors should be given major consideration.

Results of preliminary visits to AEC plants have indicated the need for a detailed questionnaire which summarizes the information required for the survey. This would serve the following purposes: (1) provide a compact outline of program objectives and thereby minimize extraneous effort in pursuit of data, (2) ensure that information from the various sites may be properly correlated.

A tentative outline of the basic material which this laboratory believes should be included in the survey questionnaire is presented in this paper. It is recognized that there may be serious omissions and that the general arrangement of material may be disputed. Therefore, it is planned to distribute the questionnaire in essentially the same form as that appearing in this report to site management and personnel who are directly concerned with air cleaning operations. It is strongly urged that the outline be reviewed critically so that its final form will represent the composite expression of those individuals requested to use it as a guide.

The outline has been arranged in two parts which cover (1) pertinent descriptive and operational data and (2) air and/or gas cleaning costs. Section I should furnish a complete picture of the dust collecting device, i.e., identification, classification and type. If the cleaner represents a site development, detailed design and testing data should be supplied giving literature references wherever possible.

Under the category of Operational data, Section II, the following items are considered important: A. Site application, such as prefilter for supply or exhaust air, and high efficiency collector for laboratory or process areas. B. Cleaning requirement and process, which should describe aerosol composition, concentration, and efficiency requirements within practical security boundaries. C. Space requirements, which frequently may be a decisive factor in collector selection. D. Operating characteristics, which should permit a thorough evaluation of collector performance. E. Method of replacement or cleaning of media. Recent data reported by the Hanford plant show that for certain operations vacuum cleaning of Absolute filters and washing of glass fiber filters have extended service life significantly. Site procedures of this type are particularly worthy of dissemination since they may lead to substantial savings in air cleaning costs. F. Criteria for cleaner changes. Reasons for filter changes may vary from one plant to another even for identical operations. Only by a thorough analysis of plant procedures can an optimum system be devised. G. Handling and disposal methods. Incineration techniques have been discarded in favor of baling and storage or burial at some installations on a basis of cost. However, problems relative to storage or burial capacity point toward re-evaluation of incineration processes. Item H. is reserved for comments on previous subjects which should reflect the personal experience of plant personnel.

Gas cleanings costs have been divided into two main classifications, Section III Equipment Charges and Section IV Labor Costs. Generally speaking, it has been assumed that initial collector costs (separated from freight charges) would not differ materially from one place in the country to another insofar as commercially available collectors are concerned. It is very possible, however, that duct and fan installations may be quite different and therefore should not be considered as part of the integral collector cost. In reporting initial cost on a basis of dollars per 1000 cfm capacity per year, the total cleaning capacity should be furnished, since average cost will decrease with large volume installations. Write-off figures which serve to prorate equipment costs over the period of useful life may vary considerably. Reasons for a particular time should be explained if these data are to be used for future design criteria. A five year write-off period, for example, may be justified from a

financial point of view, but may actually be five to ten years short in describing collector life.

Labor charges on the whole are practically meaningless unless defined in terms of man-hours and labor classification. Here an attempt should be made to distinguish between charges associated with equipment installation and those connected with routine procedures, i.e., maintenance, inspection, cleaning, filter replacement, decontamination, and several miscellaneous operations. All of the items listed in Sections III and IV represent costs that should be charged directly to air cleaning operations although individual plant bookkeeping systems may not so indicate. From the statistical viewpoint, they show in true perspective the economic consideration associated with a proposed air cleaning system.

Assessment of operations that simultaneously represent air cleaning procedures and product recovery processes should be judged on their individual characteristics. If the intrinsic value of the material to be recovered coincidentally dictates a degree of cleaning equal to or more than that required from the hazard viewpoint, the costs associated with the operation should be considered a basic production charge. On the other hand any part of the air cleaning system whose sole function is to prevent dissemination of toxic materials should be considered separately.

However, regardless of charge classification, a cost analysis should be attempted since these figures would apply equally well to another system where everything but the recovery value of the dust is the same.

It is proposed that each site investigate only representative air and gas cleaning systems for typical operations. However, if one particular installation appears to be well out of line with respect to both average cost and performance, the unusual features should be described.

Insofar as possible, results of the survey will be presented by the nature of the operation upon which the collector is installed without reference to location.

At present there appears to be a universal agreement on the necessity for an economic survey of air and gas cleaning operations within the AEC. However, the problem of time and manpower allocations at the various sites still presents a stumbling block.

Since authorization from plant management will be required in most cases for extensive participation, the Division of Reactor Development is planning to contact site managers and operators to formulate a practical approach.

The benefits to be derived from a comprehensive survey are summarized below.

1. The AEC and contractor groups will obtain a clearcut picture on the actual cost of air and gas cleaning operations.
2. Evaluation of cost and performance data will permit selection of optimum cleaning techniques for new operations and elimination of unsatisfactory methods for existing operations.
3. Compilation of survey results in the form of a manual will permit a reasonable estimate of the cost and air cleaning problems associated with the forthcoming application of nuclear engineering in the field of private industry.
4. Examination of total costs may indicate that a centralization of responsibility for the handling of air cleaning problems may in itself lead to considerable savings.

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**BASIC INFORMATION REQUIREMENTS FOR  
ECONOMIC SURVEY OF AIR AND GAS CLEANING  
OPERATIONS WITHIN THE ATOMIC ENERGY COMMISSION  
(Tentative Outline)**

**Descriptive and Operational Data**

**I Descriptive data**

**A Manufacturer**

**B Trade name**

**C Cleaner classification and type**

**1 Roughing or precleaning**

- a Oil coated metal screens, ribbon, expanded metal
- b Coarse fiber-bulk or preformed glass, mineral, metal, synthetic
- c Low efficiency paper
- d Electrified fiber media
- e Wet cell washers
- f Wet scrubbers, water or chemical
- g Others

**2 High efficiency precleaner or final cleaner**

- a Low voltage, 2 stage electrostatic precipitator
- b High voltage electrostatic precipitator
- c Fiber bed, bulk or preformed
- d Woven and felted fabrics
- e Deep bed sand or fiber filters

**3 Ultra (Absolute) filter, CWS or AEC types**

- a Cellulose asbestos
- b All glass

**II Operational data**

**A Site application**

**1 Prefilter, supply air**

- a General ventilation
- b Special hoods
- c Process air (cooling)
- d Other

**2 Precleaning, exhaust air**

- a Laboratory, level, isotope
- b Production areas
- c Other

**3 Final cleaning, exhaust air**

- a Laboratory, level, isotope
- b Production area
- c Other

**4 After cleaning, exhaust air**

- a Emergency system
- b Special applications

**5 Product recovery**

**B Cleaning requirement and process**

- 1 Dust, mist, fume, vapor removal, also rare gases
- 2 Aerosol composition

- 3 Particle size characteristics
  - 4 Concentration, weight or activity/unit volume of gas
- C Space requirements**
- 1 Over-all dimensions (unit collectors) and capacity, cfm, or with parallel or banked units
  - 2 Cubic feet per cfm cleaning capacity
  - 3 Face area per 1000 cfm cleaning capacity
- D Operating characteristics**
- 1 Filtering velocity, fpm
  - 2 Pressure loss, inches water
    - a Initial (clean filter)
    - b Maximum allowable before removal or cleaning
  - 3 Power requirements, hp per 1000 cfm air
    - a Fan system
      - (1) Based on cleaner pressure loss only
      - (2) Based on entire system, including other cleaning devices and hood, duct, and stack system
    - b Water sprays or scrubbing liquid, pump hp per 1000 cfm air
    - c Electrical power, electrostatic precipitators kw per 1000 cfm air
  - 4 Cleaner service life
    - a Before cleaning or replacement, or
    - b Mechanical overhaul
  - 5 Operating temperatures and humidities
  - 6 Water or scrubbing liquid volume, gallons per 1000 cfm air
    - a Spray nozzle type and pressure, lb per sq in., gage
    - b Per cent recycle
    - c Chemical requirements, lb of reagent per 1000 cfm air
  - 7 Collection efficiency, weight and activity basis
- E Method of replacement or cleaning of media**
- 1 Washing, steam cleaning
  - 2 Washing and reoiling
  - 3 Replacement of filter media, i.e., airmat paper, felt bags
  - 4 Replacement of complete package unit, i.e., Dust Stop, AEC filter
  - 5 Vacuum cleaning
  - 6 Other
- F Criteria for cleaner changes**
- 1 Pressure loss
  - 2 Activity
  - 3 Time cycle
  - 4 Other, including mechanical failure due to erosion, corrosion, or chemical attack, or due to faulty design or application
  - 5 Who determines criteria for maintenance? Health Physics Dept., Engineering Dept., Industrial Hygiene Dept., Maintenance Dept., or other
- G Handling and disposal methods**
- 1 Personnel protection
  - 2 Packaging
  - 3 Baling
  - 4 Incineration
  - 5 Burial or storage
- H Comments, relative to above items**
- 1 Reason for selection of any one type of cleaner
  - 2 Is this device satisfactory as to quality of cleaning, over-all cost?

- 3 Suggestions for improving performance based on field experience
- 4 Recommended research

#### Gas Cleaning Costs

Note: Equipment and replacement parts should be defined in terms of purchase price. Freight charges should be given separately. Installation charges, if not included in collector price, and all labor costs arising from maintenance repair, inspection, etc., should be expressed in terms of man-hours per 1000 cfm/yr. Indicate labor category, such as laborer, millwright, technician, and health physicist.

#### III Equipment charges, average yearly costs

- A Initial collector cost (separate from freight costs), including filter frames, \$'s/1000 cfm not including fan, or duct work, or installation; unless some special factors involved such as sprays in duct system, special materials or linings, etc., - explain
- B Item A based on 5- to 10-year write-off, \$'s/1000 cfm/yr. Indicate write-off period and explain
- C Replacement parts, over-all yearly cost, \$'s/1000 cfm/yr
  - 1 "Throwaway" filters, roughing type
  - 2 "Ultra" filters, AEC type
  - 3 Replacement media
  - 4 Filter bags
  - 5 Other
- D Replacement parts, item C cost/standard replacement unit

#### IV Labor charges, over-all yearly cost

- A Installation over and above equipment cost, based on equipment write-off period, man-hours/1000 cfm/yr
- B Routine maintenance and inspection, man-hours/1000 cfm/yr
- C Cleaning or replacing filter media, man-hours/1000 cfm/yr
- D Handling and disposal, man-hours/1000 cfm/yr
- E Labor charges, individual filter replacement, man-hours/1000 cfm/yr
  - 1 Cloth bags
  - 2 Absolute filters
  - 3 Other
- F Costs associated with clean out and repair of hoods, duct work decontamination pertaining to maintenance, etc., man-hours/1000 cfm/yr
- G Miscellaneous costs
  - 1 Average cost of lost production due to equipment downtime or exhauster
  - 2 Fan maintenance
  - 3 Costs of air cleaning as per cent of total plant maintenance cost
  - 4 Indirect costs: How much of the time and/or labor in equipment's failure or maintenance is hidden in other departments and not directly charged to the collector maintenance: for example engineering, health physics, maintenance, etc.

# AIR CLEANING COSTS—A STUDY OF THREE SYSTEMS

Harry S. Jordan  
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## 1 INTRODUCTION

It is evident that, as experience is gained in all phases of handling radioactive materials, the expense of experimentation can no longer be justified in the cost of a basic facility. This is true of air cleaning facilities, but if unsatisfactory experiments are not to be repeated, the operating experience with the air cleaning facilities installed in the early days of the atomic energy industry must be reported. The purpose of this paper, therefore, is to detail experiences and costs in operating three of the earlier air cleaning facilities that were designed for the Los Alamos Scientific Laboratory for DP West Site, CMR Building, and Ten Site. These systems, with some modifications which will be discussed, are still in use, and they cover air cleaning problems of aerosols from plutonium oxides and salts, chemical and metallurgical research, and beta-gamma activity.

## 2 METHOD OF PRESENTATION

Each system is described in detail and the nature of the original problem discussed. The cost of air cleaning per cubic foot per minute per year is developed from three factors: depreciation, operation, and maintenance.

The depreciation factor consists of two items: (1) the estimated depreciation of the air cleaning system, and (2) the depreciation of the building housing the unit. These figures are estimates but will indicate two important features of the systems, namely, the expected life of the system based on close observation and the floor area provided for housing the units.

The operating cost item includes computations for the cost of renewing the air cleaning media; utilities, including waste disposal; and health services. The labor cost shown will be the actual cost of labor chargeable to the item by the service company serving the town of Los Alamos and the Laboratory. Because most servicing and repair must be done after the regular working hours, much of the labor is overtime, plus hazard pay for the skilled crafts.

Utilities are charged at the established rates for the Los Alamos Scientific Laboratory: \$0.27 per 1,000 gallons of water; \$0.007 per kilowatt-hour of electrical energy; \$0.90 per cubic foot for collection and burial of radioactive dry trash;<sup>1</sup> \$0.009 per gallon<sup>1</sup> in the case of CMR Building, and \$0.01 per gallon in the case of Ten Site for disposal of radioactive liquid waste.

The cost of health services is based on the number of man-hours, estimated from experience, necessary to cover each individual job. This item obviously will be largely dependent upon the number of workers employed to accomplish the task and the manner in which it is done, but the time estimate should be reasonably correct for any reasonable approach to the job. The cost per man-hour of monitoring has been set at \$5 by LASL, under the cost allocation system used here.

The maintenance item is the cost of repairing pumps, water lines, and other apparatus connected with the air cleaning system. It is the maintenance engineer's best estimate based on actual operating experience. The cost may appear high but, again, overtime and hazard pay is a consideration.

Table 1 summarizes costs for all three systems which are also discussed individually.

## 3 AIR CLEANING FACILITY FOR DP WEST

DP West is the LASL's plutonium facility engaged in the formation of plutonium metal from its salts, fabrication of the metal, and recovery of the metal. Consequently, the aerosol con-

sists of plutonium oxides and salts. The air cleaning system to handle this plutonium aerosol was designed, however, at a time when the designer could not be told it was to remove plutonium from the air. It is reasonably certain that the design criterion was for a metal fume of extreme toxicity. When the threshold limits for nonradioactive poisonous materials, which are in the  $1 \times 10^{-1}$  mg/m<sup>3</sup> range, are compared to that for plutonium of  $1 \times 10^{-8}$  mg/m<sup>3</sup>, it is reasonable to suppose that the thinking of the designer could have been wrong by several orders of magnitude in this respect.

Table 1—SUMMARIZED ANNUAL COSTS OF AIR CLEANING

System	Depreciation	Operation	Maintenance	Total cost	Flow rate, cfm	Cost per cfm
DPW						
Electro-Matic	\$15,690	\$4,450	\$10,700	\$30,840	184,000	\$0.17
PL-24	1,760	10,250	1,500	13,510	184,000	0.07
Combined	17,450	14,700	11,700	43,850	184,000	0.24
CMR	6,830	12,660	4,140	23,630	35,000	0.68
Ten Site	9,970	8,820	6,040	24,830	27,600	0.90

The system as originally installed consisted of the American Air Filter Electro-Matic unit followed by PL-24, 10-ply paper filters. Sufficient units were installed to handle 184,000 cfm at half of rate air cleaning capacity. (See Fig. 1.)

Inasmuch as the Electro-Matic units were taken out of service in 1949, very little data on their operation are available. The units were discontinued, because of the required maintenance, when Absolute type filters became available for air filtration at the source of contamination. The PL-24 filters have been continued in service, however, to serve as a backup for prefiltered air and a minimum filtration for exhaust air that is not prefiltered. The efficiency of the PL-24 filters is approximately 60 per cent for the plutonium aerosol which ranges in median size from 0.3 to 1.0  $\mu$  with a standard deviation of 1.5 to 3.

#### 4 DP WEST AIR CLEANING COSTS

The cost figures for the air cleaning systems at DP West are summarized in Table 1 and detailed below.

##### 4.1 Depreciation

For the purpose of establishing the influence of the initial costs in the cost for air cleaning per cubic foot of air per minute, the initial cost of the air cleaning equipment has been estimated. The American Air Filter Electro-Matic unit's initial cost was estimated<sup>2</sup> at \$400 per 1,000 cubic feet per minute rated capacity and the useful life set at 10 years. For a system of 184,000 cfm at one-half capacity, the total initial cost would be \$147,200 and the annual depreciation \$14,720.

The initial cost for the PL-24 filters was computed on the basis of \$50 per cell installed. Thus, the annual cost of 315 cells with an estimated system life of 20 years is \$790.

##### 4.2 Occupancy Charge

The occupancy charge is based on the square foot of building space that logically could be assigned to the air cleaning units. The cost of such space is estimated at \$10 per square foot with a 20-year depreciation period. In this case, the Electro-Matic and PL-24 units each occupy a space 97 by 20 ft. The annual occupancy charge is, therefore, estimated at \$970.

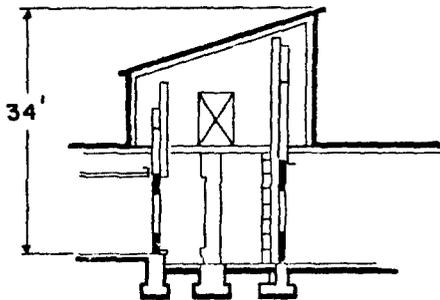
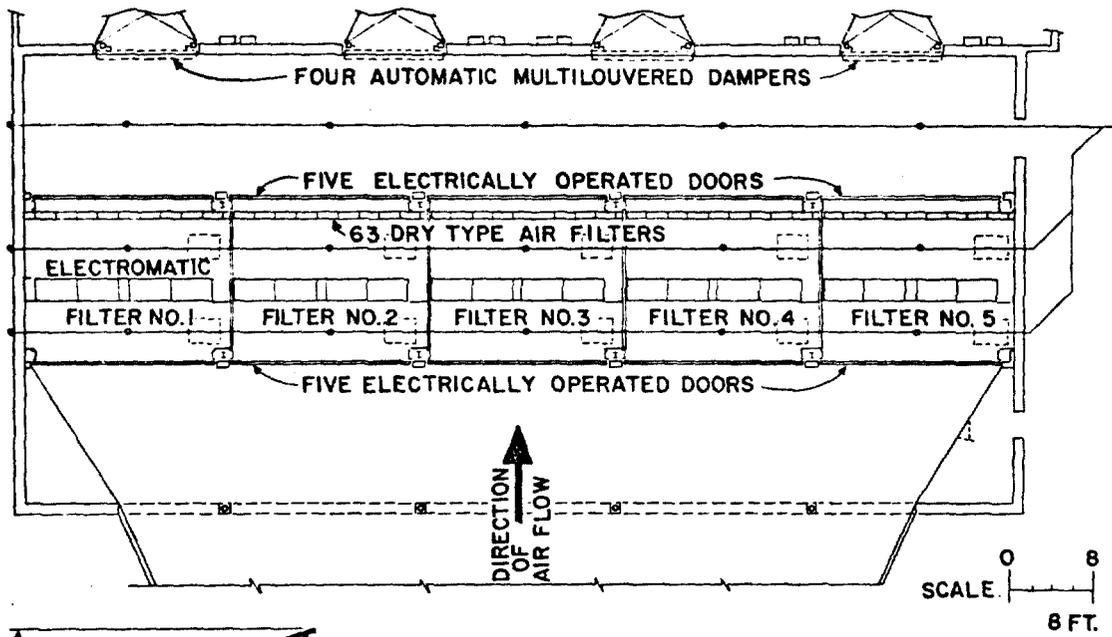


Fig. 1—DP West air cleaning facility.

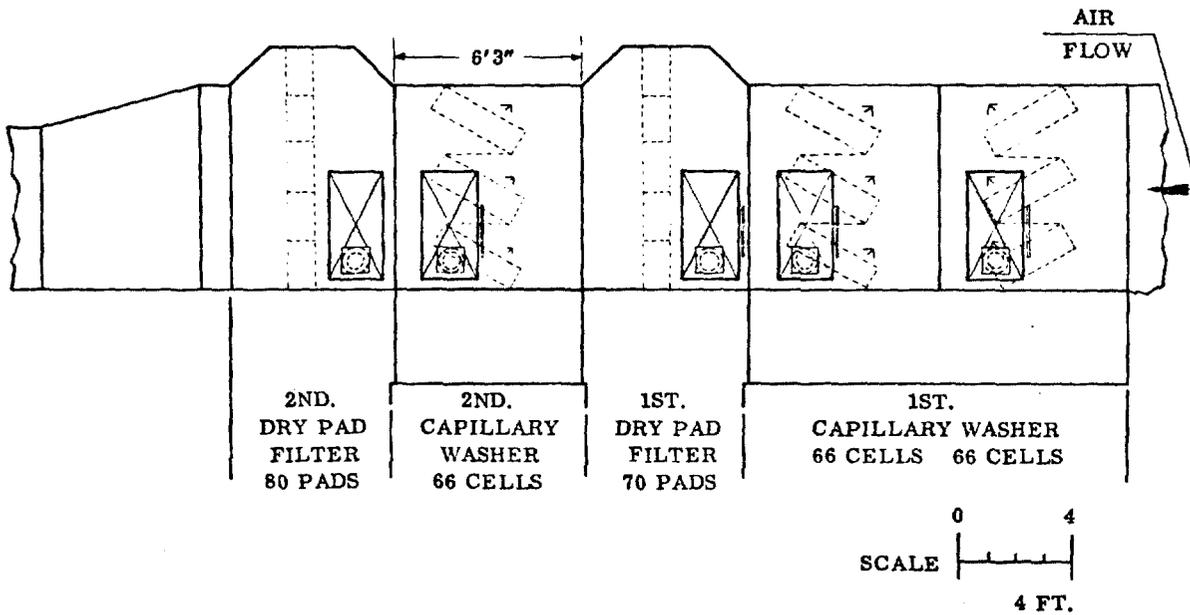


Fig. 2—CMR Building air cleaning facility.

### 4.3 Operating Costs

The operating cost for the Electro-Matic units has to be estimated since the units were taken out of service in 1949. The estimated annual electrical operating cost, including the power pack, of \$450 is derived from the Handbook on Air Cleaning<sup>2</sup> and adjusted for power costs of \$0.007 per kilowatt-hour, 8,760 hours per year operating time, and 184,000 cfm. The last year in which the Electro-Matic units were operated, the total cost of maintenance and operation was \$13,135. Of this amount it is estimated that about \$4,000 could be charged to operation.

The operating costs for the PL-24 filters operating without the Electro-Matic units are available in detail. It has been found that for operating reasons the filters must be changed three times a year. The cost of each filter change at present Los Alamos prices is as follows:

1. Material		
40 rolls of PL-24 10-ply paper, at \$7 per roll		\$ 280
2. Labor		
32 man-hr at straight time		
143 man-hr at hazard pay (straight time + 10 per cent)		
113 man-hr at double time		
Total labor		1,912
Zia Company overhead charge at 7 per cent		152
3. Health services		
Equipment (coveralls, boxes, etc.)		300
Monitoring, 130 man-hr at \$5 per hour		650
4. Waste disposal		
100 cu ft, at \$0.90 per cubic foot		90
	Total	\$ 3,384
5. Total annual cost (3 filter changes per year)		\$10,152

The electrical operating cost computed on the basis of a pressure drop of 0.05 in. water, exhaust rate of 184,000 cfm, 8,760 hr of operation per year and \$0.007 per kilowatt-hour, amounts to \$100 per year. Total annual operating cost for the PL-24 filters alone is, therefore, \$10,250.

### 4.4 Maintenance

As stated above the total cost of maintenance and operation for the Electro-Matic units was \$13,135. Approximately \$9,200 of this amount could be attributed to maintenance. Health services for this amount of maintenance have been estimated at approximately \$1,500. The total annual maintenance, therefore, amounts of \$10,700.

Maintenance on the PL-24 filters would be limited to maintenance of the filter housing and appurtenances. After 10 years about 100 frames need replacing, and it is estimated that 400 frames will be replaced in the 20-year life of the system. Actual cost of the frames is \$31.27 and the estimated cost per frame installed in place is \$50. The annual cost of replacing frames, therefore, could be set at \$1,000. The cost of miscellaneous maintenance together with necessary health services would also approximate \$500 and the total cost of maintenance would be \$1,500 per year.

In summary, it can be stated that the figures for the PL-24 filters accurately reflect the cost of operating (\$10,250) and maintaining (\$1,500) the filters. The figures for depreciation (\$790) and occupancy (\$970) are believed to be reasonable estimates. The total annual cost for the PL-24 filters, therefore, is \$0.07 per cubic foot per minute, and of this the operation and maintenance cost is \$0.06 per cubic foot per minute.

If the estimates and known costs for operating the Electro-Matic units are added to the PL-24 filter cost, the total annual cost is \$0.24 per cubic foot per minute.

## 5 CMR BUILDING

The CMR Building is a large laboratory devoted to radioactive chemical and metallurgical research. It was originally thought that the air cleaning systems would have to handle exhaust air containing plutonium and uranium ( $U^{235}$ ) in every possible dispersoidal form and in such quantity as to be economically feasible to recover. There was also considerable concern that the anticipated quantity of acid fumes in the effluent might create a nuisance. It was believed, therefore, that a wet air cleaning system would aid in the recovery of fissionable metals, prevent the emission of acid fumes, and be more economical to operate and maintain. Unfortunately, none of these presumptions has been borne out. The increased supply of fissionable material has reduced the value of recovery operations, and the advantages of wet recovery over dry recovery are not pronounced. The amount of acid fumes released to exhaust air did not create a nuisance problem, nor is it anticipated that it will. Actual operation of the systems has indicated that the original estimate of operation and maintenance costs was completely unrealistic.

The system as designed for the CMR Building is shown in Fig. 2. The air first passes through two wet pads. The wet pads consist of a random pack of 300- $\mu$  glass fibers packed 6 lb/cu ft in a 20- by 20- by 8-in. cell. The first bank of cells is sprayed countercurrent and the second bank sprayed concurrent at the rate of 8 gal/min/cell. The air next passes through zigzag water eliminator plates before being filtered by dry pads. The dry filters consist of 1½ in. of 100- $\mu$  glass fiber pad plus a ½-in. pad of 10- $\mu$  glass fibers. The air then passes through another wet washer of 300- $\mu$  glass fiber sprayed concurrently, then eliminator plates, and finally another dry pad identical to first dry filters.

## 6 CMR BUILDING AIR CLEANING COSTS

The cost figures for a CMR Building air cleaning system are summarized in Table 1 and detailed below.

### 6.1 Depreciation

In 1950 the installation cost of the CMR Building system was \$2.40 per cubic foot per minute and each system exhausted 35,000 cfm. Total cost, therefore, was \$84,000 for each of the ten systems. The estimated useful life of the system, if operated as designed, is 15 years. The depreciation per year, therefore, would be \$5,600.

### 6.2 Occupancy Charge

The amount of floor space that logically could be assigned to the air cleaning unit is 56 by 44 ft, or 2,464 sq ft. At \$10 per square foot depreciated over a 20-year period, the occupancy charge per year is \$1,232.

### 6.3 Operating Costs per System

The unit costs for changing the air cleaning media are as follows:

#### 1. Wet cells

Cost per cell for changing (material \$12, labor \$3)	\$15	
Total number wet pads per system	198	
Expected life of wet pads	2 years	
Annual cost for changing wet pads		\$1,485

#### 2. Dry pads

Cost per pad for changing (material \$2, labor \$2)	\$4	
Total number pads	150	

Expected life of pads, 1st bank (70)	1 year	
2nd bank (80)	2 years	
Annual cost for changing dry pads		\$ 440
<b>3. Utilities</b>		
a. Water		
Evaporation, 1.5 gpm	8,760 hr/year	
Bleed off, 1.5 gpm	8,760 hr/year	
Cost of water	\$0.27 per 1,000 gallons	
Annual cost of water		\$ 425
b. Electrical		
3 pumps, 15 hp	8,760 hr/year	
Pressure drop through system	1.75 in. water	
Air flow rate	35,000 cfm	
Fan efficiency	65 per cent assumed	
Cost of electrical power	\$0.007 per kilowatt-hour	
Annual cost of electrical power pumps	\$2,050	
Pressure drop	\$ 690	
Total annual electrical cost		\$2,740
c. Waste disposal		
Liquid waste volume, 1.5 gpm	8,760 hr/year	
Cost of waste treatment	\$0.0093 per gallon	
Annual cost of liquid waste	\$7,332	
Dry waste volume	200 cu ft	
Cost of collection and burial	\$0.90 per cubic foot	
Annual cost of dry waste disposal	\$180	
Total annual cost of waste disposal		\$7,512
<b>4. Health services</b>		
Wet pad changes	8 man-hr/year	
Dry pad changes	4 man-hr/year	
Cost of health services	\$5 per man-hour	
Total annual operating health costs		\$ 60
<b>5. Total annual cost of operation</b>		<b>\$12,662</b>
<b>6.4 Maintenance Cost per System</b>		
1. Water nozzle cleaning		
Labor	6 times/year	\$3,000
Water—8,000 gal draw and fill 6 times		
per year		\$20
Waste disposal, 48,000 gal		\$450
Health services, 24 man-hr at \$5 per hour		\$120
Total		\$3,590
2. Miscellaneous maintenance		
Cost per year		\$ 500
Health services		\$ 50
<b>3. Total annual cost of maintenance</b>		<b>\$4,140</b>

It should be mentioned that the actual annual cost of operation and maintenance per system is \$16,800 or \$0.48 per cubic foot per minute as compared to an original estimated cost of \$1,730 or \$0.05 per cubic foot per minute.

The total annual cost per system including depreciation is \$23,630 or \$0.68 per cubic foot per minute.

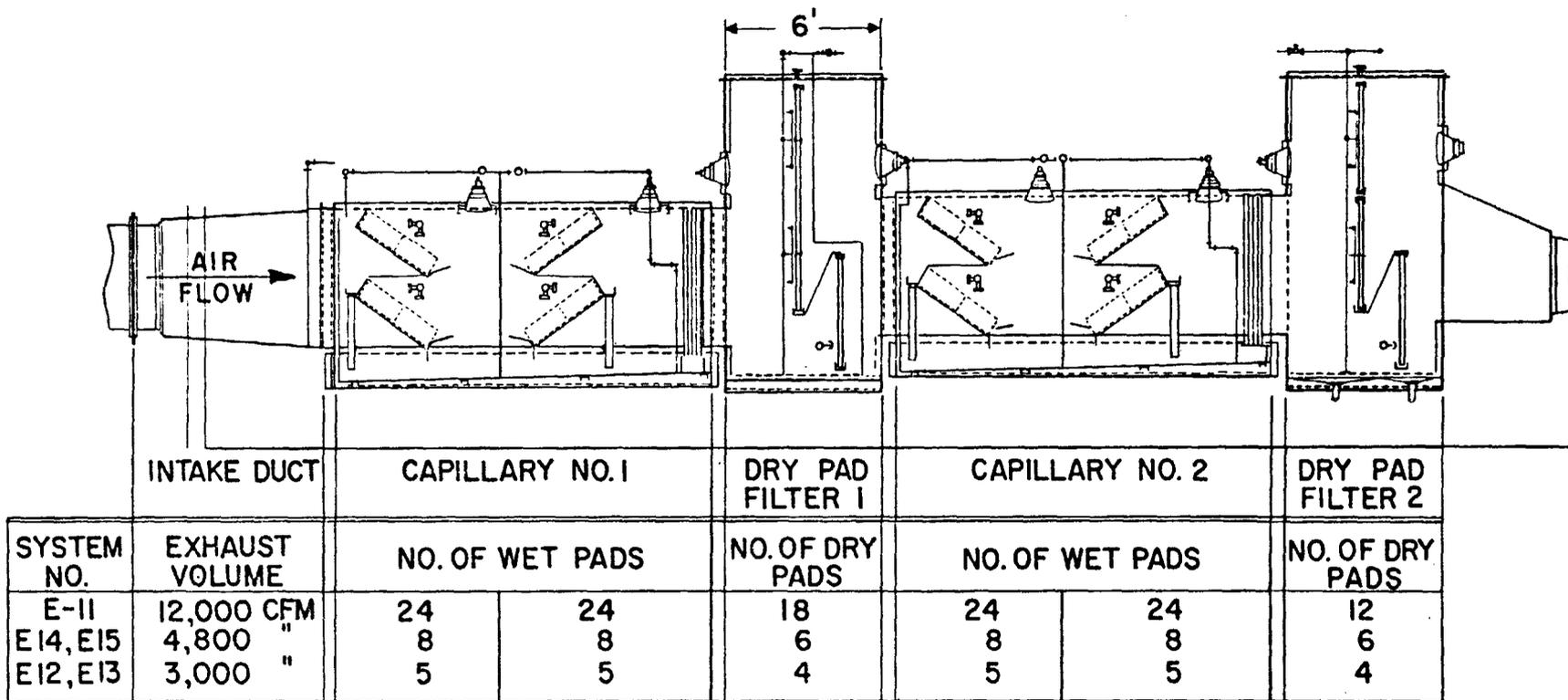


Fig. 3—Ten Site air cleaning facility.

The main operating problem in connection with this system was the plugging of the nozzles. This was caused by short lengths of the 300- $\mu$  glass filaments becoming suspended in the recycled spray water, and eventually sealing the nozzles completely. As noted in the analysis of cost, this difficulty required draining the system and cleaning the nozzles every 2 months. Efforts to strain the glass fibers were never very successful, since the fibers would become so oriented as to pass coarse filters and would mat over a fine filtering device. The water supply for Los Alamos contains 200 ppm total dissolved solids, but even with this relatively low percentage of solids, the recycled water became highly concentrated. It became evident that to prevent undue plugging of the wet washers and faster plugging of the spray nozzles owing to salt buildup, it would be necessary to bleed off the concentrated water at the same rate the water was evaporated. Preliminary design considerations indicated that ion exchange system for treating the water would cost \$50,000 plus the cost of operation. Because of the cost of operating the wet system, it has been decided to replace all the systems with a type of dry filtration specifically designed to handle the aerosol produced in each specific area of the building.

## 7 TEN SITE AIR CLEANING SYSTEM

The entire air cleaning facility for Ten Site consists of five separate systems that are identical except for their capacity. The Ten Site air cleaning system as shown in Fig. 3 is essentially the same as the air cleaning system for CMR Building, with the major exception that laboratory liquid waste and the exhaust air are carried in the same duct. There is also an additional bank of wet washers. The waste water is used as the source of spray water for the air washers. This necessitates the incorporation into the combined system of four 50,000-gal storage tanks. In the following cost analysis the depreciation of only one of the tanks is charged to the cost of the air cleaning system, since the other three could logically be charged to liquid-waste disposal.

The system was designed to handle an aerosol with beta-gamma activity, predominantly one resulting from handling barium-lanthanum equilibrium mixture. Thus, although there was no recovery problem in connection with the aerosol, it was thought that the wet washer would be more effective in collecting the Ba-La aerosol which is evolved in an acid fume and, by washing the filter media, reduce the time the air cleaning system would be a source of gamma radiation. The system has accomplished these objectives reasonably well. The main problem in connection with this system was the rather belated discovery that the Ba-La mixture contained small variable amounts of strontium ( $\text{Sr}^{90}$ ) and that the concentration of  $\text{Sr}^{90}$  present in the waste water was too high for discharge. This meant that a waste-water treatment facility had to be added to the liquid waste-exhaust air system. A proportionate part of the cost of this facility has been assigned to the air cleaning system.

## 8 TEN SITE AIR CLEANING COST

The air cleaning costs for Ten Site are summarized in Table 1 and detailed below.

### 8.1 Depreciation

The installation cost for this system has been set at \$3 per cubic foot per minute. The total exhaust capacity of all the systems is 27,600 cfm and the expected life is 15 years. The total cost, therefore, would be \$82,800 and the annual depreciation \$5,520. The cost of the storage tanks has been estimated at \$1 per gallon capacity plus \$4,000 per tank for appurtenances. The total cost per tank would be \$54,000 and, with an expected life of 20 years, the annual depreciation would amount to \$2,700.

### 8.2 Occupancy

The floor area necessary to house the systems is 66 by 53 ft, or about 3,500 sq ft. At \$10 per square foot and a 20-year life the annual occupancy charge is \$1,750.

### 8.3 Operating Costs

#### 1. Wet cells

Cost per pad for changing media (material \$12, labor \$3)	\$15	
Total number of wet pads all systems	200	
Expected life of wet pads	2 years	
Annual cost for changing wet pads		\$1,500

#### 2. Dry pads

Cost per pad for changing (material \$2, labor \$15)	\$17	
Total number of pads all systems	70	
Expected life	2 years	
Annual cost for changing dry pads		\$ 595

#### 3. Utilities

##### a. Electrical

9 pumps, 3 hp	8,760 hr/year	
2 pumps, 8 hp	8,760 hr/year	
1 pump, 1½ hp	8,760 hr/year	
Total horsepower hours per year	384,500	
Air flow rate	27,600 cfm	
Pressure drop	2 in. water	
Fan and efficiency	65 per cent assumed	
Annual cost of electrical power		
Pumps	\$2,000	
Pressure drop	\$ 600	
Total		\$2,600

##### b. Waste disposal

Liquid waste volume	1,000 gal/day	
Cost of waste treatment	\$0.01 per gallon	
Annual cost liquid waste		\$3,650
Dry waste volume per year	250 cu ft	
Cost of collection and burial	\$0.90 per cubic foot	
Annual cost of dry waste		\$ 225

#### 4. Health services

Wet cell changes	20 man-hr/year	
Dry pad changes	30 man-hr/year	
Cost of health services	\$5 per man-hour	
Annual cost of operating health services		\$ 250

#### 5. Total annual cost of operating

\$8,820

### 8.4 Maintenance Cost

#### 1. Nozzle cleaning

Labor per year	\$2,000	
Health services (48 man-hr)	\$240	
Total	\$2,240	

#### 2. Miscellaneous maintenance

Health services	\$3,500	
	\$300	

#### 3. Total annual maintenance cost

\$6,040

The annual cost of operating and maintenance for the Ten Site air cleaning facility is \$14,820 or \$0.54 per cubic foot per minute. The total annual cost, including depreciation, is \$24,790 or \$0.90 per cubic foot per minute.

## 9 SUMMARY

In connection with these three systems, it should be mentioned that their efficiencies and loadings are comparable and that the dry filtration system is serviced more often than normal, while the wet system would be in definite need of servicing at the end of the time intervals noted for changing pads and nozzles. Consequently, there is some danger that the cost variation between the wet systems and the dry system, detailed above, might be construed as more significant than is really justified. It should be stressed, therefore, that the cost analysis presented in this paper only compares one type of wet air cleaning with one type of dry air cleaning.

The variations in cost between the wet and dry systems, and the discrepancy between the original estimate of expected operating and maintenance cost and the actual cost of these factors does indicate that there are factors of cost involved in a wet air cleaning system that should receive careful consideration prior to adopting such a system. At Los Alamos, we feel that wet methods of air cleaning are inherently more expensive than dry filtration and that, unless the unique properties of wet collection are required by the nature of the aerosol, dry filtration is generally preferable.

The desirability of designing the air cleaning system so that air cleaning media can be readily changed is emphasized by the \$15 labor charge per dry pad change in the Ten Site system. In this case, the dry pads are held in place by an unduly complicated method. The matter of requiring men to enter highly contaminated areas in protective equipment to change filter media should also receive more attention. The men generally earn hazard pay and must work at a slower rate in such a situation.

## ACKNOWLEDGMENT

The assistance of Group ENG-4 at LASL, particularly L. P. Page, C. A. Reynolds, D. B. Ritter and F. H. Rossiter, in collecting the data presented in this paper is gratefully acknowledged.

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# STUDY OF THE FUNDAMENTAL PROPERTIES OF AEROSOLS

H. F. Johnstone

*University of Illinois*

The work on the project has been retarded during the past year because of illness of the Director who has been on disability leave from the University since September 1956. He has, however, been able to direct the work of three part-time research assistants and some things have been accomplished that may be of practical interest and value in the control of aerosol problems in nuclear energy plants. These will be described briefly here and reported in detail in forthcoming technical reports.

A complete theoretical analysis has been made of the effect of electrostatic charges on the deposition of aerosols on cylindrical collectors. The work supplements that reported two years ago on spherical collectors which was published in a paper by H. F. Kraemer and H. F. Johnstone.<sup>1</sup> The cases studied include those in which an electrostatic charge exists on the aerosol particles or on the collector, or both. Experimental studies were made which verify the theoretical conclusions. These included measurements on the filtration of charged aerosol particles and filtration by tangled wire dipole mats and by charged filter mats. These devices have been suggested as means of improving the filtration of very small aerosol particles. The results show that the existence of a charge either on the particles, or on the filter mat, increases the filtration efficiency, but the charge on the mat must be maintained in some way. Several methods of doing this have been suggested and still others are suggested by the work.

It has been interesting to find that when charged aerosol particles are collected on glass fiber filter mats the efficiency increases at first, passes through a maximum, and gradually decreases with time.

A brief study was made on the removal of aerosol particles from gases by means of pellets charged electrostatically by pneumatic conveyance through a duct. The work was done on a small 18-in. cyclone equipped with means for introducing the charged pellets at the center of the rotating gas stream. Aerosols of ammonium sulfite and ammonium chloride particles with mean diameters of 1.3 and 0.4  $\mu$ , respectively, were used. The pellets were 30- to 100-mesh glass or plastic beads which were circulated at the rate of only 3 to 20 g/cu ft of gas. While the efficiency of the collection of the particles was low, the results show that the device might be developed for large scale use in the filtration of submicron particles in large cyclones. Under such conditions the efficiency appears to increase with larger gas flow and smaller particles. The AEC has indicated interest in filing a patent application on the device.

Experiments were made under similar conditions using charged droplets of water fed to the center of the rotating gas stream. This required high potential and careful insulation of the water system. The device gave higher efficiency of collection of small aerosol particles than either a dry cyclone or a wet cyclone with uncharged droplets.

Further work has been done on the nature of agglomerated aerosol particles consisting of aggregates of unitary particles. Several distinctly different aerosols were used, including uniform spherical primary particles and needle shape particles. The principal result of this work has been the adaptation of the Millikan cell for measurements which provide information on the settling and impactability properties of aerosols which are often encountered in practice. Certain generalizations have been found that may serve as a rough correlation of the properties of aerosol agglomerates.

Brief studies were made on the self-nucleation of the formation of the liquid phase in the condensation of water and alcohol. These studies are important as a basis of using selective nucleation for the control of massive reactions in the atmosphere.

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# AIR CLEANING STUDIES AT HARVARD UNIVERSITY (1956-57)

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*Harvard School of Public Health*

The scope and functions of the Harvard Air Cleaning Laboratory are in the field of consultation, research, and development. The Harvard Air Cleaning Laboratory was established as the result of an AEC request of ten years ago. Our work can be described under five main objectives.

1. We are concerned with the development of test methods for the evaluation of equipment. In this respect I have appended to this paper a statement of policy in regard to these evaluations.

2. We are interested in the collection and correlation of information. This seminar (for the first time open to access permit holders) is in that regard. We desire to bring together all the available information that bears upon this problem.

3. There are many unsolved problems that continually develop in nuclear energy applications. We are often requested to provide evaluation of equipment for AEC application on an unbiased basis. This is done for sites or contractors desiring an opinion of their approach.

4. Our major responsibility is research on new procedures and modifications of existing ones to solve AEC problems.

5. We provide a certain amount of training and education for AEC personnel by assignment to our laboratory; by conference sessions with different groups; and by seminars such as this one.

It is rather interesting to point out what has happened in the 10 years we have been involved in the air and gas cleaning investigations for the Commission. I can remember the first session I attended on stack gas cleaning several years ago with AEC people. The wonderful performances of wet collectors were outlined to us along with some phenomenal results which later proved somewhat below par. One major advantage pointed out for wet collectors was the fact that once the aerosol was trapped in water in the air cleaner, you merely pumped it to the liquid waste disposal group and forgot about it. The circle has now been completed because the waste disposal boys now are going to make aerosols out of their liquid wastes. This again introduces new aerosol problems.

In AEC philosophy, as we interpret it for air and gas cleaning problems, the importance of containment has been well impressed upon us. We desire to place active materials in a situation from which they cannot disseminate and expose the site personnel or the public. Hence when considering the question of gas cleaning we believe the process should be modified so that gas or air volumes are maintained as low as possible. You will recall that some of the gas volumes mentioned at this seminar are in milliliters or liters per minute. Even in these small volumes considerable activity may be involved, hence the cleaning problems created by such small quantities can be serious.

Our efforts, as Professor Dennis has indicated, are now directed toward more information on economics. I believe Dr. Lieberman put his finger on what we are trying to do, essentially to get the cost of air and gas cleaning within reason for commercial as well as AEC applications. A number of engineers sometimes think in physicist's or academician's terms in regard to costs. In many cases this has been necessary because of health physics requirements.

In our development activities we have been interested in finding inexpensive methods of cleaning. One study we have continued for some time is in regard to electrostatic charging. We reported at previous seminars on charging fibrous filter beds, doing this either by mechanically rubbing or carding synthetic resin cloths or fibers in static beds and determining their performance and life. From this we have progressed to another basic approach, which Mr. Anderson will cover in detail, on the development of a "triboelectrified" fluidized bed for aerosol filtration.

Another problem with which we are concerned is the filtration or removal of fumes resulting from burning of liquid metals. At the moment unless it contains radioactive contami-

nants it is largely a nuisance problem. In the handling of the contaminated liquid metals it will become more serious. Mr. Kristal will report on this subject.

A problem that has plagued industry in general, as well as AEC, is the cleaning of particulates from high-temperature gases. Precipitator installations will perform well for certain aerosols in terms of public health or nuisance requirements. Their cost in large size installations can be expensive. A parallel project we are doing for the American Iron and Steel Institute is on high-temperature furnace gas cleaning. Some of this information will be of value for AEC and other activities. We have been working on an inexpensive slag wool filter which Professor Billings will cover in detail.

We have been asked by the AEC to develop an inexpensive air cleaner for the Bureau of Mines 30-lb/hr incinerator (BOMAEC-30). The Bureau was given a contract several years ago to develop an inexpensive incinerator for disposing of institutional radioactive wastes. It has turned out to be more expensive than anticipated. The problem of cleaning is also not as simple as planned. Plugging and bag cleaning difficulties are caused by tars formed during combustion. Complete combustion with a minimum production of a tar aerosol is desirable but absence of tar seems unlikely. The incinerator is a cylindrical tangentially overfired unit. For air cleaning it is provided with a spray type heat exchanger, followed by a cyclonic unit with glass cloth filter bags. An additional chamber is provided so that a combustible AEC filter may be inserted if necessary. This filter can be incinerated after its resistance becomes too high for adequate flow.

We have also considered the application of slag wool for an incinerator filter. Results are too preliminary to discuss in detail, but it appears to be useful as a prefilter or possibly the final filter. Because of its depth we are not concerned with plugging of tars as occurs on the glass cloth bag surface.

The slag wool development which Professor Billings will talk about has a corollary application for the removal of acid gases. This was discovered during field tests. We found in our field studies on open hearth furnaces that significant sulphur dioxide was removed by the wet slag wool. The wool used is made from basic blast furnace slag. It has considerable available alkali which serves a useful purpose in removing acids. Mr. Kurker will present detailed results of these studies.

The most recent application of slag wool investigated for AEC uses is to treat its surface with silver to determine its effectiveness for iodine removal. Iodine ( $I^{131}$ ) removal is a considerable problem which is of frequent occurrence in chemical processing. At present silver nitrate coated Berl saddle reductors maintained by heaters at a temperature of about  $150^{\circ}\text{C}$  are used. For some operations they have applied caustic scrubbers which give efficiencies from 85 to 95 per cent. The silver nitrate reactors will remove 99 per cent or more  $I^{131}$ . There is need to further reduce effluents with less expensive devices and additional work on this problem is indicated.

We have made some preliminary studies that look promising. Slag wool has been coated by chemical silver mirroring using the Rochelle salts process. When operating this bed at 50 to 100 ft/min, the velocity used for removal of iron oxide fume, we obtained 96 to 97.5 per cent removal on a 2-in., 5-lb/cu ft layer with a resistance of approximately 1 in. water. Only milligrams of iodine must be removed in practice because of its high specific activity. We believe other techniques can be used to place reactive silver compounds on the fiber. Some site monitoring people at Savannah River have found it possible to dip CC-6 paper in silver nitrate solution. This will do a fairly good job in field monitoring for iodine. Silver or silver nitrate coating of slag wool looks promising as an inexpensive way to reduce effluents from present reductors or scrubbing equipment. It is being investigated further at the present time.

Tables 1 and 2 present data on the applications of slag wool to other aerosols. These data were obtained on Mineralite slag wool filters of 3 lb/cu ft density at velocities of 150 to 500 ft/min in the thickness stated. Resistance in inches of water gauge ranged from 1 to 3 in. on the average but values as high as 7 in. were obtained. Data in Table 1 were obtained with re-suspended Cottrell ash ( $0.5 \mu$  by count). The average efficiencies shown indicate that with rather high velocities for slag filters (our approach to getting economical size filtering units

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Table 1—EFFICIENCY OF MINERALITE SLAG WOOL FILTERS  
ON RESUSPENDED NBS FLY ASH

Filter thickness in.*	Filtering velocity, ft/min	Average fly ash conc., g/cu ft	Average resistance, in. wg			Average operating time, mins.	Average efficiency, %	B, %†	B/Δ p
			Initial	Final	Δp				
1	150	0.068	1.00	1.94	0.94	139	83	52	55
1 (5)	150	0.066	1.48	2.35	0.87	97	84	26	30
1 (10)	150	0.062	3.80	6.30	2.50	128	92	18	7
2 (2.5)	150	0.064	0.91	1.34	0.43	118	87	31	72
2 (5)	150	0.066	2.74	5.00	2.26	181	96	28	12
1	170	0.100	1.13	2.13	1.00	68	88	52	52
1	210	0.068	1.22	1.58	0.36	56	69	29	81
1	235	0.094	1.89	3.09	1.20	52	81	51	42
1	275	0.095	2.50	3.30	0.80	28	68	26	32
1	300	0.200	2.36	4.17	1.81	30	76	87	48
1	330	0.078	3.12	3.67	0.55	18	60	16	29
1	500	0.160	4.12	7.36	3.24	19	59	50	15

\*Three pound per cubic foot packing density except as indicated, other densities shown in parentheses.

†Fly ash collected per initial filter weight, by weighing (expressed as per cent).

Table 2—RESULTS OF FLY ASH (CREATED BY DIRECT COAL BURNING) FILTER TESTS  
MINERALITE SLAG WOOL

Filter characteristics		Face vel., fpm	Temp., °F	Length of run, min.	Upstream concentration, g/ft <sup>3</sup>		Vola- tiles, %	In- itial Δ p, "H <sub>2</sub> O	In- crease Δ p, "H <sub>2</sub> O	Total eff.,* %	Fly ash eff.,* %	Total A,† %	A/Δ p rise
Thick- ness, in.	Den- sity, lb/ft <sup>3</sup>				Total	Fly ash							
1	3	147	550	36	0.026	0.012	54	1.2	1.4	97.0	93.5	4.3	3.1
		135	460	39	0.019	0.0061	68	1.0	0.6	96.9	93.9	2.6	4.3
1	5	129	435	43	0.017	0.0063	65	2.3	0.7	98.9	99.0	1.8	2.6
		129	405	45	0.027	0.0091		2.6	3.0	99.8	99.0	2.9	1.0
1	10	134	475	30	0.040	0.011	75	2.7	1.1	98.8	95.0	1.8	1.6
		127	415	35	0.033	0.011		4.5	1.5	99.3	98.0	1.5	1.0
2	3	122	405	20	0.022	0.0075		1.4	0.4	98.0	94.0	0.95	2.3
2	5	134	410	32	0.029	0.010	65	1.9	0.4	98.0	94.0	1.2	3.0
		127	365	40	0.026	0.0058	78	2.1	0.6	99.4	96.2	1.4	2.3

\*Gravimetric.

†Fly ash collected as total from upstream concentration, efficiency and time of run.

and possibly obtaining more filter life), we can obtain values as high as 96, but at extremely high velocities only 60 per cent removal is found. The B factor seen in Table 1 is a measure of the amount of material removed per unit weight of fiber expressed in per cent, in other words these filters remove a high percentage of their own weight. These are quite high on resuspended dust. On fume only 5 per cent removal is obtained, however, washing and reuse is possible for some particulates. In rating performance we divide the weight gain by the unit pressure drop as shown in column 10. The fly ash was generated by an NBS type solid aerosol generator. We know that this does not produce perfect dispersal.

Figure 1 indicates stain efficiencies of a given layer with continued testing time. The measurement of stain was done by the National Bureau of Standards technique. High stain efficiencies can be obtained as indicated. This performance would be comparable to fine fiber bonded fiber-glass values, but at higher velocities and corresponding resistance.

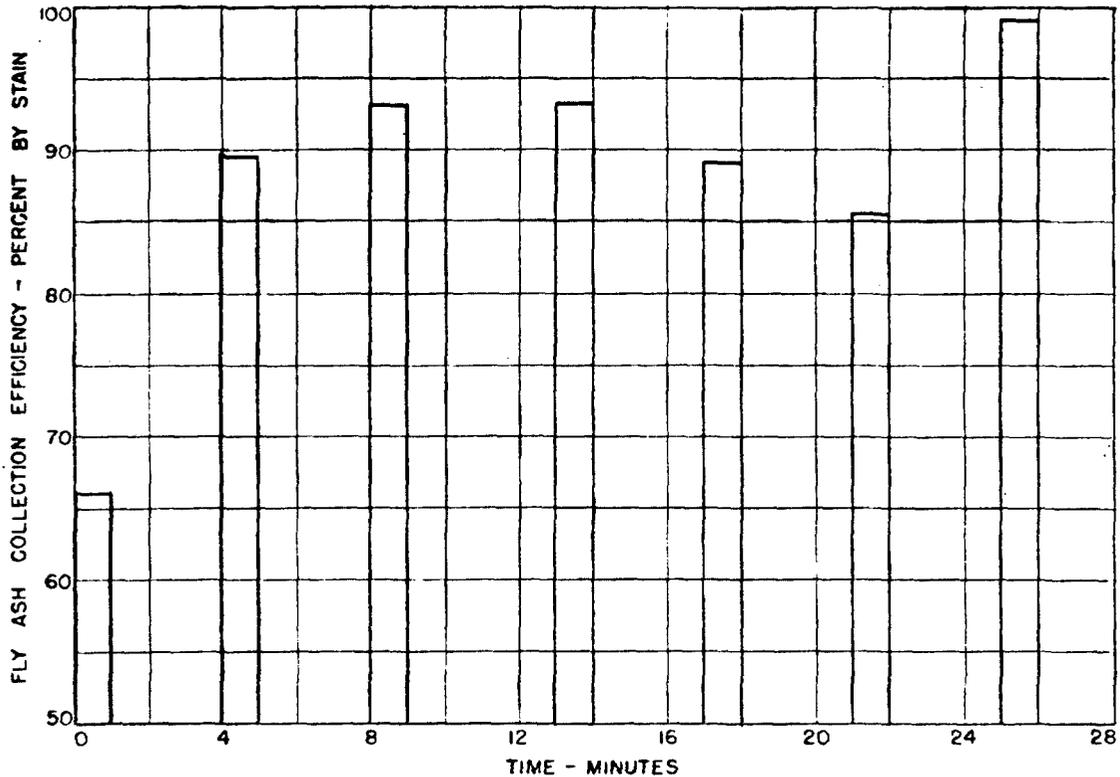


Fig. 1—Stain efficiency of slag wool filters for fly ash as a function of time.

Efficiency data are highly dependent on aerosol generation. Table 2 shows the results on slag wool beds tested against an aerosol created by burning powdered coal. It was not possible to burn the pulverized coal completely even with oxygen. Table 2 shows the per cent of combustibles remaining in the aerosol. These data were at fairly high loadings and temperatures. Slag wool will filter at 1100°F. Table 2 efficiencies are higher than those in Table 1 for resuspended fly ash. The recovery values, however, are below 5 per cent. Instead of a 50 per cent weight removal factor at these velocities we obtained only 10 per cent of this value. Apparently the aerosol generated by burning pulverized coal produces some freshly formed slag fume from the silicates present. This and fine carbon are the particulates which cause the filter to plug rapidly. The method of aerosol generation is obviously a prime factor in air cleaner evaluation. In our equipment evaluation work we employ a number of aerosols of different size ranges and characteristics, such as specific gravity and shape, to get performance data applicable to a wide range of conditions.

## STATEMENT OF POLICY

### The Evaluation of Commercial Air Cleaning Equipment by the Air Cleaning Laboratory of Harvard University Under Contract with the U. S. Atomic Energy Commission

The purpose of this memorandum is to delineate the status and policies of the Harvard University Air Cleaning Laboratory in relation to the evaluation of commercial dust collection apparatus.

1. Air and gas cleaning investigations conducted by this laboratory are performed under contract at the request of the U. S. Atomic Energy Commission. Our contractual obligations require that all requests for testing of commercial dust collectors originate with the Commission.

2. The purposes of such requests are: (1) to determine whether or not a new collector design or a novel modification of an existing collector appears to offer distinct advantages over and above those of other commercially available equipment; (2) to evaluate air cleaning equipment currently installed at AEC sites either through field or laboratory testing; (3) to evaluate representative models of commercial air cleaning apparatus to obtain performance data for basic designs, such as wet or dry inertial units, scrubbers, fabric filters, and electrostatic precipitators.

3. Since it is impossible for this laboratory to test every new air or gas cleaner that is conceived or developed, the joint policy of the AEC and the Air Cleaning Laboratory has been to avoid as much duplication as possible. If, based upon past experience and investigations, a new product appears to offer no specific advantages over competitive products, we do not consider a test program justifiable unless the manufacturer can substantiate his claims with performance data. Should the manufacturer's performance data show unusual merit according to accepted testing procedures we would recommend that the AEC consider evaluation tests. The manufacturer should be able to supply information on typical applications; collection efficiency for particles of varying size, physical properties and loadings; total pressure loss; water and power consumption; thermal and pressure limitations; space requirements; and gas handling capacity.

The priority assignment of such proposed tests, if undertaken, will depend upon whether or not there is an urgent need for this type of apparatus, since the activities of the Air Cleaning Laboratory are not limited by any means to evaluation and testing of commercial control equipment.

4. Rejection of a request to undertake evaluation tests on a dust collector does not necessarily imply that it is considered as unacceptable for AEC use.

5. There is no official policy that the AEC or its contractors must restrict their purchases to equipment recommended by the Air Cleaning Laboratory. A primary function of this laboratory is to act in advisory capacity to the Commission on air cleaning problems. Therefore, we are obliged to present the merits and disadvantages of any equipment under consideration.

6. There is no such thing as an "Air Cleaning Laboratory Approval." In view of the fact that time and cost limitations prevent a comprehensive survey of all commercial dust collecting equipment, we definitely wish to avoid associating the name of Harvard University or its Air Cleaning Laboratory with any commercial product regardless of source. It is our policy to recommend a group of competitive or equivalent products whenever possible.

7. Persons or manufacturers having an air cleaner of new or improved design potentially applicable to AEC operations and who can provide performance data as indicated in item 3, may contact the U. S. Atomic Energy Commission, Division of Reactor Development, Washington, D. C.

# FURTHER INVESTIGATIONS OF THE CONTINUOUS SLAG WOOL FILTER

C. E. Billings, C. Kurker, Jr., E. C. Hickey, L. H. Levenbaum, and L. Silverman  
*Harvard School of Public Health*

Results of the first pilot plant study on a continuous slag wool filter for open hearth fume have been reported.<sup>1,2</sup> The following is a report on the continuation of that study with a redesigned filter unit.

In the manufacture of steel by the open hearth process, a shallow bath of molten metal is reduced in carbon content by directing an oil or gas flame across the exposed upper surface. A roof above the bath directs the heat down onto the metal. Vaporization and agitation of the molten bath cause fine particles of iron oxide to be dispersed in the gas, along with the particles of other materials present in the reaction, such as lime, ore, and silicates. Mean size of these particles is less than  $0.1 \mu$  by counts so that many are carried through the heat exchanger and on out the stack. Temperature of the gas is about  $1400^{\circ}\text{F}$  after leaving the heat exchanger and it may be carrying an average particulate loading of 0.4 grain/cu ft. For a 250-ton furnace this represents about a ton of fume per day.

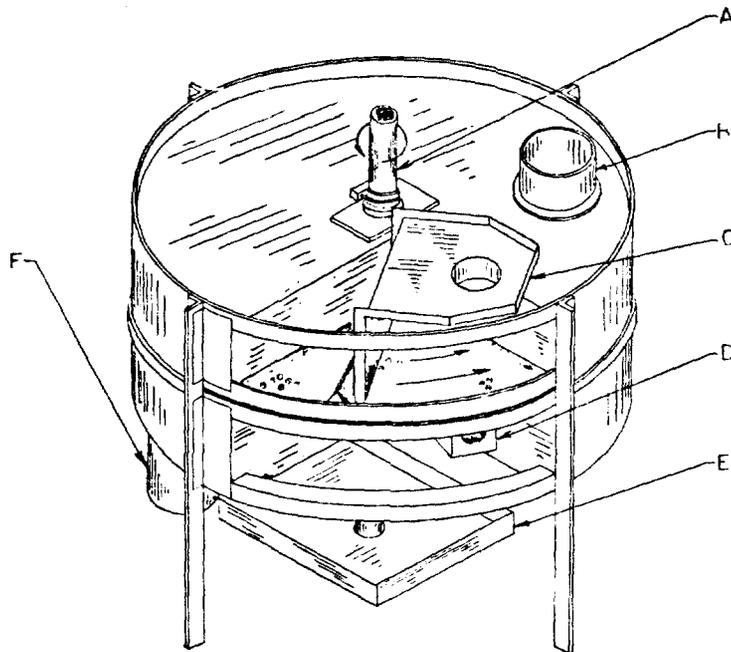


Fig. 1— Continuous slag wool filter for high-temperature fume— Pilot Plant II.

The American Iron and Steel Institute through its Subcommittee on Air Pollution Abatement is sponsoring research on high-temperature gas cleaning at Harvard University. One phase of this research has been directed toward the use of slag wool as a filter fiber. Wool is made by spinning or blowing molten slag from the blast furnace, and its present primary use is for thermal insulation.

Laboratory studies have shown that a 1-in. thick layer of slag wool, at a packing density of 5 lb/cu ft, will remove over 90 per cent of a fine iron oxide fume from a  $1000^{\circ}\text{F}$  gas stream at 100 fpm filtering velocity. Resistance to flow is about 2 in. of water initially and increases as the fume is collected. Each pound of fiber will take up about 5 per cent of its own weight while causing the resistance to rise an additional 2 in.

In the first pilot tests on an open hearth furnace, a continuous web of slag wool was formed from the fiber and was carried by a conveyor into a gas plenum to filter the fume. An average

collection efficiency of about 60 per cent was obtained in this unit. Lowered efficiency was attributed to mechanical factors such as the difficulty of sealing the moving bed of fibers to a stationary surface and to thin areas in the bed produced during formation.

With the experience gained from this first study, a second pilot plant unit has been constructed and tested under identical conditions. Since space requirements are at a premium in an existing steel mill the new pilot plant incorporates a circular disc to carry the filter bed in and out of the gas stream, instead of the former conveyor belt. A disc yields maximum usable area and operations take place over the whole surface, as opposed to a chain conveyor where a certain proportion cannot be used.

This unit is shown in Fig. 1. A 4-ft diameter disc of  $\frac{3}{16}$ -in. perforated steel is driven by a central shaft (A), through a gas plenum covering three quarters of the disc. As in the original unit, a suspension of slurry of the slag wool fibers in water is used to form the filter bed. The slurry is introduced at tray (C), where it flows over the left edge and down onto the disc in the open quadrant. The majority of the water runs through the perforations in the disc into sump (E), leaving the fiber behind on the surface as a wet lap. As the disc slowly rotates, the fiber bed passes over a dewatering suction box (D) where the interstitial water is removed. The bed then advances into the hot gas plenum where it dries and acts as a fiber filter. This unit filters 750 cfm of gas at temperatures over 900°F. After three-fourths of a revolution the used web emerges and is removed to a fiber washing stage for recovery and reuse. Gas from the furnace enters and leaves the filter at (B) and (F) respectively.

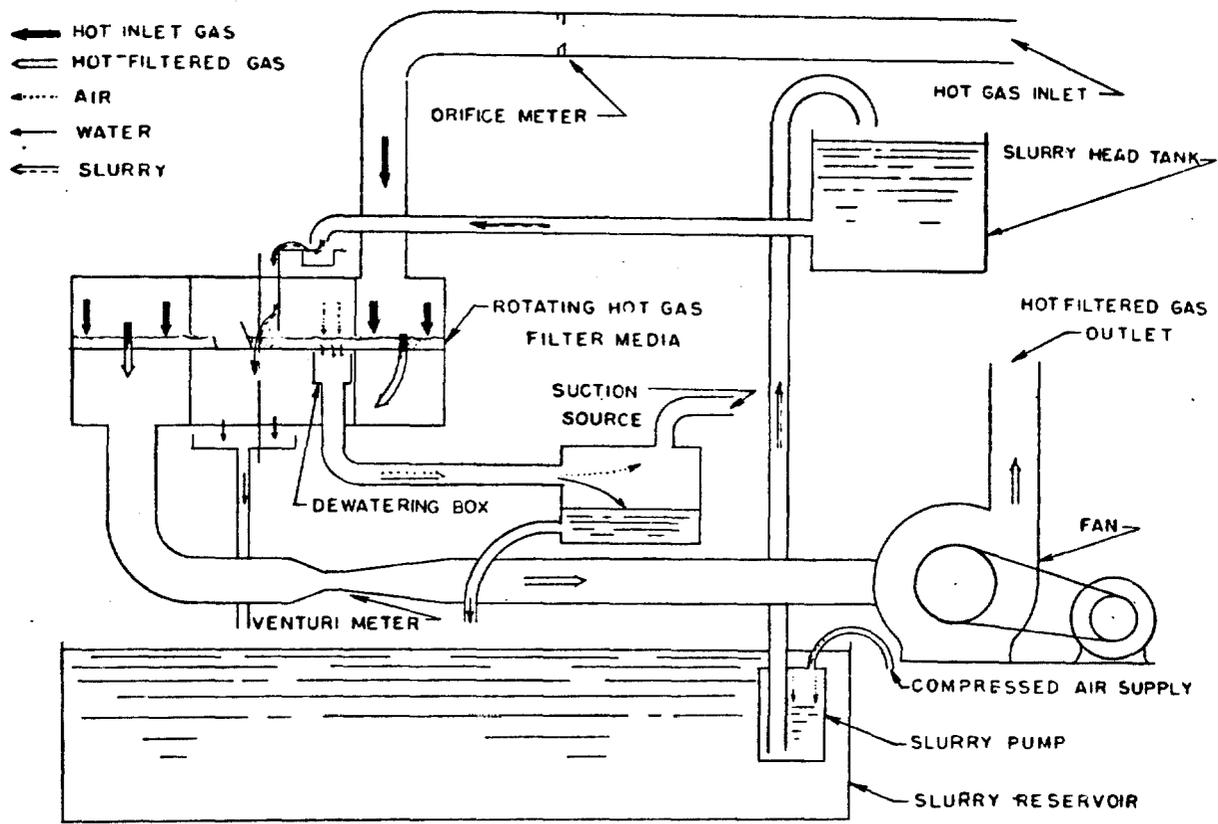
Figure 2 shows a schematic representation of the complete unit including the main slurry tank at the bottom, and overhead surge tank, and fiber slurry and hot gas flow lines.

Figure 3 is a picture of the unit set up for tests in a steel plant. The overhead tank is shown on the right. Slurry flows down to the filter from the constant level tank through the line running from the lower right corner up into the center of the picture. Hot gas enters through the large line on the left, and leaves through the Venturi shown below this line, passing to the fan and stack in the background. The mechanism in the center is used to drive the disc. Used fiber enters the washing tank at the top of Fig. 4 and is carried by overflowing water onto a vibrating separation screen directly beneath the water box shown in the center. Dirty water is filtered (again by slag wool) in the liquid filter at the lower section. Clean fiber and clean water are returned to the main tank from this area.

Another phase of the high-temperature gas cleaning program has been directed toward methods of inducing particulate agglomeration in open hearth fume. If the fume particle size can be increased to an appreciable degree then filter performance should be better, efficiency will be higher, and the rate of build-up of filter resistance will be lower, thus requiring less fiber per unit of time. A rotary screw agglomerator has been developed which consists of several flights or turns of a standard conveyor screw housed in a cylindrical chamber, as shown in Fig. 5. Gas is caused to flow in a tight spiral path and particulate material is subjected to turbulent, centrifugal, and thermal forces which should cause agglomeration and wall deposition. The screw is rotated slowly to keep the walls of the cylinder clean. Figure 6 shows the agglomerator installed during the recent field studies for use with the pilot filter unit.

A number of filter tests have been made both with and without the agglomerator in series. Without the agglomerator, the average collection efficiency was not substantially different from that obtained in the first pilot unit (i.e., about 60 per cent) with values ranging from 10 per cent to 90 per cent as was previously found. The lowered efficiency is believed to be due to the same two factors, peripheral leakage of the open hearth fume by the filter bed, and nonuniform bed formation. To obtain a better edge seal, the circular disc rides in a peripheral track formed by two rolled angle iron rings above and below the disc. As the filter bed is formed, fibers are deliberately overlapped onto the upper surface of the top angle. This then provides a drag seal so that when the bed rotates the fibers should take whatever form is required to keep gas from leaking past the filter.

Since the efficiency with this method of sealing was not significantly higher than with the previous unit, it was suggested that perhaps a moving seal of such simple construction would be insufficient. Therefore, a series of tests were made with stationary filter beds to attempt to



SCHEMATIC ARRANGEMENT FOR HOT GAS FILTRATION APPARATUS

Fig. 2—Schematic arrangement for hot gas filtration apparatus.

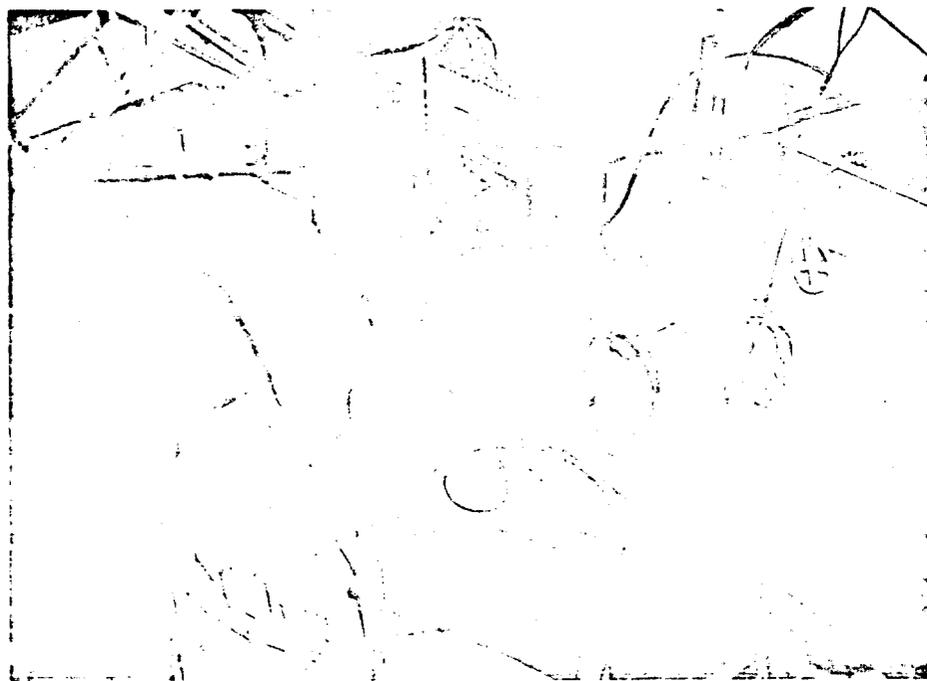


Fig. 3—Field installation of continuous slag wool filter—Pilot Plant II.

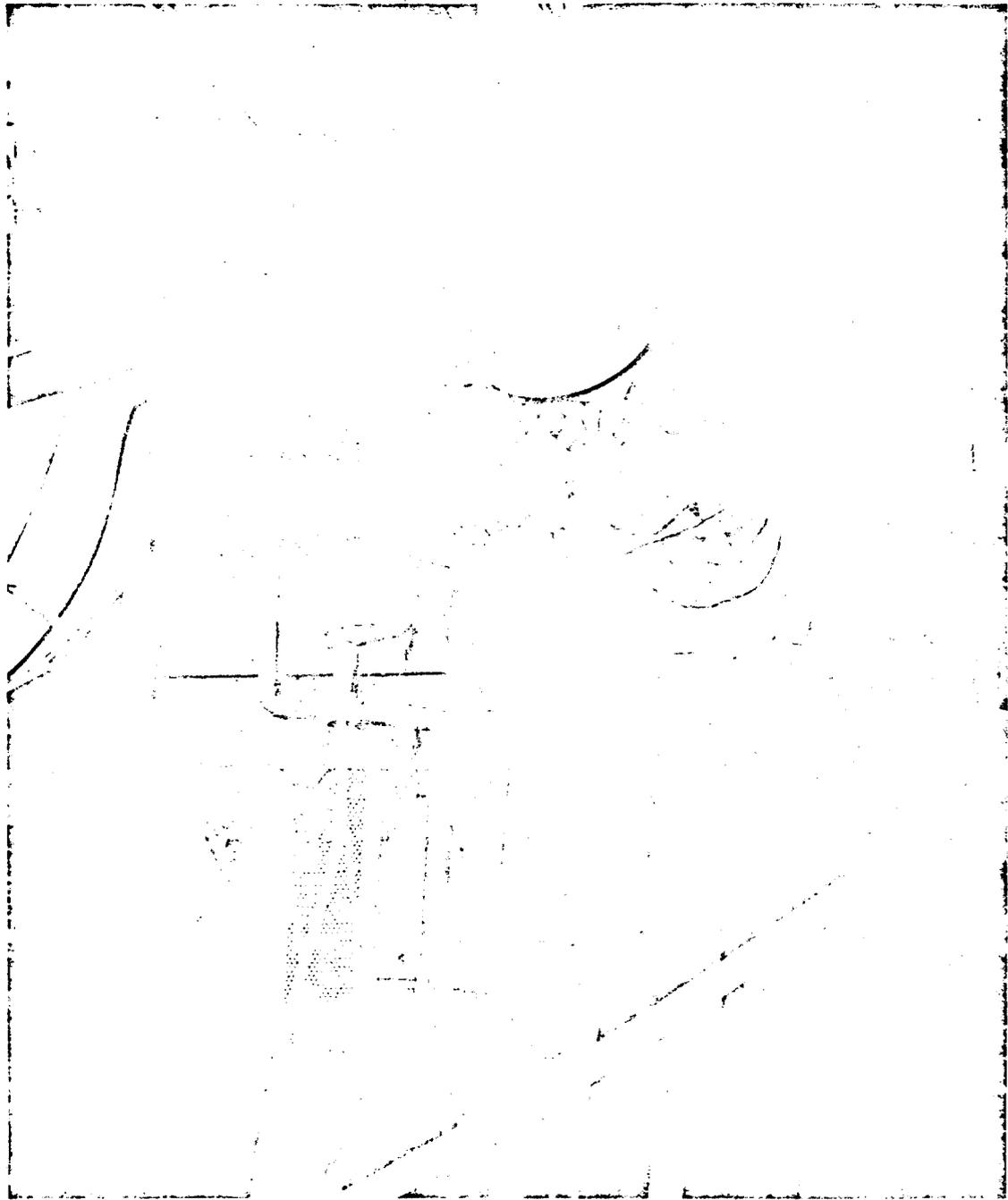


Fig. 4—Used fiber reclaiming system for continuous slag wool filter—Pilot Plant II.

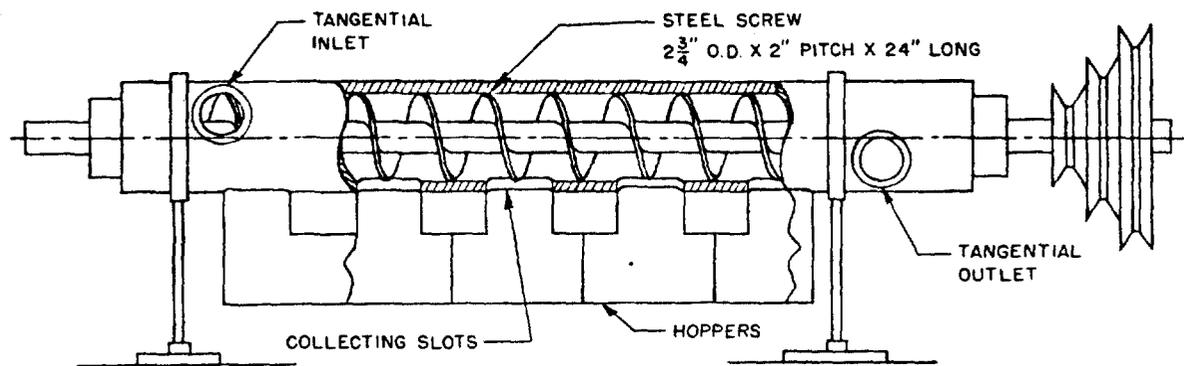


Fig. 5—Rotary screw agglomerator and inertial collector.

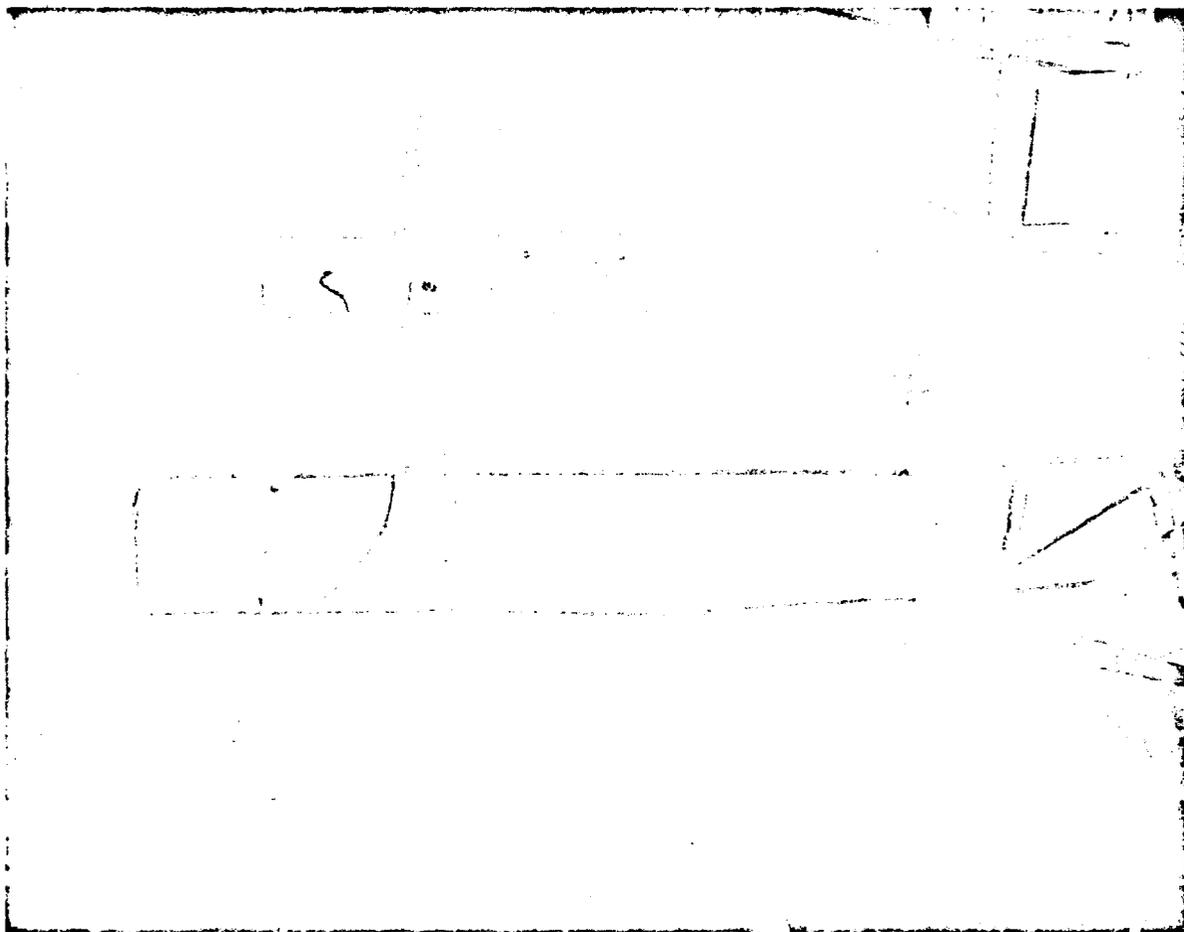


Fig. 6—Twelve-inch rotary screw agglomerator installed for field tests—Pilot Plant II.

eliminate the effect of peripheral leakage by the moving seal. A clean bed was run into the unit before the gas was admitted from the flue, and held stationary while the resistance to gas flow was allowed to increase. The average efficiency of these runs was 75 per cent, ranging from 40 per cent to 90 per cent, with half being about 90 per cent or better.

To investigate the effects of the agglomerator in the inlet line to the filter, tests were made with (1) the filter operating normally, i.e., rotating slowly, and (2) stationary filter beds. The average efficiency of the normally operating filter based on the inlet loading to the filter, not including whatever was removed in the screw agglomerator, was about 60 per cent also, the same as for operation without the agglomerator. When the unit-combination was operated with a stationary bed, however, the average efficiency of the filter rose to 87 per cent, or very near values found in laboratory tests. Two-thirds of the efficiency measurements were greater than about 90 per cent, ranging from 60 to 98 per cent.

Since the filter was stationary, a criterion of 10 in. water was used as opposed to the 4 in. water criterion used for continuous filter operation. Average resistance of the stationary beds was 6 in. water for the filter only; and 6.3 in. water for the combination agglomerator plus filter. The ranges were 1.1 to 10.8 in. water, filter only, and 1.3 to 11.0 in. water, filter and agglomerator.

To further establish the effect of the agglomerator, the average increase in resistance per unit of time for stationary beds can be compared. If the change in resistance is divided by the time interval during the change, an average value of 0.216 in. water is obtained for the filter alone, and 0.163 in. water/min for the combination of agglomerator and filter, indicating a definite advantage for the combination. The resistance across the agglomerator was about 1.5 in. water. If the clean filter resistance is assumed to be 2 in. water and 2 in. water increment is allowed, as previously assumed, then the stationary filter alone will operate 9.3 min without exceeding 4 in. water. The similar comparison for the combined agglomerator and filter is 12.3 min, or about 30 per cent longer. This implies that the agglomerator will extend fiber usage by about 30 per cent, or that 30 per cent less fiber is required.

Fume loading to the unit ranged from practically none to more than 0.3 grain/cu ft, as found in the first study, depending on furnace operation.

Other investigations were made on the removal of sulphur dioxide by the fiber bed. It has been found that a damp bed of basic slag fiber will collect acid gases with a reasonable efficiency. A study was made for the efficiency of SO<sub>2</sub> removal, analysis being made by three separate methods, primarily to check their reliability: I<sub>2</sub>-KI, nephelometrically as BaSO<sub>4</sub>, and with the specific fuchsin-formaldehyde technique. Average sulphur dioxide removal efficiency was 50 per cent, combining the data for all tests.

More extensive analyses of the field results have been presented elsewhere<sup>3,4</sup> and are available upon request. These tests have indicated the feasibility of use of slag wool on a pilot plant basis for continuous filtration of high-temperature fume. Based on these tests a larger unit is contemplated for 5000 cfm of furnace gas.

Additional investigations into the mechanisms of agglomeration of submicron fumes and their practical applications are presently being conducted in the laboratory.

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# SLAG WOOL FOR ACID GAS AND MIST REMOVAL

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## 1 INTRODUCTION

Economical methods for air pollution control from steel production operations are under investigation at Harvard University through the support of the American Iron and Steel Institute. The atomic energy industry is not usually concerned with the visibility loss aspect of air pollution because of much lower toxicity levels. However, some of the developments of this project may be useful. Studies<sup>1</sup> have indicated that a 1-in. thick pad of slag wool, at 5 lb/cu ft packing density, will collect 80 to 95 per cent of submicron iron oxide fume from gas streams up to 1200°F at a filtering velocity of 100 fpm. By continuously forming fiber filters from a water slurry, it is possible to reclaim the slag wool as much as eight times. Under these conditions, each pound of fiber will recover ½ lb of fume, while filter resistance is maintained continuously at 4 in. water. Collected fume is removed from fibers by reslurrying. After separation of the liquid it is reused by filtering through wet slag wool layers.

During field studies of a continuous slag wool filter pilot plant on open hearth fume, a certain amount of fiber attrition was observed which could be attributed to acid attack by sulfur dioxide in the flue gas. Preliminary tests indicated that slag wool was removing sulfur compounds. Subsequent laboratory studies showed that these fibers remove substantial amounts of SO<sub>2</sub> gas and H<sub>2</sub>SO<sub>4</sub> mist. Laboratory filters exposed to acid mist deteriorate similarly to those used in the field.

Many commercially available slag fibers contain in excess of 25 per cent CaO, from limestone used as a flux. Acid gas and mist removal efficiency have been investigated as to their application to off-gases and other air pollutants.

Simultaneous removal of acid gas and particulate materials is a unique feature of the slag wool filter which was not originally anticipated. It is useful for applications requiring simultaneous collection of aerosol particles and acid gases. One additional feature is that it can be used at high temperatures, up to 1200°F. Slag fiber cost is low, ranging from \$20 to \$40 per ton.

## 2 FIBER CHARACTERISTICS

Three kinds of mineral fibers were evaluated. Mineralite wool is made from basic blast furnace slag which is spun into fibers about 4 μ in diameter. Baldwin-Hill loose insulation wool is spun from a mixture of copper and iron slags and also has a mean fiber size of 4 μ.

Kaowool (Babcock and Wilcox Co.) is made by melting kaolin clay (Al<sub>2</sub>O<sub>3</sub> · 2SiO<sub>2</sub> · 2H<sub>2</sub>O) in an electric furnace and spinning 4 μ fibers. Kaowool A is designated as lubricated and Kaowool B as unlubricated. We have not tested these fibers for upper temperature limit, but it is presumably close to 2000°F.

The alkalinity of each of these four fibers was determined by immersion in known amounts of acid and titrating with a standard base. Results are given in Table 1. It can be seen that alkalinity is slightly dependent upon the normality of the acid. Based on several runs, approximately 1 g of Mineralite fiber will react with, and neutralize, 8.5 meq (0.31 g) of HCl and 6.0 meq (0.29 g) of H<sub>2</sub>SO<sub>4</sub>.

Our basic slag wool fibers thus will neutralize about ⅓ g of acid per 1 g of wool. Mineralite fibers are slightly more alkaline, but Kaowool fibers are effectively neutral.

These wools were tested dynamically as filters and absorbers for acid gases and mists. Six-inch diameter pads were placed in the equipment shown previously (Fig. 1, reference 1, p 276) and their performance measured at various filtering velocities, dry and wet, and at room

Table 1—FIBER CHARACTERISTICS OF MINERAL WOOLS USED FOR  
ACID GAS AND MIST STUDIES

Wool	Approx. diameter, $\mu$	Acid	Normality	Alkalinity, meq/g	Remarks
Mineralite	4	HCL	0.1	3.6	Basic
Mineralite	4	HCL	0.3	9.9	blast
Mineralite	4	HCL	1.0	12.2	furnace
Mineralite	4	H <sub>2</sub> SO <sub>4</sub>	0.1	3.2	slag.
Mineralite	4	H <sub>2</sub> SO <sub>4</sub>	0.3	9.4	white
Mineralite	4	H <sub>2</sub> SO <sub>4</sub>	0.7	14.3	
Baldwin-Hill	4	HCL	0.1	2.8	Nonferrous
Baldwin-Hill	4	HCL	0.3	6.0	copper and
Baldwin-Hill	4	HCL	1.0	6.0	iron slag
Baldwin-Hill	4	H <sub>2</sub> SO <sub>4</sub>	0.1	2.6	
Baldwin-Hill	4	H <sub>2</sub> SO <sub>4</sub>	0.3	7.0	
Baldwin-Hill	4	H <sub>2</sub> SO <sub>4</sub>	0.7	8.5	
Kaowool A	4	HCL	0.1	0.2	Kaolin
Kaowool A	4	HCL	0.7	0.3	wool
Kaowool B	4	H <sub>2</sub> SO <sub>4</sub>	0.1	0.1	
Kaowool B	4	H <sub>2</sub> SO <sub>4</sub>	0.7	0.3	

and elevated temperatures. All filters were formed from a 1 per cent water slurry of the fibers and dried prior to tests, except as noted.

### 3 ACID MIST STUDIES

#### 3.1 Sulfuric Acid (H<sub>2</sub>SO<sub>4</sub>)

To investigate the cause of the slag wool fiber attrition observed during field studies, preliminary tests were made on Mineralite and Baldwin-Hill filters with sulfuric acid mist generated by dropping 50 per cent acid on a heated plate, approximate particle size 0.8  $\mu$  mass median diameter.<sup>2</sup> Samples were collected upstream and downstream of the test filters on Millipore filters and analyzed by titration with NaOH.

Results of these studies are presented in Table 2. Average collection efficiency was 52 per cent for B-H filters and 69 per cent for Mineralite filters. This exposure produced a condition identical to that observed on slag wool that had been used to filter open hearth stack gases during pilot plant field studies. The upstream face of the filters showed deterioration of the fibers and additional embrittlement was observed throughout the depth. It was concluded from these results that acid attack (H<sub>2</sub>SO<sub>4</sub>) was the principal cause of fiber attrition in field tests.

Further acid mist removal studies were made to investigate usable filter life on Mineralite fiber. Mist was generated with a compressed air aspirator. Large droplets were removed by impingement on a baffle placed in front of the nozzle, and also by elutriation as the mist rose upward to leave the container, approximate particle size 4.5  $\mu$  mass median diameter (reference 2, p. 19). Samples were collected upstream and downstream of the test filter on Millipore paper and analyzed by conductivity.

Results of these tests are shown in Table 2, lines 6 and 7, and the efficiency is recorded as a function of time. Over a one-hour period there was no serious loss in efficiency due to acid attack of the fibers. The filters when removed were observed to be in good condition and attacked slightly at the upstream face. Qualitative observation indicated that only a small part

Table 2—SLAG WOOL FILTER\* EFFICIENCY FOR SULFURIC ACID MIST

Wool	Average inlet conc., <sup>†</sup> mg/m <sup>3</sup>	Filtering velocity, <sup>‡</sup> fpm	Resistance, in. H <sub>2</sub> O		Efficiency during period, %			Average efficiency, %
			Initial	Final	0-20 min	20-40 min	40-60 min	
Mineralite	50	500						65
Mineralite	100	2000						73
Baldwin-Hill	200	320						32
Baldwin-Hill	100	550						56
Baldwin-Hill	50	970						68
Mineralite	50	120	0.35	0.42	63	69	70	69
Mineralite	100	65	0.50	0.56	73	71	70	71

\*All filters 2 in. thick and 4 lb/cu ft packing density.

<sup>†</sup>100 mg/m<sup>3</sup> = 25 ppm H<sub>2</sub>SO<sub>4</sub>.

<sup>‡</sup>At 70°F.

of the fiber had reacted. Average filter efficiency during these tests, 70 per cent, was about the same as in the first group.

Since the fiber alkalinity indicated that Mineralite fibers could neutralize about 0.4 g of sulfuric acid per gram of wool, a calculation of the total amount of material collected by the filter is indicative of the relative amount of total possible acid recovery during these tests. In the last test, line 7, the initial filter weight was about 50 g. It was exposed to 20 cu ft of air per minute, at 100 fpm.

Total acid removed by the filter is then:  $65 \text{ mg/m}^3 \times 20/35 \text{ m}^3/\text{min} \times 60 \text{ min} \times 0.71 = 1580 \text{ mg}$ .

Fifty grams of fiber should be expected to neutralize a maximum of  $0.4 \times 50 = 20 \text{ g}$  of H<sub>2</sub>SO<sub>4</sub>. The amount recovered of the possible total is then  $1.58/20 \times 10 = 7.9$  per cent, which agrees with the observation of the filter itself. On this basis maximum filter life would be about 10 to 15 hr at this concentration.

The assumption that all fiber alkalinity is available for reaction may not be strictly correct because mist collection occurs primarily at the fiber surface. A sulfate layer on the surface would interfere with further reaction and effectively reduce the total amount of material collected.

Higher concentrations will presumably reduce life in direct proportion to concentration. Higher efficiency can be obtained with a deeper filter bed, in accordance with the logarithmic penetration law. Resistance would be expected to increase in direct proportion to bed length.

### 3.2 Sulfur Trioxide (SO<sub>3</sub>)

Tests with sulfuric acid mist discussed above were made with relatively large particles. If the acid is formed from oxidation of sulfur at high temperature, then the gaseous sulfur trioxide will absorb moisture from the air and form very small particles. An attempt was made to use catalytic conversion of SO<sub>2</sub> to SO<sub>3</sub> with vanadium pentoxide in a device similar to that of Gillespie<sup>3</sup> to generate small particles. Because of technical difficulties encountered and catalyst poisoning, this method was not used.

Sulfur trioxide generation was accomplished in preliminary equipment by oxidizing SO<sub>2</sub> gas with ozone. A stream of commercial oxygen (3 liters/min) was passed through a small laboratory electrostatic precipitator (15 kv, a-c) (reference 4, p. 158) where approximately 10 per cent was found to be converted to ozone. The oxygen-ozone stream was then combined with SO<sub>2</sub> gas (0.05 liters/min) and passed into a 40 liter carboy whose walls were moistened by blotters. From the total gas flow and carboy volume a residence time of 13 min was allowed for conversion of SO<sub>2</sub> to SO<sub>3</sub>. A white mist emerged from the carboy outlet, indicating that the generation method was successful. To obtain the SO<sub>3</sub> free of residual SO<sub>2</sub>, stoichiometric volumes

were used, but variations in ozone production led to some doubt as to the complete oxidation of SO<sub>2</sub>. A further acid gas absorbent would probably have been required. The efficiency of conversion was not determined. This method was therefore abandoned in favor of the one described below.

Tests of Mineralite fiber on SO<sub>3</sub> were made by gently heating fuming sulfuric acid and passing the vapor-mist combination through a large electrostatic precipitator to remove H<sub>2</sub>SO<sub>4</sub> droplets. The gaseous SO<sub>3</sub> escaped and passed into the test unit, picking up moisture rapidly from dilution room air to form small droplets. From the work of Gillespie (reference 3, p. 16) it has been shown that this occurs very rapidly (approximately 0.01 sec.) and that particles so produced are on the order of 0.5 μ mass median diameter.

Test results are given in Table 3. Average collection efficiency of 2-in. thick filters was 31 per cent, and no significant change in efficiency was observed during a continuous running period of 100 min. Efficiencies are lower than those for H<sub>2</sub>SO<sub>4</sub> mist because of the smaller

Table 3—SLAG WOOL FILTER\* EFFICIENCY FOR SULFUR TRIOXIDE MIST

Average inlet conc., <sup>†</sup> mg/m <sup>3</sup>	Resistance, <sup>‡</sup> in. H <sub>2</sub> O		Efficiency during period, %				Average efficiency, %
	Initial	Final	0-25 min	25-50 min	50-75 min	75-100 min	
98	0.64	0.69	22	40	41		34
56	0.70	0.78	33	36	31	30	32
37	0.40	0.68	19	32	23	30	26

\*All filters 2 in. thick and 4 lb/cu ft packing density, Mineralite fiber.

<sup>†</sup>100 mg/m<sup>3</sup> = 31 ppm, SO<sub>3</sub>.

<sup>‡</sup>At 100 fpm filtering velocity, 70°F.

particle size. The total filter life can be estimated from calculations; for example, at an average inlet concentration of 50 mg/m<sup>3</sup>, the filter was tested for 100 min at an average efficiency of 31 per cent, so amount of fiber used would be:

$$50 \text{ mg/m}^3 \times 20/35 \text{ m}^3/\text{min} \times 100 \text{ min} \times 0.31 = 880 \text{ mg}$$

$$0.88/20 \times 100 = 4.4\%$$

Expected filter life at an average concentration of 50 mg/m<sup>3</sup> would be about 2.7 hr, or approximately twice as long as found during H<sub>2</sub>SO<sub>4</sub> tests, where the concentration was 90 mg/m<sup>3</sup> or about twice as high. The same limitation of sulfate formation on fiber surfaces discussed above is possible here, so the estimate given above may be too high.

### 3.3 Nitric Acid (HNO<sub>3</sub>)

Mineralite slag wool filters were tested on nitric acid mist generated by dispersing concentrated HNO<sub>3</sub> (80 per cent) with a compressed air aspirator<sup>2</sup> as was done for sulfuric acid mist. Samples were collected before and after the test filter on Millipore filters followed by sintered glass absorbers. Colorimetric analysis was made with the brucine reagent described by Snell.<sup>5</sup>

Dry slag wool filters were tested at filtering velocities of 50, 100, and 150 fpm at room temperature. Two runs were also made at room temperature and 100 fpm velocity with filters that contained moisture remaining after partial drying. Two tests were made at a gas temperature of 500°F. Data for these tests are indicated in Table 4. Increased filtering velocity makes a slight but significant increase in filter efficiency at constant inlet loading as seen by comparing the average efficiency at 50 fpm (74 per cent) with that at 150 fpm (84 per cent). A threefold increase in filter loading at constant velocity, lines 2 and 3, makes an appreciable

improvement in efficiency, from 75 to 87 per cent. The outlet concentration has increased only slightly in this case from 35 mg/m<sup>3</sup> to 40 mg/m<sup>3</sup>, indicating that the generation of the higher concentration did not produce a significantly greater quantity of large particles.

Table 4—SLAG WOOL FILTER<sup>a</sup> EFFICIENCY FOR NITRIC ACID MIST

Filtering velocity, fpm	Average inlet conc., <sup>b</sup> mg/m <sup>3</sup>	Resistance, <sup>c</sup> in. H <sub>2</sub> O		A, <sup>d</sup> %	Efficiency during period, %					Average efficiency, %	No. of tests
		Initial	Final		0-20 min	20-40 min	40-60 min	60-80 min	>80 min		
50	123	0.30	0.43	5	70	81	77	79	66 <sup>e</sup>	74	2
100	139	0.49	0.72	9	80	72	76	71	70 <sup>f</sup>	75	3
100	309	0.53	0.81	22	82	94	72	54		87	1
150	141	0.98	1.25	13	90	91	80	56		84	2
100 <sup>g</sup>	234	0.95	0.57	9	41	42	54	68		49	1
100 <sup>g</sup>	314	0.83	0.41	17		80	63	51	50 <sup>h</sup>	60	1
100 <sup>k</sup>		1.28	1.28		42	45	79	68		58	2

<sup>a</sup>All filters 2 in. thick and 4 lb/cu ft packing density, Mineralite fiber.

<sup>b</sup>100 mg/m<sup>3</sup> = 39 ppm HNO<sub>3</sub>.

<sup>c</sup>At indicated filtering velocity, 70°F, except line 9 at 500°F.

<sup>d</sup>Filter rating factor based on first 80 min of test, pounds of material collected per 100 lb of slag wool, calculated from inlet mist loading (L), flow rate (Q), time exposed (T), filter efficiency (E), and initial weight of filter (W):  $A = LQTE/W$ , expressed as per cent.

<sup>e</sup>At 110 min.

<sup>f</sup>At 170 min.

<sup>g</sup>Filter contained residual moisture from formation process at start of test.

<sup>h</sup>At 150 min.

<sup>k</sup>At 500°F.

Filters tested with residual moisture, lines 5 and 6, showed a slightly lower average efficiency than dry ones at the same filtering velocity. Wet filters were observed to sag slightly away from the upper surface of the filter holder. This could have caused peripheral leakage around the filter, causing lower efficiency, average about 55 per cent. The resistance of these filters fell during testing, columns 3 and 4, as interstitial moisture dried out.

Two tests at high temperature indicated a slightly lowered collection efficiency. This is either due to evaporation of mist droplets to a smaller size, to the gas phase, or to the effects of high temperature on impaction efficiency (presumably the mist particle size is in the range of impaction rather than diffusion). The theoretical consideration of filtration mechanisms at elevated temperatures have been presented recently.<sup>6</sup>

The calculated filter rating factor indicated in Table 4 (A, %; column 5) represents the amount of nitric acid mist the filter recovers per hundred pounds of slag wool. All filters tested, at room temperature, reacted with the acid to form a white powdery product, presumably calcium or potassium nitrate, on the upstream face for about the first half inch. Most measurements were for 1½ hr with some extended nearly 3 hr. During this period no significant loss of efficiency occurred to indicate a "break-point" or total utilization of the filter capacity to collect acid mist. Filter rating factors ranged from 5 to 15 per cent on an inlet concentration of approximately 125 mg/m<sup>3</sup> of mist, and it is presumed that filters could operate ten times as long without substantial decrease in efficiency or a total run time of probably about 20 hours. With a threefold increase in inlet loading, lines 2 and 3, the filter rating factor increased by about the same amount, from about 8 to about 22.

Average dry filter efficiency at 100 fpm, room temperature, is about 80 per cent. Higher inlet concentration and filtering velocity apparently produce improved collection efficiency.

## 4 ACID GAS STUDIES

### 4.1 Sulfur Dioxide (SO<sub>2</sub>)

As discussed under sulfuric acid mist, tests were initiated in the laboratory to determine the cause of slag wool fiber attrition observed during field tests of the first pilot plant filter unit. A comparable series of tests was also made with SO<sub>2</sub> gas since this is the major product from sulfur-bearing fuel. Commercial cylinder gas was metered into the test unit and samples were collected in sintered glass absorbers containing hydrogen peroxide. Analysis was made by measuring the electrical conductivity of the solution. Results of these tests, presented in Table 5, indicate 0 per cent removal for all dry filter beds and for wet Kaowool fibers. In all

Table 5—SLAG WOOL FILTER\* EFFICIENCY FOR SULFUR DIOXIDE GAS

Wool	Filtering velocity, <sup>†</sup> fpm	Average inlet conc., ppm	Average efficiency, %	Remarks
Mineralite	100		0	Dry
Baldwin-Hill	100		0	Dry
Kaowool A	100		0	Dry
Kaowool B	100		0	Dry
Mineralite	300	50	24	Wet
Mineralite	300	100	29	Wet
Mineralite	300	200	12	Wet
Baldwin-Hill	300	50	20	Wet
Baldwin-Hill	300	100	27	Wet
Baldwin-Hill	300	200	31	Wet
Kaowool A			0	Wet
Kaowool B			0	Wet

\*All filters 2 in. thick and 4 lb/cu ft packing density.

<sup>†</sup>At 70°F.

cases the fibers appeared to be unaltered. Wet Mineralite filters removed an average of 26 per cent SO<sub>2</sub> which reacted with the fibers and caused bleaching and size reduction. Upon drying, the filter was white, brittle, and powdery. This condition was similar to that observed in field tests. Comparable tests with Baldwin-Hill wool gave an efficiency of 22 per cent.

Sulfur dioxide samples have since been taken during continuous field operation of a second pilot plant unit.<sup>7</sup> Filters were formed continuously by the slurry process, so that there was residual moisture present. Samples were analyzed by three different methods to evaluate the most useful one, with results as reported in Table 6. The method indicated as I<sub>2</sub>-KI is the one worked out by Pearce and Schrenk,<sup>8</sup> the fuchsin method is that of Stang, Zatek, and Robson,<sup>9</sup> and the BaSO<sub>4</sub> method is the turbidimetric estimate of the precipitate.

Average inlet sulfur dioxide concentration by each method is 66 ppm I<sub>2</sub>-KI, 62 ppm fuchsin, and 98 ppm BaSO<sub>4</sub>, indicating that the I<sub>2</sub>-KI and fuchsin methods give similar results. Average positive collection efficiency by each of the three methods is 39 per cent I<sub>2</sub>-KI, 72 per cent fuchsin, and 13 per cent BaSO<sub>4</sub>. For all positive tests average collection is 49 per cent.

After the first four preliminary tests with I<sub>2</sub>-KI, the testing was done serially as indicated by numbers in the last column of Table 6. Simultaneous upstream and downstream samples were taken for each of the three methods in succession. In test 1, the I<sub>2</sub>-KI method was used first, line 5, then the sample for fuchsin analysis was obtained, line 9, and finally the BaSO<sub>4</sub> sample was taken, line 13. This procedure was repeated in tests 2, 3, and 4. Comparing concentration and efficiency results on the basis of test number does not give a strong correlation between methods of analysis. A comparison of average inlet concentrations indicates that the specific fuchsin method yields the lowest value while the nonspecific I<sub>2</sub>-KI and BaSO<sub>4</sub> methods give results that are somewhat higher.

Table 6—SULFUR DIOXIDE REMOVAL BY CONTINUOUS SLAG WOOL FILTER  
OPERATING ON OPEN HEARTH FUME

Filtering velocity, fpm	Average resistance, in. H <sub>2</sub> O	SO <sub>2</sub> concentration, ppm		Efficiency, %	Temperature, °F	Analytical method for SO <sub>2</sub>	Test No.*
		Inlet	Outlet				
88	7.2	38	56		750	I <sub>2</sub> -KI	1
77	7.1	56	13	73	800	I <sub>2</sub> -KI	2
88	6.3	36	25	30	820	I <sub>2</sub> -KI	3
110	4.8	24	14	42	830	I <sub>2</sub> -KI	4
110	3.2	43	65		850	I <sub>2</sub> -KI	1
101	3.9	74	102		850	I <sub>2</sub> -KI	2
89	5.9	189	125	34	900	I <sub>2</sub> -KI	3
109	3.3	68	58	16	840	I <sub>2</sub> -KI	4
102	3.9	45	19	59	860	Fuchsin	1
101	4.0	94	38	61	880	Fuchsin	2
79	6.8	70	8	89	900	Fuchsin	3
97	3.2	43	10	78	775	Fuchsin	4
92	4.1	55	59		740	BaSO <sub>4</sub>	1
100	4.6	176	235		920	BaSO <sub>4</sub>	2
108	4.1	90	78	13	870	BaSO <sub>4</sub>	3
98	4.2	72	77		830	BaSO <sub>4</sub>	4

\*First four I<sub>2</sub>-KI tests were preliminary.

Based on these tests, the slag wool filter removes about 50 per cent of SO<sub>2</sub> from an average of 75 ppm in open hearth furnace gas, while performing its primary function as a particulate filter. Filters in the above tests were approximately 1 in. thick and 4 lb/cu ft packing density, so that improved performance on the gas could be obtained by a thicker filter.

#### 4.2 Nitrogen Dioxide (NO<sub>2</sub>)

The efficiency of Mineralite slag wool filters was determined on nitrogen dioxide gas by metering commercial cylinder gas into the test unit. Samples were collected upstream and downstream of the test filter in sintered glass absorbers with sulfanilic acid and  $\alpha$ -naphthylamine solution.<sup>5</sup> The resulting color was measured on a colorimeter. Test results are given in Table 7. Average efficiency of dry filters was 10 per cent and of wet filters 28 per cent. There was no marked decrease in collection efficiency during 80 min continuous testing.

Table 7—SLAG WOOL FILTER\* EFFICIENCY FOR NITROGEN DIOXIDE GAS

Filtering velocity, <sup>†</sup> fpm	Average inlet conc., ppm	Resistance, in. H <sub>2</sub> O		Efficiency during period, %			Average efficiency, %	Remarks
		Initial	Final	0-15 min	15-45 min	45-80 min		
100	30	0.45	0.48	11	12	8	10	Dry
100	35	1.28	0.94	27	22	35	28	Wet

\*All filters 2 in. thick and 4 lb/cu ft packing density, Mineralite fiber.

<sup>†</sup>At 70°F.

Table 8—MINERAL WOOL FILTER EFFICIENCY FOR HYDROFLUORIC ACID GAS

Wool*	Filter vel., fpm	Inlet conc., ppm	Resistance, <sup>†</sup> in. H <sub>2</sub> O			Efficiency during period, %						Min. eff., %	Max. time, min	No. of tests
			Initial	Final	A, <sup>‡</sup> %	0-10 min	10-25 min	25-40 min	40-55 min	55-70 min	70-85 min			
M	80 <sub>4</sub>	390	0.8	1.4	13	80	78	65	65	40	23	0	120	2
M	160 <sub>4</sub>	310	2.3	4.8	15	59	72	63	47	31	21	0	110	2
M <sup>§</sup>	80 <sub>5</sub>	580	3.7	1.2	16		80	80	83	94	90	62	180	2
M <sup>§</sup>	160 <sub>5</sub>	440	8.9	4.6	35	93	96	97	97	95	67	46	90	2
M <sup>¶</sup>	160 <sub>3</sub>	350	2.4	3.5	6	32	48	50	40	33		0	170	2
B-H	80 <sub>4</sub>	490	1.2	2.1	9	65	69	60	45	31	29	12	135	4
B-H	160 <sub>4</sub>	250	2.1	4.5	14	75	96	94	73	49		6	100	2
B-H <sup>§</sup>	80 <sub>5</sub>	420	5.2	2.0	12		73	66	60	53	38	11	160	2
B-H <sup>¶</sup>	160 <sub>4</sub>	480	6.8	7.2	10	45	15					4	55	2
K-A	80 <sub>4</sub>	260	4.2	0.2	4	48	67	33				9	80	2
K-A	160 <sub>3</sub>	300	5.9	0.3	21	76	81	48				25	55	2
K-B	80 <sub>3</sub>	480	2.5	0.8	7	48	33					6	30	2
K-B	160 <sub>4</sub>	430	3.7	0.6	18	68	41					24	30	2

\*All filters 2 in. thick, packing density varied from 3 to 5 lb/cu ft, as indicated by subscript. Wool tested: Mineralite (M), Baldwin-Hill (B-H), and Kaowool A (K-A) and B (K-B).

<sup>†</sup>At indicated filtering velocity, 70°F, except lines 5 and 9 at 500°F.

<sup>‡</sup>Filter rating factor based on first 60 min of test (prorated for shorter tests), pounds of acid recovered per 100 lb of fiber.

<sup>§</sup>Contained residual moisture from formation process at start of test.

<sup>¶</sup>At 500°F.

### 4.3 Hydrogen Fluoride (HF)

Hydrofluoric acid gas and mist removal was then investigated. Anhydrous HF was supplied from a cylinder and metered through a polyethylene tubing flowmeter. Samples were collected upstream and downstream of the filter in sintered glass absorbers.

The fluoride ion was determined by its bleaching action on ferric thiocyanate.<sup>5</sup>

Mineralite, Baldwin-Hill, and Kaowool filters were tested dry at room temperature at filtering velocities of 80 and 160 fpm as shown in Table 8. Mineralite and B-H filters were also tested dry at 460°F and wet at room temperature.

The pressure loss for dry Mineralite and B-H filters increased with HF exposure time as a result of the HF plasticizing reaction with the fibers. A powdery product was formed which increased the surface area for reaction, and also filled voids, causing an improved efficiency, up to saturation. The reaction is assumed to take place in two steps. First, the alkalinity of the fibers is neutralized by the acid, and second, the HF reacts with the silicates in the fibers. Mineralite and B-H filters were bleached to a white and grayish-white color after reaction, but no holes were visible. Reaction occurred throughout the depth of the filter.

Kaowool filter pressure losses decreased continuously from the start of HF exposure. On removal from the test unit these filters felt wet and contained many holes.

Wet Mineralite and B-H filters were tested and their resistance decreased steadily due to drying.

Several tests were made at elevated temperatures with Mineralite and B-H filters. The filters showed very little visible reaction. Apparently water acts as an absorbent in the reaction between the fibers and the HF, and at 460°F, no water is present. At room temperature HF picks up a considerable amount of water and the reaction with filters is quite rapid.

Table 8 also shows the variation of removal efficiency with time. Mineralite and B-H fibers have longer life and higher removal efficiency than Kaowool. Filtering velocity, exposure time, and acid concentration are governing factors in the life of a filter. In every case a definite "break-point" was observed when filter efficiency dropped sharply to indicate that the fiber had been consumed for practical purposes.

In most cases the "A" factor was higher for Mineralite. Efficiency for the wet Mineralite filters was higher than 90 per cent.

## 5 SUMMARY AND CONCLUSIONS

Investigations of acid collection by Mineral wool filters have indicated that 2-in. thick filters at 4 lb/cu ft packing density remove from 30 to 80 per cent of acid mist and up to 72 per cent of acid gases. Slag wool fibers have an alkaline residual due to the use of limestone as a flux which may run as high as 50 per cent of fiber weight (average 35 per cent). For most mineral acid tests (excepting HF) the total filter life depends upon the acid concentrations. Continuous fiber replacement can be achieved with equipment discussed in another section, so that acid gas and mist removal can be obtained automatically over extended periods. Table 9 summarizes the results of the tests.

Acid gas collection is generally improved (excepting HF) by the presence of moisture on slag wool filters. Absorption occurs in the acid-moisture-alkali reaction by leaching the flux from the fibers. Hydrogen fluoride collection is due to alkali neutralization and also to direct reaction of the acid with silicates in the fiber.

Additional filter studies on this phase of the project are being conducted on phosphoric and hydrochloric acids, silicon tetrafluoride and ammonium bifluoride. Parallel investigations are being conducted on the use of slag wool for fly ash, iodine, and incinerator effluent gases and particulates.

The use of slag wool for the combined simultaneous removal of acid gases, mists, and solid particulates presents a unique method with application for many problems.

Table 9—SUMMARY OF TEST RESULTS

Wool*	Acid mist	Acid gas	Approx. av. eff., %	Approx. loading	Approx. life, hr
Mineralite	H <sub>2</sub> SO <sub>4</sub>		70	90 mg/m <sup>3</sup>	12
Mineralite	SO <sub>3</sub>		31	50 mg/m <sup>3</sup>	24
Mineralite	HNO <sub>3</sub>		80	125 mg/m <sup>3</sup>	20
Mineralite		SO <sub>2</sub>	49	75 ppm	
Mineralite		NO <sub>2</sub>	20	30 ppm	
Mineralite		HF	72	400 ppm	1
Baldwin-Hill	H <sub>2</sub> SO <sub>4</sub>		52	90 mg/m <sup>3</sup>	12
Baldwin-Hill		SO <sub>2</sub>	22	300 ppm	
Baldwin-Hill		HF	60	500 ppm	1
Kaowool A		SO <sub>2</sub>	0	300 ppm	
Kaowool A		HF	60	300 ppm	1/2
Kaowool B		SO <sub>2</sub>	0	300 ppm	
Kaowool B		HF	40	500 ppm	1/2

\*Average velocity 100 fpm, filter thickness 2 in., packing density 4 lb/cu ft.

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# AGGLOMERATION OF PARTICULATE MATERIALS

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## 1 INTRODUCTION

The factors affecting submicron particulate agglomeration are being studied as part of research in methods of cleaning high-temperature gas streams sponsored by the American Iron and Steel Institute at Harvard University. The primary objective is to induce particulate agglomeration in dynamic gas streams so that particle size may be increased and simple and economical gas equipment can be used. Although methods are being developed principally for the controlling of air pollution from steel production operations, they also may have application in other high-temperature problems, particularly those associated with nuclear energy processes such as incineration of radioactive wastes or use of nuclear fuels as heat sources for power production.

During the making of steel in the open hearth process, large quantities of iron oxide fume particles about  $0.03 \mu$  count median diameter are generated from vaporization of the metal at high temperature. Since the gas from the furnace may be carrying an average loading of 0.4 grain/cu ft, this represents a serious problem from the standpoint of obscuring visibility even when discharged from high stacks. Due to the fine particle size and high dust loadings, any agglomeration which occurs among the particles by natural or induced methods can be an important consideration in the development or application of cleaning equipment. Increased agglomeration will improve the collection efficiency of devices such as the slag wool filter presently under development and permit each pound of fiber to recover more fume before a limiting resistance is reached.

## 2 AGGLOMERATION MECHANISMS

Iron oxide is a metallurgical fume which is produced in high concentrations and flocculates vigorously. Natural Brownian diffusion causes significant agglomeration when particle number concentrations exceed  $10^6$  per cubic centimeter ( $2.8 \times 10^{10}$  particles/cu ft).<sup>1</sup> For a count median particle size of  $0.03 \mu$  and a weight concentration of 0.4 grain/cu ft as found in field studies, particle numbers are on the order of  $10^{19}$  per cubic foot which indicates that agglomeration will occur naturally.

Unaided diffusional agglomeration will proceed according to the following equation for homogeneous aerosol particles:

$$-\frac{dn}{dt} = Hn^2 \quad (1)$$

and if this is integrated using  $n_0$  as the initial concentration, then:

$$\frac{1}{n} - \frac{1}{n_0} = Ht \quad (2)$$

where  $n$  is the number concentration at any time,  $t$ , and  $H$  is the coagulation constant which for ferric-oxide has been shown to be  $6.7 \times 10^{-10}$  cc/sec.<sup>2</sup> One can determine the rapidity with which agglomeration occurs in this fume by solving equation (2) for the time required to reduce the initial concentration above  $10^{15}$  per cubic foot, or approximately  $0.35 \times 10^{11}$  per cubic centimeter to one-tenth of this value<sup>1</sup> as follows:

$$\frac{1}{0.35 \times 10^{10}} - \frac{1}{0.35 \times 10^{11}} = 6.7 \times 10^{-10}t$$

from which the time is on the order of 0.4 sec. Calculations of this type<sup>3</sup> have indicated that the time required for passage of fume through the furnace heat exchanger (waste heat boilers) is sufficient to cause significant agglomeration. Electron photomicrographs of fume from before and after the waste heat boiler have shown an increase in count median particle diameter from 0.047  $\mu$  entering the boiler to 0.057  $\mu$  leaving.

In addition to diffusional processes, agglomeration will be promoted by any other forces which can be applied to particles to cause them to move, such as turbulence in the gas or thermal, electrostatic, magnetic, and sonic effects. Due to the high temperature of flue gases (1000°F), the thermal effects are probably of major significance. Laboratory studies on agglomeration are concerned with induced turbulent and thermal mechanisms.

### 3 MEASUREMENT OF PARTICULATE AGGLOMERATION

An instrument for the direct measurement of agglomeration of iron oxide fume less than 0.2  $\mu$  is required so that characteristics of agglomerators may be determined. Previous investigations of the phenomena have been successfully conducted by using the small particles as nuclei for condensation of water in a supersaturated atmosphere. This increases their size making them visible under proper lighting. A commercially available model (General Electric) has been tried for this purpose, but was found to have too low a particle concentration range. A laboratory instrument has been constructed and tested using this principle. The particle cloud is introduced into a chamber, after saturation, and a slight vacuum is applied, causing moisture to condense on the particles. The actual or relative number concentration of particles is determined by the amount of light transmitted through the cloud to a photocell. Tests were conducted with various aerosols, such as ammonium chloride and iron oxide fume produced by thermal decomposition of iron carbonyl. The light response of the cell is linear to a certain number concentration but beyond this point it increases too rapidly to enable an estimation of large particle numbers to be made reliably. It is now proposed to modify this counting chamber by the addition of a small Polaroid Land Camera which permits a photograph of a known volume of cloud to be made, from which direct counts can be taken. Agglomeration measured in this manner should be indicated by decreases in particle number at different points in the screw agglomerator. The development, construction, testing, and modifications of this instrument are presented in a recent report.<sup>4</sup>

To produce turbulent, centrifugal, and thermal forces in a dynamic aerosol stream, a device has been developed which consists of a standard conveyor screw mounted on a steel pipe shaft and enclosed in a sheet metal casing with tangential inlet and outlet ports. This unit provides an extended gas path in a relatively small space which gives increased contact time. Centrifugal and turbulent forces have an opportunity to act in the rapidly spiralling gas, and if the walls of the container are cooler than the gas a significant thermal force is present.<sup>5</sup> Particles moving under these conditions have an increased chance of colliding with others in the gas. If deposition occurs on the walls of the container, slow rotation of the screw will remove this material to a collecting hopper at the bottom.

### 4 AGGLOMERATOR TESTS

A 3-in. laboratory screw agglomerator was constructed and tested using an iron oxide fume generated from combustion of iron carbonyl. The screw was rotated to keep the walls free from deposits and to push the material through slots into hoppers beneath as shown in Fig. 5, p 118. Although it was not constructed as a collecting device, tests indicated that it acted as a low efficiency inertial separator when operated nonisothermally (uninsulated). When a small settling chamber was located downstream of the agglomerator, collection efficiencies ranged from 25 to 83 per cent with an average value of 47 per cent. Inlet temperature was 500°F, outlet temperature 300°F, inlet velocity of about 3700 fpm, and loadings ranged from 0.12 to 0.18 grain/cu ft. Similar tests conducted under isothermal conditions (entire agglomerator insulated) showed negligible collection efficiency. It is concluded that a large tempera-

ture difference is necessary to produce collection and that thermal deposition is the major factor.

Pilot plant field studies on a 12-in. rotary screw agglomerator on open hearth fume showed collection efficiencies in the order of 15 per cent with inlet temperature 1000°F, outlet temperature 500°F, inlet velocity 3000 fpm, and loading on the order of 0.15 grain/cu ft. In addition to efficiency studies on the 12-in. agglomerator, samples were collected upstream and downstream on electron microscope targets with a special 15 kv a-c electrostatic precipitator, to determine the extent of particle build-up. Electron photomicrographs showed a 30 per cent increase in particle size in passage through the unit. It is interesting to note that the particle size increase of iron oxide fume was found to be approximately 30 per cent in both passage through the waste heat boiler and the 12-in. agglomerator.

In both laboratory and field studies it has been observed that a high-temperature drop occurs between the inlet and outlet. Gas temperature decreases on the order of 40 per cent. It is believed that the turbulent flow at the boundary layer film inside the agglomerator considerably increases the transfer of heat to the ambient air.

After completing determination of gas flow characteristics on three geometrically similar rotary screw agglomerators, the agglomerating, collecting, and heat transfer characteristics of a 6-in. diameter unit was investigated in the laboratory. Heat transfer properties were measured at 1000°F and 700°F inlet temperatures and inlet gas velocities of 3000 to 5000 fpm. Gas temperature drops from 1000°F to 700°F or from 700°F to 500°F in going from the inlet to the outlet of the screw, a distance of about 4 ft. In addition to these studies with tangential gas inlet and outlet, studies are also being conducted at present with axial inlet and outlet, to determine the effects of the axial location.

Over-all coefficient of heat transfer for the uninsulated screw casing ranged from 2 to 3½ times greater than values reported in the literature, and also those calculated from theory, for gas to air cooling tubes. When a water spray was introduced on the outside of the casing, heat transfer increased to above twice the gas to air values. The large increase in heat transfer in the rotary screw is probably due to the turbulent spiralling flow causing a reduction in boundary layer film thickness. In effect, the rotary screw agglomerator is a self-cleaning heat exchanger with a potential heat transfer more than twice that of equivalent tubular type exchangers.

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# PROGRESS REPORT ON FILTRATION OF A FRESHLY GENERATED NaK FUME

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## 1 INTRODUCTION

The Harvard University Air Cleaning Laboratory was requested to evaluate the performance of various commercial filters with a mixed sodium-potassium (NaK) oxide aerosol. The desired operating characteristics, as specified originally, were as follows:

1. The filter should be noncombustible.
2. The space requirements for the cleaning system should approximate those of standard Absolute type (AEC) filters, that is, a 24-in. square filter handles 500 and 1000 cfm for 6 and 12 in. of filter depth, respectively. Additional depth is available for prefiltering if required.
3. The total fume holding capacity for a 1000-cfm filter should be approximately  $\frac{1}{2}$  lb (3500 grains) without excessive pressure loss across the filter. This is equivalent to 3.5 grains/cu ft of filtering capacity.
4. The pressure loss across the filtration device at rated gas flow should be as low as possible although resistances as high as 15 in. water are permissible.
5. The filter should be at least 90 per cent efficient by weight.
6. Filter units should be corrosion resistant during the period of expected service, i.e., until maximum holding capacity is reached ( $\frac{1}{2}$  lb).

It was proposed, originally, that Absolute type filters be investigated in view of their high efficiency for submicron material. Furthermore, tentative building design and space allocation for gas cleaning equipment made dry filtration a desirable, and economic, choice, although it was recognized that other devices, i.e., a Venturi scrubber or low voltage electrostatic precipitator, might produce satisfactory cleaning.

The following report presents results of tests conducted in this laboratory with several types of dry filtration equipment on commercially available and experimental filters. Aerosol generation apparatus, analytical procedures, and test duct systems are described briefly.

For any one filter design the efficiency, pressure loss, and fume holding capacity are indicated with respect to air flow rate. The feasibility of employing any one of the dry filters evaluated in the laboratory is based upon the original design criteria, i.e., efficiency, holding capacity, pressure loss, and resistance to corrosion and combustion.

## 2 TEST PROCEDURES

### 2.1 Test Apparatus

Preliminary tests to evaluate analytical methods were conducted with 500 cfm cellulose-asbestos AEC type filters mounted in a special 24-in. square ductwork system. Rapid plugging of these filters with a pure sodium oxide fume, produced by burning metallic sodium, indicated that they were unsuitable for this application. A filter fire which occurred during this test series indicated that combustion hazards should be reduced by scaling down test apparatus.

The final test system, Fig. 1, consisted of two, 8-in. square ducts made up in 4-ft sections with provision to mount test filters between them. A high speed centrifugal exhauster of 50-cfm capacity with 10 in. water pressure loss across the filter was connected to the test duct.

The inlet to the test system consisted of a 2-in. diameter, 5-in. length of pipe connected to a 3-in. diameter, 8-in. length of pipe which in turn was attached to the 8-in. square duct. A Stairmand disc in the 3-in. diameter pipe provided high velocity mixing of the metal fume and air. Further mixing was obtained in the 8-in. square duct with the use of an additional Stairmand plate. An air flow calibration vs entry loss to the smaller pipe provided the necessary flow metering. Pressure taps were located immediately before and after the filter to measure resistance.

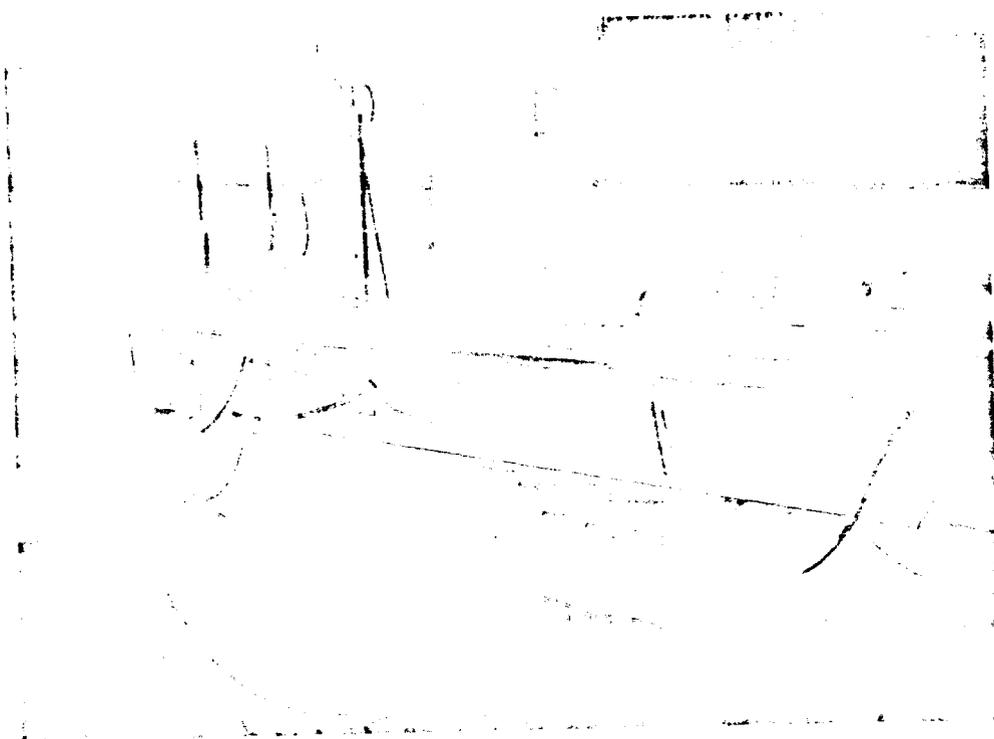


Fig. 1—Filter test assembly.

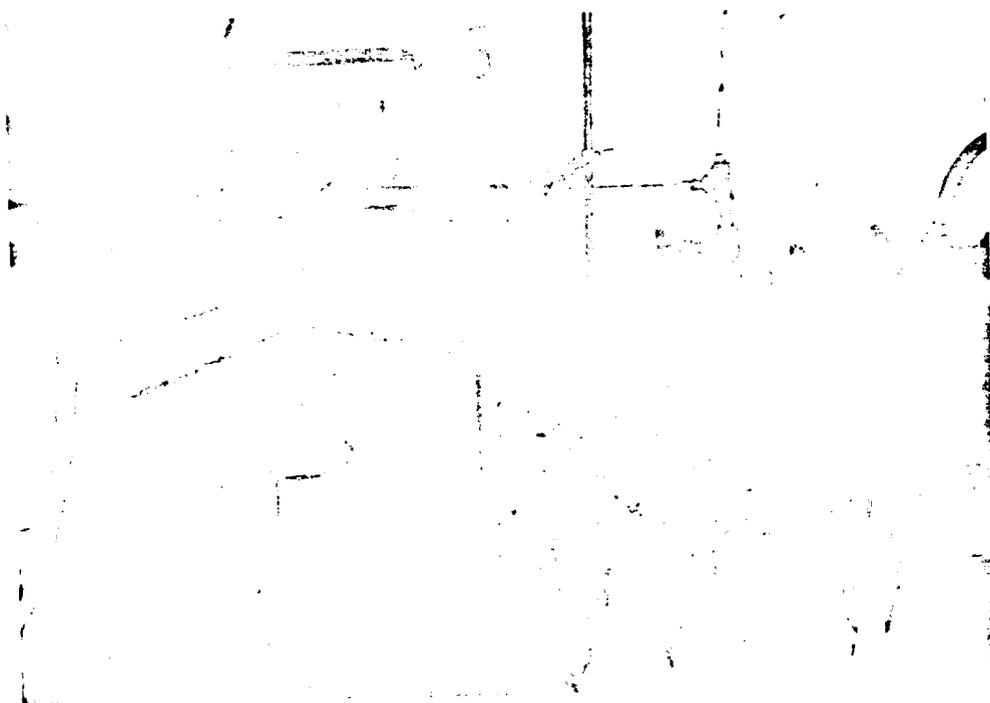


Fig. 2—Generation equipment for NaK aerosol.

## 2.2 Fume Generation Equipment

A mixed sodium and potassium oxide fume was generated, Fig. 2, by burning the liquid metal at the tip of a  $\frac{1}{4}$ -in. diameter brass feed tube placed near the inlet to the test filter system. A continuous and very slow flow of liquid metal was ejected from the metal reservoir by application of pressure from a nitrogen cylinder. Inlet fume concentrations within the test gas stream ranged from 0.2 to 2.0 grains/1000 cu ft of air. Loadings as high as 10 grains/1000 cu ft could be generated continuously. Loadings estimated at 50 grains/1000 cu ft were obtainable for brief periods.

## 2.3 Sampling and Analytical Methods

Aerosol samples upstream and downstream of the test filter were collected with HA Millipore filter papers which were located in holders placed in and facing the gas stream.

After sampling, Millipore filters were washed individually several times with water that had been distilled and demineralized. The washings were made up to known volumes and subsequently analyzed for sodium content with a Beckman Flame Spectrophotometer. The spectrophotometer permitted very rapid determination of sodium for concentrations as low as 0.1 mg/liter of solution. The intense sodium background in the sample made it difficult to determine the amount of potassium present by this technique.

Metal fume concentrations approaching commercial pleated filters and the total quantity of fume deposited on them were determined by continuous aerosol sampling. However, when test filter media could be removed and washed in a leaching tank, the total filter loading was determined directly by analyzing an aliquot of the washings.

The final composition of the reaction product collected on the filter is probably a mixture of sodium and potassium hydroxides plus an undetermined amount of water. Because of this factor, air concentrations (grains/1000 cu ft) and filter holding capacities (pounds) are expressed in terms of metallic sodium.

The liquid metal used to generate the fume contained 56 per cent sodium and 44 per cent potassium. Assuming complete conversion to hydroxides following oxidation there would be 3 g of mixed hydroxides for every gram of sodium.

Based on a criteria of  $\frac{1}{2}$  lb of mixed hydroxides for a 24- by 24- by 12-in. filter, the equivalent loading for a 50-cfm test filter should be about 3 g of metallic sodium.

## 3 TEST RESULTS

### 3.1 Absolute Filters

*Fume Holding Capacity vs Pressure Loss.* Initial tests were conducted with 50 cfm capacity, all glass, 8- by 8- by  $5\frac{7}{8}$ -in. filters. Collection efficiency of these filters decreased from an original value of 99.9 per cent to approximately 99.5 per cent after intermittent exposures to fume loadings over a period of several days.

By continuously loading a clean filter with 0.4 to 0.6 g of sodium, the pressure loss was increased from 0.8 to 5 in. water. A conservative linear extrapolation of these data indicates that 3 g of sodium would raise the pressure loss to approximately 30 in. water. Since pressure loss is a function of filter loading raised to some power greater than one, actual pressure losses would probably exceed this value. Upon standing approximately four days following loading, the pressure loss returned to its initial value. The filter was loaded again and upon further standing was found to return to approximately its initial pressure loss although as much as 1.2 g of sodium were deposited on it. This phenomenon was attributed to the deliquescent properties of the fume which, through hydroxide formation, cause chemical destruction of the glass fiber. Since the filtration system must be able to handle a liquid metal spill in a short time, the reduction of pressure loss upon standing is of limited practical use.

Additional tests were conducted with a cellulose-asbestos filter. Loading-pressure loss characteristics were essentially the same as those for all-glass filters but initial collection efficiency was slightly lower (99.4 per cent).

**Agglomeration Studies.** The possibility that natural agglomeration mechanisms might be enhanced by increasing fume retention time within a ventilation system was investigated in the laboratory. Two 55-gal drums, with baffles, placed between the fume generator and the test filter increased fume holding time from 2.6 to 9.6 sec. No improvements were noted in filtration characteristics, based upon tests on a Cambridge Absolute filter.

### 3.2 High Efficiency Roughing Filter

The Cambridge Aerosolve 95 filter was rated at 50 cfm with a clean pressure loss of 0.32 to 0.38 in. water and an average discoloration efficiency of 90 to 95 per cent against atmospheric dust. The clean pressure loss was found to be 0.36 in. water at rated flow. Initial weight collection efficiency was 55 per cent for the NaK fume which was far below minimum collection requirements. When the pressure loss increased to 4 in. water, corresponding to a filter loading of 0.4 g of sodium, the efficiency of the Aerosolve 95 increased to 94 per cent.

The Cambridge Aerosolve 85 filter was less than 10 per cent efficient which precluded its practical application for NaK removal.

### 3.3 Combination High Efficiency Roughing and Absolute Filter

An attempt to increase the fume retention of a filtration system while maintaining high efficiency was made by placing an Aerosolve 95 filter upstream of the Absolute filter. The prefilter was intended to prevent the rapid plugging of the Absolute filter. The initial resistance of the combination was 2 in. water. After loading the system with 0.6 g of sodium, the pressure loss rose to 6.7 in. water. Extrapolation indicated that a loss in excess of 30 in. water would result with fume retention of 3 g of sodium.

The failure of this system to provide high fume holding capacity at moderate resistance is attributed to the small (relative to the Absolute filter) filtration area of the prefilter. This resulted in rapid plugging of the prefilter despite its initial low efficiency. Since the commercial filters tested did not meet design criteria, several experimental filters were fabricated and tested in the laboratory.

### 3.4 Slag Wool Filter

Basic slag wool appeared to offer some advantages as a dry filter media because of its low cost, fire-resistant properties, and availability in small fiber sizes, 4  $\mu$ . Slag wool filters were prepared by (1) slurring the bulk medium in a washing tank with compressed air agitation to disperse fibers and remove shot and (2) by subsequent dewatering and drying of the cleaned slurry to form the filter bed.

Table 1—PRESSURE LOSS, FUME RETAINED, AND COLLECTION EFFICIENCY OF SLAG WOOL FILTERS (4  $\mu$  FIBER DIAMETER)

Packing density, lb/ft <sup>3</sup>	Filter weight, lb	Filter depth, in.	Pressure loss		Fume retained as Na, g	Collection efficiency, %
			Initial, in. water	Final, in. water		
11.4	0.141	0.52	2.1	11.9	0.0964	84.6
11.0	0.137	0.53	1.4	10.6	0.0793	71.8
6.6	0.245	1.57	7.7	±29	0.44	97.8
6.2	0.229	1.57	6.9	9.9	0.23	95.3

Table 1 gives pressure loss, fume retention, and collection efficiency for the slag wool filters tested. Examination of the filter bed showed that most of the fume had caked on the upstream surface which caused high resistance and reduced fume holding capacity. The efficiency of these filters at the higher packing densities was satisfactory but eventual reaction between the alkali and fiber would destroy the medium.

### 3.5 Curled Glass Fiber Filter

The performance of filter beds composed of 30  $\mu$  curled glass fibers are tabulated in Table 2. The initial efficiency of the densest filter tested (packing density of 6.4 lb/cu ft) was only 68.1 per cent. The holding capacity which extrapolated to 3 g of sodium for an approximate pressure drop of 30 in. water was also well below cleaning requirements. Alkali-glass reaction would be similar to the slag wool.

Table 2—PRESSURE LOSS, FUME RETAINED, AND COLLECTION EFFICIENCY OF GLASS FIBER FILTERS (30  $\mu$  FIBER DIAMETER)

Packing density, lb/ft <sup>3</sup>	Filter depth, in.	Pressure loss		Fume retained as Na, g	Collection efficiency, %
		Initial, in. water	Final, in. water		
1.5	2.5	0.24	0.33	0.093	17.6
3.3	2.5	0.94	4.72	0.578	46.5
6.4	2.5	0.98	2.03	0.322	68.1
6.4 one	2.5		4.07	0.565	84.1
6.4 filter	2.5		5.46	0.688	91.4
6.4 used	2.5		7.96	0.830	95.1

### 3.6 Curled Saran Fiber Filter

Another filter tested was a 30 denier curled saran fiber bed, Table 3. The initial efficiency was lower than desired and the extrapolated pressure loss, for 3 g of sodium retained, was considerably in excess of 30 in. water.

Table 3—PRESSURE LOSS, FUME RETAINED, AND COLLECTION EFFICIENCY OF CURLED SARAN FIBER FILTERS (30  $\mu$  FIBER DIAMETER)

Packing density, lb/ft <sup>3</sup>	Filter depth, in.	Pressure loss		Cumulative fume retained as Na, g	Collection efficiency, %
		Initial, in. water	Final, in. water		
7.0	5	2.13	2.72	0.097	75.0
7.0	5	2.72	3.93	0.212	81.2
7.0	5	3.93	7.07	0.444	93.3

### 3.7 Bulk Dynel Fiber Filter

Several tests were made with beds composed of bulk, 3 denier, Dynel fibers which has a mean diameter of 29.5  $\mu$  according to microscopic size measurements. The spread in data, Table 4, was attributed to the difficulty of hand-packing uniformly a loose fiber of variable bulk density.

This fiber appeared to approach the desired filtration criteria except for the difficulty of reproducibility in packing. To minimize the packing problem it was decided to obtain a more uniform nonwoven, bonded, Dynel fabric, cut into pads.

### 3.8 Nonwoven Bonded Dynel Fiber Filter

*Efficiency and Loading Study.* A nonwoven Dynel medium\* consisted of loosely felted fibers bonded by spraying with various adhesives to form a  $\frac{3}{8}$ -in. thick pad. The adhesive may

\*Fabricated by J. P. Stevens Co., New York, N. Y.

Table 4—PRESSURE LOSS, FUME RETAINED, AND COLLECTION EFFICIENCY OF BULK DYNEL FIBER FILTERS (29.5  $\mu$  FIBER DIAMETER)

Packing density, lb/ft <sup>3</sup>	Filter depth, in.	Pressure loss		Fume retained as Na, g	Collection efficiency, %
		Initial, in. water	Final, in. water		
4.0	4	4.6	7.86	3.6	69.2
4.0	4	4.4			75.2
4.8	4	8.6	9.2		74.4
4.8	4	7.4	12.8	2.5	88.1
4.8	4	10.9	12.2	2.6	88.8

be applied throughout its depth or to one or both surfaces. Preliminary studies with a coarse, 45  $\mu$  average diameter, nonwoven Dynel filter bed indicated very low efficiencies.

Final tests, Table 5, were conducted with units composed of mixed 3 and 6 denier fibers (average diameter by microscopic examination 29.5  $\mu$ ) which were surface-sprayed on both sides. The weight of the fabric was given as 8.0 oz/sq ft by the manufacturer.

Table 5—INITIAL PRESSURE LOSS AND COLLECTION EFFICIENCY VS NUMBER OF LAYERS OF NONWOVEN, BONDED, DYNEL FIBER FILTERS (AVERAGE DIAMETER 29.5  $\mu$ , WEIGHT PER LAYER 0.0202 LB)

Packing density, lb/ft <sup>3</sup>	Filter depth, in.	Pressure loss initial, in. water	Number of layers	Collection efficiency, %
2.79	4 <sup>5</sup> / <sub>8</sub>	2.75	15	36.1
3.72	5 <sup>5</sup> / <sub>8</sub>	4.18	20	48.5
6.51	4 <sup>5</sup> / <sub>8</sub>	8.35	35	69.5
6.45	6	10.90	45	81.4

Table 6—COMPARISON OF CALCULATED AND EXPERIMENTAL COLLECTION VS NUMBER OF LAYERS OF A NONWOVEN, BONDED, DYNEL FIBER (AVERAGE DIAMETER 29.5  $\mu$ )

Packing density, lb/ft <sup>3</sup>	Filter depth, in.	Pressure loss initial, in. water	Number of layers	Experimental collection efficiency, %	Calculated* collection, %
			5		15.0
2.79	4 <sup>5</sup> / <sub>8</sub>	2.75	15	36.1	39.6
3.72	4 <sup>5</sup> / <sub>8</sub>	4.18	20	48.5	47.8
6.51	4 <sup>5</sup> / <sub>8</sub>	8.35	35	69.5	68.0
6.45	6	10.90	45	81.4	76.9

\*Calculations based on the assumption that 5 layers of the bonded fiber will remove 15% of the fume, and that the log penetrations law is applicable.

Tests with a filter composed of 45 layers of bonded Dynel fiber indicated a fume retention of 7.5 g of sodium accompanied by a 6-in. rise in pressure loss (10.9 to 16.8 in. water). Final pressure loss for a 3-g holding was calculated to be 14 in. water.

The relationship between collection efficiency and number of pads or layers was closely approximated by the log penetration law as shown in Table 6. It is estimated that 70 layers of 29.5  $\mu$  fibers will be required to obtain a collection efficiency of 90 per cent.

No significant change in collection efficiency was observed over the face velocity range of 90 to 200 fpm.

*Resistance Study.* There are two direct methods to reduce the pressure loss of the 45 layer filter discussed in the preceding section; reduce the packing density by increasing the depth of bed or decrease the filter face velocity. It was necessary to determine the effect of these variables on pressure loss. Experimental data indicated that pressure loss could be expressed by the following relationship:

$$\frac{\Delta P}{L} = K (\rho')^{1.3} V^{1.25} \quad (1)$$

where:  $\Delta p$  refers to pressure loss,  $\rho'$  to packing density,  $V$  to face velocity, and  $L$  to bed depth (consistent units).

By means of the relations indicated in Eq. 1, it was estimated that a filter bed composed of 70 layers of bonded Dynel, packed to a 24-in. depth,† would be 90 per cent efficient in the collection of freshly generated NaK fume. The initial (clean) and final pressure loss for the bed should be 12.7 and 15 in. water, respectively, at a face velocity of 180 fpm. This is equivalent to an air flow of 700 cfm through a filter face area of 4 sq ft.

*Procedure for Reclaiming Filters.* When it is desired to clean the filter, the following procedure has been found satisfactory:

1. Gently submerge the filter in the horizontal position in water.
2. Slowly remove the filter and allow it to drain and dry.
3. If immediate use is necessary, replace the filters in air cleaning system and maintain a reduced air flow through them so that the pressure across the filter does not exceed 8 in. water until dry.

#### 4 CONCLUSIONS

Commercial and experimental filters were tested for the filtration of a mixed sodium and potassium oxide fume. One experimental model approached the requirements of efficiency, fume retention, maximum pressure loss, corrosion, and fire resistance. This filter was composed of a nonwoven Dynel fabric having an average fiber diameter of 29.5  $\mu$ . Performance characteristics for a 24- by 24- by 24-in. filter, based upon extrapolation of test data are as follows:

1. Air flow, 700 cfm (180 fpm)
2. Initial resistance, 13.0 in. water
3. Final resistance, 15 in. water
4. Efficiency, 90 per cent
5. Fume holding capacity, 0.5 lb mixed sodium and potassium hydroxides

Improved performance can be anticipated if finer fibers are incorporated into nonwoven media for fabrication of filter units. A graded density filter should give optimum results.

The estimated cost of this reusable medium for this filter is \$25. With proper washing techniques, the plugged medium can be restored.

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†This depth does not interfere with previous construction since space was provided for prefilters.

# DEVELOPMENT OF A "TRIBOELECTRIFIED" FLUIDIZED BED FOR AEROSOL FILTRATION

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## 1 INTRODUCTION

Electrostatic effects in aerosol filtration have been known to exist for some time. It has only been recently, however, that any fundamental research has been undertaken to delineate the magnitude of the electrostatic forces.<sup>1-3</sup> The use of mechanically induced electrostatic charges on fibrous media and on fabrics has been investigated.<sup>2,3</sup> It has been shown that the filtering efficiency of such media, due to interception, inertial impaction, gravity, and diffusion, can be increased significantly, in some cases more than doubled because of the added electrostatic forces.

The most vexing problem encountered in the use of fibrous and fabric media has been the difficulty of continually replacing the charge which is constantly "leaking" off the surfaces of the fibers to ground. Some success has been found in continually charging the surface of fabric media but the studies have shown<sup>3</sup> that for optimum utilization of electrostatic forces a longer path of aerosol travel is necessary than can be attained with fabrics. It is also important that the surface charge producing the electrostatic forces be distributed uniformly throughout the media and not merely on the surface layers. Several methods have been considered for continually charging a deep fibrous bed but the necessity for obtaining intimate contact between the fiber surfaces and the charging surfaces created problems which were not readily solved.

"Triboelectrification" requires an intimate contact between two dissimilar materials.<sup>4</sup> Such an intimate contact is much easier to obtain with spheres than with cylinders because of their geometries. This concept involves using a packed bed of spheres of a chargeable material continually charged by some means. Since beds of spherical materials are easily fluidized they provide the contact necessary for triboelectrification, i.e., the random motion and "turnover" of the fluidized spheres. The dissimilar charging material can be the walls of the container, provided enough mixing of the bed is attained. If such is not the case then the charging material itself can be fluidized in a mixed bed.

Thus, it appears that a study of the electrostatic properties of fluidized beds as they effect aerosol filtration may be fruitful in the eventual development of a practical, high efficiency, continually charged electrostatic filter.

## 2 THEORY

### 2.1 Triboelectrification

An extensive search of the literature on this subject has been made, the results of which are reported elsewhere.<sup>3</sup> In summary it can be stated that the several theories explaining the "contact" charging mechanisms are not consistent and that a complete and rigorous theory awaits further developments in the field of solid state physics. Most investigators have shown, however, that the charge generated on two dissimilar materials is independent of the relative motion, contact time, and pressure between the two and depends only on the intimate contact and subsequent separation of the two.

The most important property of a material, next to its inherent "chargeability," is its ability to "hold" a charge. This is related to its surface resistivity when dry and its water adsorption characteristics. In general, plastics possess high surface resistivities and low moisture adsorption properties and therefore "hold" a charge for considerable periods of time. Whether plastics in general possess any special intrinsic property which permits them to acquire high charges (in preference to nonplastic materials) is not known but experiments show that high surface charge densities are acquired and can be maintained provided the humidity is not too high.<sup>2</sup>

## 2.2 Fluidization

The term "fluidization" is used to designate the gas-solid contacting process in which a bed of finely divided solid particles is lifted and agitated by a rising stream of process gas. At the lower end of the velocity range, the amount of lifting is slight, the bed behaving like a boiling liquid, hence the term "boiling bed."

As the velocity is increased, a point is reached where the pressure drop becomes equal to the sum of the weight of the bed per unit cross-sectional area plus the friction of the bed against the walls. At this point, for free-flowing materials, the bed expands and assumes a more open arrangement so that the gas can flow without the pressure drop exceeding the unit bed weight. Another increment of velocity results in over-all circulation of the bed, often with transient upward-flowing gas streams in channels that contain relatively few particles, and downflow of clumps of particles. This is called "aggregative" fluidization. It is this aggregative vibration and circulation which it is hoped will produce the necessary triboelectrification of the bed.

## 2.3 Electrostatics and Electrostatic Attraction

*Charge measurement.* The basic principle of static charge measurement makes use of the "Faraday cage" and is based upon a fundamental theorem of electrostatics which states that "the space completely enclosed within the outer bounding surface of a conductor, or within any surface, every point of which lies in conducting material, contains a zero total net electric charge."<sup>5</sup> If a net free charge  $+q$  be located within a closed cavity of a conductor, a charge totaling exactly  $-q$  must appear as surface charge on that part of the conductor boundary which forms the cavity, i.e., the inner surface of the cavity. Such surface charge is said to be "induced" by the presence of the free charge  $+q$ . This charge  $-q$  distributes itself over the cavity boundary such that the surface becomes equipotential; this is a function of the surface geometry or capacitance,  $C$ , defined as  $Q/V$  which has the units of length (in the unrationalized cgs electrostatic system,  $C$  has the units cm or statfarads). Thus by measuring  $V$  and  $C$  the enclosed charge  $+q$  is determined.

*Electrostatic collection forces.* The data obtained to date do not justify extensive theoretical treatment. The basic electrostatic collection forces, however, have been delineated previously.<sup>1-3</sup> Basically we shall consider three forces: coulombic attraction, image attraction, and "dielectrophoresis." The latter two are often called "inductive" forces.

## 3 MACROSCOPIC CHARGING TESTS

### 3.1 Manual Tests

Of primary importance in this study is the ability of the bed particles to acquire and hold a charge. Synthetic plastic materials have shown the best possibilities and preliminary measurements were made with them. Materials available in spheres in the fluidization size range were: (1) Dylene Polystyrene unlubricated beads (Koppers Company, Pittsburgh, Pa.), (2) Styrene-Divinylbenzene microspheres (Dow Chemical Company, Midland, Mich.), and (3) Urea-formaldehyde "Micro-balloons" (Colton Chemical Company, Cleveland, Ohio).

The apparatus for measuring the surface charge on the experimental spheres (Fig. 1) has been developed by Rossano<sup>2</sup> and is based on the "Faraday ice pail" principle. A charged object when placed in the cage will induce a charge of equal sign and magnitude on the metal sleeve surrounding the Lucite tube (11 in. long, 5¼ in. diameter) and on the metal wires and plates of the leads, capacitor, and voltmeter. Provided the material is placed within the central portion of the cage (central 1 in. long) most of the field lines from the charged object will terminate on this brass sleeve. The electrostatic problem involved has been solved by Masters.<sup>6</sup>

The easiest and most efficient method for obtaining a static charge on spheres by the contact mechanism is by shaking small amounts of material in containers of large contacting surface. The preliminary charges determined below were obtained in this manner although in a fluidized bed the contacting efficiency will not be as high. The material was shaken with a rotary action for one minute and then carefully poured into a glass beaker housed in the Faraday cage and the induced voltage measured.

In Table 1 the results of this limited evaluation are shown. Tests were made at a temperature and humidity below the limit for which charge leakage from surfaces of high resistivity becomes important.<sup>3</sup>

From the quantitative data and qualitative observations of Table 1, several observations can be made. Using the same particulate material (Dylene-Polystyrene) and varying the container in which contact charging occurs (tests 2 and 3) the conducting material (steel) produces an effective net charge of several orders of magnitude greater than the dielectric (glass) for the same weight of material. The term effective combines the charge produced and the force necessary for separation of charge. It is this energy for separation which results in the net charge left on each surface. Presumably the greater the force necessary for separating a particle from the wall, the greater the charge apparent on separation although this effect may be somewhat obscured by Van der Waal's forces. The ideal material for contacting is that which will readily give up a particle and retain an appreciable charge. In these experiments the force for dislodging the particles was attained by rapping the side of the container vigorously with a wooden stick and was measured only qualitatively.

On the basis of the observed facts that only the portion at or near the walls has significant charge (tests 1, 2, 3) and that smaller increments of the same material show a higher average charge per particle (tests 3 and 4) it is obvious that a large ratio of charging to charged area is necessary. These observations agree with those of Rossano.<sup>2</sup> A comparison of tests 4 and 5 show that Dylene Polystyrene appears better for contact charging than Styrene-Divinylbenzene. Both of these materials are essentially polystyrene with the latter having an 8 per cent divinylbenzene molecular cross linkage. This change in molecular structure is apparently sufficient to change the surface work function from above that of steel to below that of steel.<sup>7</sup> The latter material may charge as highly as the former but the surface forces holding these particles are greater so that the effective charge per unit mass is less for the same weight of material.

The final material tested, urea-formaldehyde, shows no net charge developed since the surface forces in this case are so great none of it can be dislodged from the walls, even with violent agitation. The first two materials have about the same size and density and are directly comparable. This material exists as fine hollow spheres (16  $\mu$ , mean diameter vs 200  $\mu$  mean diameter) and has an effective specific gravity of 0.3 vs 1.05 for the other two materials. Thus the mass per particle is very much smaller and the image forces (from initial contact-separation) evidently cause "welding."

The maximum charge density magnitude developed (test 4) is very encouraging and shows that, although crude, the contact-charging method used is very efficient. Rossano<sup>2</sup> using Saran fibers and taking great care to charge in small increments using steel teeth drawn through a fibrous bundle was able to develop a maximum surface charge density of 0.72 statcoulombs/cm<sup>2</sup> or about 9 per cent of the theoretical limit before gaseous discharge.<sup>8</sup> Test 4 shows a maximum charge of 2.36 statcoulombs/cm<sup>2</sup> or nearly 30 per cent of maximum. Considering that in very efficient static generators, e.g., Van der Graaf machines, the highest charge developed is only 25 per cent of theoretical maximum, these results are indeed encouraging.

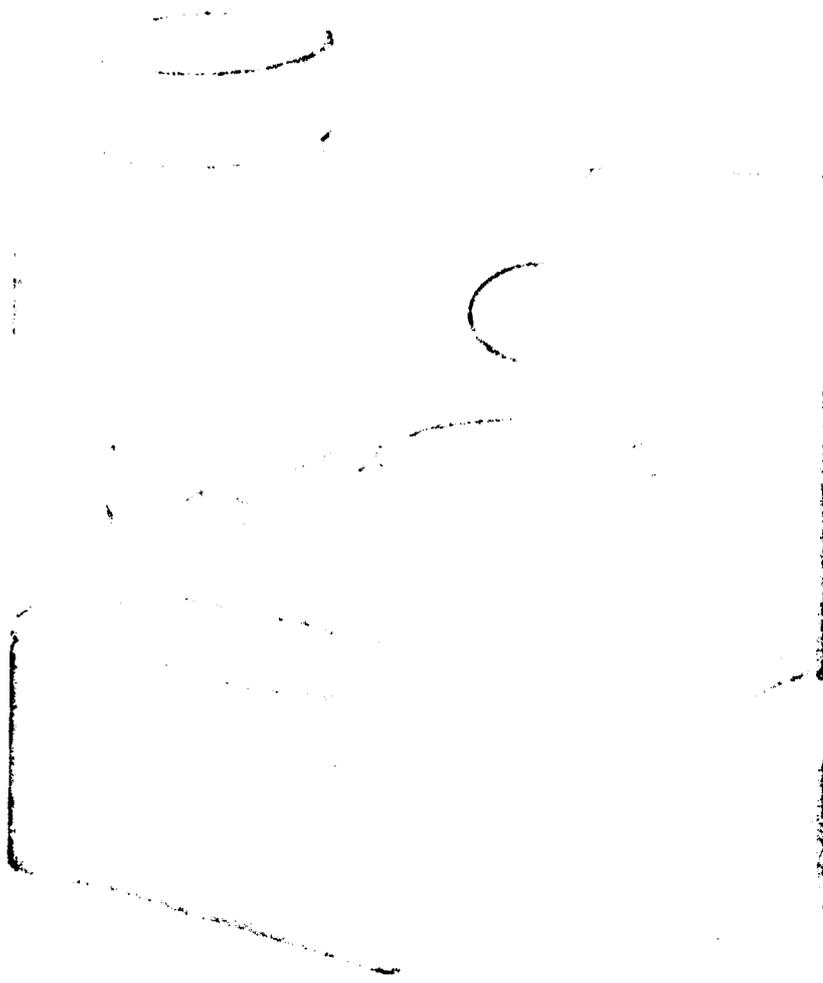
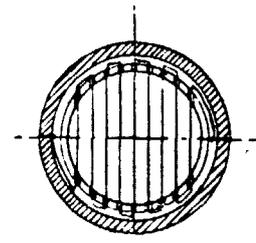
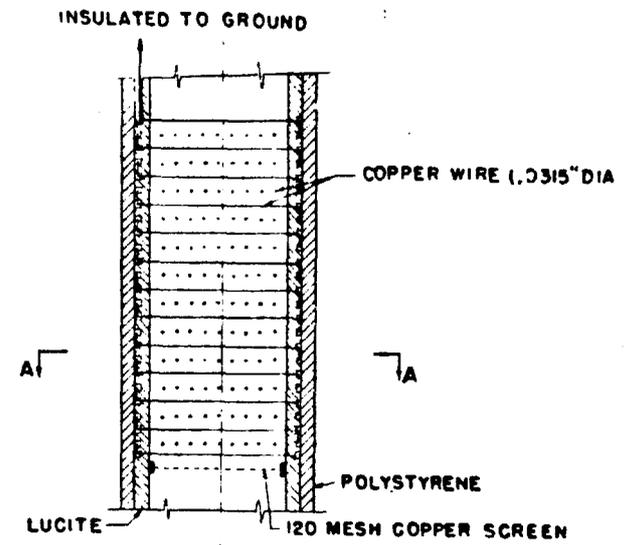


Fig. 1—Apparatus for measuring surface charge.



SECTION "A-A"

Fig. 2—Wire matrix system for "in-situ" bed charging.

Table 1—MECHANICALLY PRODUCED STATIC CHARGE ON VARIOUS FLUIDIZED BED MEDIA\*

Test No.	Material	Container	Sample weight, g	Q/M, statcoul/g	Q/part. statcoul	Average surface charge density, statcoul/cm <sup>2</sup>	Percent of theoretical maximum, %	Remarks
1	Dylene-Polystyrene	Polyethylene bottle	30	-0.73	$-0.33 \times 10^{-5}$	0.0026	0.03	Most charge appears from fraction of particles which will dislodge from wall—some remains.
2	Dylene-Polystyrene	Pyrex glass flask	10	-6.05	$-2.72 \times 10^{-5}$	0.022	0.34	All charge from wall—bound particles, most of which will not dislodge.
3	Dylene-Polystyrene	Steel can†	10	-130.0	$-59.0 \times 10^{-5}$	0.47	5.80	Most charge from wall—bound particles, most of which dislodges.
4	Dylene-Polystyrene	Steel can†	1.0	-656.0	$-295.0 \times 10^{-5}$	2.36	29.5	All particles adhere to wall and may be dislodged completely.
5	Styrene-Divinylbenzene	Steel can‡	1.0	+379.0	$+170.0 \times 10^{-5}$	1.36	17.0	All particles adhere to wall but fair percentage will not dislodge.
6	Urea-Formaldehyde	Steel can‡	1.0	0	0	0	0	No charge observed except on wall-bound particles which will not dislodge at all.

\*t = 78.5°F, w = 75 grains water per pound of dry air.

†Particles possess such a high charge that on removal of beaker from Faraday cage the electrostatic repulsive force (due to like-charged particles) causes them to jump right out of beaker, a distance of 6 in. to 8 in. vertically. While in cage the particle fields are compelled to terminate on the metal.

‡Same as above but particles do not jump as high.

### 3.2 Fluidized Bed Tests

The beds tested were housed in a polystyrene tube, 1 ft by  $1\frac{3}{4}$ -in. O. D. by  $1\frac{1}{2}$ -in. I. D., and supported on 120 mesh copper screen (polystyrene having the highest surface resistivity of available transparent plastics—necessary for bed observation).

For initial tests heterogeneous charging was accomplished by the introduction of 14 by 18 mesh copper flyscreen (wire diam., 0.011 in.) circles at various points within the fluidized media. These screens could be grounded by an insulated wire running out the top of the test section. The plane of these screens was perpendicular to air flow. In later tests these screens were replaced by a copper wire grid arrangement as shown in Fig. 2. Copper wire (0.0315-in. diam.) was threaded through opposite holes  $\frac{1}{8}$  in. apart in alternately perpendicular layers  $\frac{1}{8}$  in. apart in the central 3-in. length of a 1 ft by 1.50-in. O. D. by 1.24-in. I. D. lucite tube. The mesh was thus composed of a single strand of wire in the form of 25 layers of 9 parallel wires each ( $\frac{1}{8}$  in. apart), the wire direction in each succeeding layer perpendicular to the preceding one. (For a section of one layer see Fig. 2.) The total length of wire in each layer was 9.44 in. for a total wire length of 19.7 ft. The volume occupied by the wire was such as to make the 3-in. central tube of the lucite cylinder have a porosity of 0.952. The entire lucite tube assembly fitted neatly into the polystyrene tube of previous tests. The mesh system could be grounded by an insulated wire running between the two tubes in a notched channel. The retaining screen was a 120 mesh screen butt-fitted  $\frac{1}{8}$  in. below the first wire layer.

Charge measurement was accomplished by the use of the Rawson voltmeter, air capacitors, and a Faraday cylinder arrangement in the form of 5 in. or 10 in. lengths of aluminum foil or aluminum-coated Mylar film wrapped around the outside of the polystyrene tube. A copper wire surrounded this cylinder and provided access to the voltmeter system. The outside Faraday cylinders were between 98 and 99.5 per cent efficient for measuring charge enclosed within their central 2 in. lengths, the maximum bed expansion.<sup>6</sup>

When it was found that ambient air possessed high charges at certain times (due to charged atmospheric dust and ions) a prefilter was added upstream of the test section. This consisted of a 6-in. diameter circle of MSA 1106B glass filter paper mounted in an appropriate cone assembly. The comparatively large cross-sectional area reduced pressure loss. This media is reported to be >99 per cent efficient on atmospheric dust<sup>9</sup> over the velocity range in which it was used. Nevertheless tests were made to determine the charge in the filtered air. These results are reported with the appropriate data.

Koppers Dylene was the first material tested since it was available in the largest quantities. A preliminary investigation showed that the 40 to 50 mesh fraction was the largest size which would flow through 14 by 18 mesh screening without clogging. This fraction was therefore used since the highest ratio of contacted to contacting areas was obtained.

Table 2 presents the results of tests using ambient unfiltered air as the fluidizing medium.

The first test shows that a comparatively low charging rate (0.025 esu/g/min) is accomplished by contacts between the wall and beads and that within 90 min an asymptotic level of charge is reached. This is due to the building up at the wall of a heavy coating of particles "bound" by image forces. In test 2, where contacts between the beads and a copper screen were added, a comparable effect (to test 1) occurred. Since the screen was not grounded the *net* charge increase must also have been due to wall contacting. In test 3, however, *non*-asymptotic *net* charging occurred under the same conditions. It was concluded that the added charge must have come from charged particles in the fluidizing air stream. Tests 4 through 9 were repeat tests with the charging screen grounded. In tests 4, 5, and 6 *non*-asymptotic charging occurred indicating possible *net* charging from the screen which is now possible, or, perhaps, added charge from the air (dust and ions). Run 4 shows a comparatively large charging rate which lasts at least 8 hr. This would be very encouraging if it were possible to attribute the charging action to the screen alone. Runs 7, 8, and 9, however, show that this is probably not the case since charging becomes asymptotic, stops, or discharging can occur, all at the same conditions as before. In tests 10 through 14 various changes in charging surfaces and conditions were made primarily in an attempt to reduce the poor quality of fluidization caused by the single copper screen. Two screens (test 10) produced even poorer conditions but

Table 2—NET CHARGE BUILD-UP ON POLYSTYRENE BEADS BY FLUIDIZATION WITH UNFILTERED AIR\*

Run No.	Bed No.	Charging source	Fluid. vel., fpm	Fluid. qual.	Bed expans., %	Maximum charge, esu/g	Time, min	Average build-up rate, esu/g min
1	1	Wall only	86	Smooth	100	-2.24	90	-0.025
2	2	1 screen† at 1 in., (U)	86	Poor‡	Variable	-0.60	60	-0.010
3	3	1 screen‡ at 1 in., (U)	86	Poor	Variable	None	60	-0.022
4	2	1 screen§ at 1 in., (G)	86	Poor	Variable	None	500	-0.263
5	3	1 screen§ at 1 in., (G)	86	Poor	Variable	None	60	-0.022
6	9	1 screen§ at 1 in., (G)	86	Poor	Variable	None	30	-0.094
7	1	1 screen§ at 1 in., (G)	86	Poor	Variable	-0.22	6	-0.037
8	7	1 screen§ at 1 in., (G)	86	Poor	Variable	loses chg.	120	+0.008
9	9	1 screen§ at 1 in., (G)	86	Poor	Variable	0.00	60	0.00
10	10	2 screens at 0.5 in. & 1.0 in., (G)	86	Very poor**	Variable			
11	11	18 parallel wires, .07 in. apart, 1 in., (G)	66	Smooth	100	-0.71	5	-0.147
12	12	1 screen at 1¼ in., (U)	100	Poor	Variable	None	15	-0.270
13	12	1 screen at 1¼ in., (G)	100	Poor	Variable	-1.20	10	-0.120
14	14	1 screen at 1¼ in., (U) plus tobacco smoke	115	Poor	Variable	None	10	-0.563

\*40-50 mesh; Dylene 3, Koppers Co.; one-inch deep (settled) beds; 18.3 g; fluidization air at 76-83°F and 45-75 grains water per pound dry air.

†Corrected for meter leakage.

‡18 by 14 mesh copper screen, 0.011 in. diam.; U, ungrounded.

§Segregated above screen.

§G, grounded.

\*\*Segregated above second screen.

parallel wires (test 11) interfered very little with smooth fluidization. This is presumably due to the absence of "holdup" which is accelerated at wire-crossing points. The charging stops, however, after 5 min, indicating a coating of the wires (observable) which prevents further net charging. Increasing the fluidization velocity and, therefore, particle momentum, seems to produce less wire coating (tests 12, 13, and 14) as evidenced by higher charge build-up rates but this again is obscured by possible charge addition from the air. Tobacco smoke, for example, when introduced in run 14 produces a charge build-up rate (non-asymptotic) of a very high level. The obvious method for clarifying the possibility of aerosol capture charging was by the use of prefiltered air for fluidization.

A 6-in. diameter filter circle of MSA 1106B media was placed upstream as a prefilter. Tests were made with highly charged tobacco smoke which showed no passage of collectable charged particles.

Table 3 summarizes the important tests with prefiltered air. The charges were computed correcting for meter leakage. In tests 1 through 4 asymptotic charge levels were reached, proving conclusively that once the walls and screen become coated further charging is impossible. In test 1 it should be noted that a comparatively high asymptotic level of charge, -47.5 esu/g, is reached when compared to the tests of Table 2 where aerosol capture charging was probably minimal, i.e., tests 1, 2, 7, 8, 9, 11, 13. This is attributed to the greater bed expansion although the bed was still segregated as in Table 2. This high expansion represents more kinetic energy per particle which causes a slower rate of build-up of the wall and screen coatings. Nevertheless these coatings are still formed. It will be noted that tests 1 and 2 were

run alternately grounded and ungrounded. By this technique a clearer picture of the actual charging process is obtained. The original data show that charging due to wall contacts *stops* much before that due to the interspersed screen or in other words, direct impingement of the fluidized beads on the wires helps inhibit the charge-destroying coating process. It will also be noted that when the fluidized material is changed to nylon spheres (test 2) the sign of the charge reverses. This is due to a "surface states" phenomenon.<sup>10</sup> This material (nylon) is of a different size range, fluidized at a low velocity (to prevent "slugging") so the data of tests 1 and 2 are not directly comparable. In test 3 the nylon spheres eventually coat the tube walls (when this is the only charging surface) and charging stops, exactly in the same way as with polystyrene.

In test 4 the bed of test 3 was allowed to discharge for 26 days in an attempt to determine the effect of screen charging alone. It was necessary to use the same bed in both tests since any change of media introduces different distributions in charge densities due to different arrangements of particles and particle surface states. In this test, charge build-up proceeded very rapidly to an asymptotic level about one-half that of test 4. Since the bed was undisturbed except for the introduction of the charging screen it is assumed that the wall coating remains intact. Therefore, this additional charging can be attributed to screen charging alone. Obviously then the screen quickly becomes coated and no increase in net charge can then occur. For this test the observed bed expansion was lower than that in test 3 (practically zero) and thus very little motion for dislodging the wire coating existed. This probably accounts for the rapid attainment of equilibrium charge.

For tests 5 and 6, Table 3, the apparatus of Fig. 2 was used. In the initial charging runs with the wire grid system the Mylar film-Faraday cylinder method employed in previous tests was used to measure the charges generated. However, the "bound" charge effect due to the matrix interference was found to obscure all but a very small percentage of the charge from the surrounding cylinder. This then suggested the use of the matrix charging system itself as the charge-measuring system. Such was the system which was employed in test 6, Table 3, and used in all succeeding tests. The shielding error of this system is 6.0 per cent (as determined by comparison of total charge measured by grid system connected to voltmeter directly and that measured by an "outside" Faraday cylinder).

In test 5, the grid system was grounded during fluidization and charge was measured by pouring the bed into a separate Faraday cage. Thus it was not possible to determine whether or not charging was asymptotic. At 75 per cent expansion the matrix contacting process generated a charge of about -340 esu on 12.2 g of 40 to 50 mesh Dylene in 15 min of operation. This was the average net charge generated on that portion of the bed easily dislodged (gravity) from the bed matrix. A mono-particle layer remained on the matrix which could only be removed by violent agitation. Table 4 shows the charge distribution on the bed "as poured" from the cylinder. Generally speaking the mixing of charged spheres seems to be fair, with the portions closest to the matrix having the highest charge per particle, as is to be expected. This indicates significant migration of charged spheres through the bed, which is very encouraging.

In test 6 the matrix was not grounded but connected directly to the electrostatic voltmeter for charge measurement. Test 6 shows a continuous charge increase in the bed of the order of 13 esu/min (corrected for leakage) during operation at about 100 per cent expansion. This rate is 3 times higher than that due to highly charged atmospheric dust (test 4, Table 2) and is indicative of the feasibility of "in bed" charging. One important consideration is the time duration for which this charging will continue. A qualitative observation is the increasing force which must be applied in rapping the bed, obviously due to the greater attracting forces which occur as the particle charge increases with continued operation.

Table 5 shows the important charge measurements for the bed of test 6. It indicates that merely from the pouring action into the bed a charge is generated which is of the order of the asymptotic values of previous tests. This charge increases at the rate of about 1.0 esu/g/min during fluidization. This is based on an entire bed average. Item 4 shows that the mono-particle layer which is the most difficult to remove possesses charges as high as 30 per cent of maximum (8 esu/cm<sup>2</sup>). These particles were removed by a high speed air jet. Their charge

Table 3—NET CHARGE BUILD-UP ON POLYSTYRENE\* AND NYLON† BEADS BY FLUIDIZATION WITH PREFILTERED AIR

Run No.	Media	Bed wt., g	Settled bed depth, in.	Charging source	Fluid vel., fpm	Fluid qual.	Bed expans., %	Maximum generated‡ charge, esu/g	Time, min	Average build-up rate, esu/g/min
1	Dylene*	13.7	0.75	1 screen§ at 1½ in. U & G	115	Poor¶	300	-47.5	100	-0.475
2	Zytel§	22.6	1.0	1 screen at 1 in. U & G	30	Poor	20	+16.2	75	+0.215
3	Zytel¶	22.6	1.0	Wall only	30	Smooth	20	+11.5	30	+0.383
4	Zytel**	22.6	1.0	1 screen at 1 in., U	30	Poor	20	+5.3	6	+0.884
5	Dylene	12.2	1.0	Matrix G††	72	Smooth with rapping	75	None	15	-1.83
6	Dylene	12.2	1.0	Matrix, U	105	Smooth with rapping	110	None	10	-2.13

Note: Prefiltration with 1106B media adequate as measured by introduction of charged tobacco smoke.

- \*40-50 mesh Dylene 3 (Koppers Co.); fluidization air at 74-82°F.
- †50-100 mesh Zytel 31 (Du Pont); 43-70 grains water per pound dry air.
- ‡Corrected for meter leakage.
- §18 by 14 mesh copper screen, 0.011 in. diam; grounded and ungrounded intermittently.
- ¶Segregated above charging screen.
- \*\*Bed of test #3, after discharging for 26 days.
- ††Matrix system: 0.032 in. D. copper wire threaded through 1.5 in. O.D. by 1.24 in. I.D. Lucite tube, 1/8 in. on centers with succeeding layers perpendicular.

Table 4—CHARGE DISTRIBUTION IN BED #5 (TABLE 3) "AS POURED"

	(1) Bed weight, %	(2) Total charge, %	Ratio (2/1)
First	24.4	8.2	0.34
Next	18.4	15.8	0.86
Next	15.7	26.0	1.65
Next	9.8	25.0	2.56
Next	31.7	25.0	0.79
	100.0	100.0	

\*Does not include a particle layer not dislodged easily (approx. 30% of bed weight).

is in the order of the highest charges produced mechanically (test 4, Table 1) and indicates charging is *very* efficient provided removal of the spheres is possible. It should also be pointed out that the matrix in this test was *not* grounded so that an infinite supply of conduction electrons does not seem to be necessary.

Table 5—NET CHARGE DEVELOPED IN BED #6 (TABLE 3)

	Total, esu	Weight, g	Charge per gram, esu/g
Original charge as poured into tube	-130.0	12.2	10.7
Indicated charge increase during 10 min fluid.	-134.0	12.2	11.0
Total charge (free pouring mat.) after 30 min fluid.	-224.0	6.9	32.5
Total charge on mono-particle layer	-136.0	0.336	403.0

## 4 FLUIDIZATION PROCESS

### 4.1 Unhindered Fluidization

Of primary concern in this research program is the determination of the behavior of the fluidized bed particles during the process of fluidization. The following tests were made to observe the quality of fluidization, to determine the appropriate quantitative correlation applying to the flow mechanisms, and to determine the charge generated on the bed due to triboelectrification, using *the vessel walls alone* as the contacting medium, and the distribution of this charge through the bed due to the fluidization process.

The fluidized media tests were the Koppers Dylene-Polystyrene beads (30 to 60 mesh). The equipment used in these tests is shown schematically in Fig. 3. Air flow passed upward through a calibrated rotameter (set of 5 used—from 0.1 to 30 liters/min), through a 4 in.-straightening section composed of soda straws, through the bed section and downstream straightening extension piece, and then to the pump. The bed section was a 1.4-in. diameter by 7.4-in. long pyrex glass tube. The bed section (1 in. long) was placed in the geometric center of the tube. The bed itself was supported on 120 mesh copper screening supported between two thin lucite rings which make a butt fit against the tube wall. The condition of the bed and its expansion was observed through the glass tube. Charges due to fluidization were measured in the equipment shown in Fig. 1.

Qualitatively the bed behaved like a boiling after fluidization began with "bubbles" rising  $\frac{1}{8}$  in. to  $\frac{1}{2}$  in. above the surface of the majority of material. These bubbles were formed by air pockets and indicated aggregative fluidization. This phenomenon occurred only mildly at low velocities (<30 to 40 fpm), most of the material experiencing a confined oscillating motion "particulate" fluidization. At high velocities (>40 fpm) the bubbles spread throughout the entire bed and aggregative fluidization predominated. The point where actual fluidization occurred was difficult to determine, the expansion taking place very slowly over a wide velocity range. The velocity point for first fluidization was therefore determined by the intercept of the observed expansion curve. A striking fact noted was that after continued fluidization the static charge generated was sufficient to hold the bed together and expansion then took place evenly with a minimum of bubbling.

Measurements were made of bed pressure loss, bed expansion, and superficial bed velocity using a 1 in. deep (settled) bed of Koppers beads. The pressure loss curves showed an increasing  $\Delta P$  after fluidization indicating some "slugging." Fluidization occurred at a pressure loss of 0.62 in. water. Theoretically it should start when the bed weight equals pressure loss (0.60 in. water). The calculated<sup>11</sup> velocity of fluidization, 13.6 fpm, also agrees well with the observed value, 11.0 fpm (provided the appropriate mean diameter is used in calculations). When the friction factor-Reynolds number correlation is made it is found that the Carman-Kozeny *fixed bed* correlation is followed from  $R_e = 0.1$  to  $R_e = 50$ , one smooth curve covering the entire range of fixed and fluidized conditions.

Table 6 shows the charge developed on the beads due to fluidization for various times at various velocities. For all these tests the charge was found to reside almost entirely on particles at or near the vessel (glass) walls. The average charge reported was for the entire weight of bed and therefore was lower than the maximum charge per particle which occurred

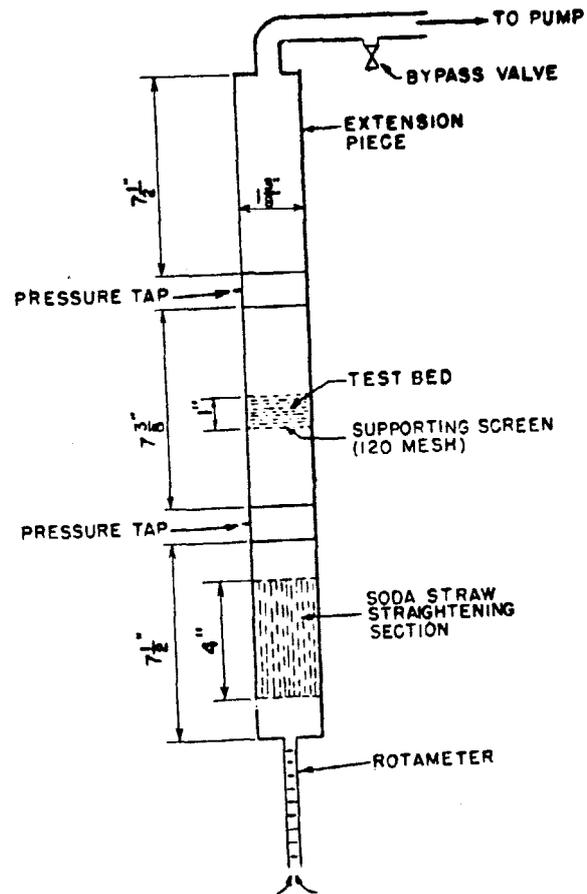


Fig. 3—Apparatus for preliminary fluidization studies.

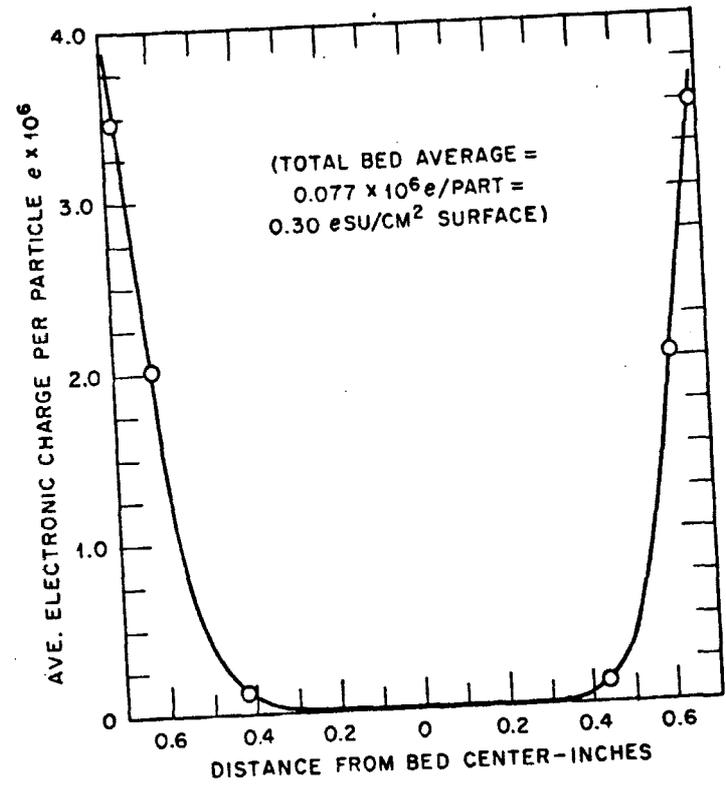


Fig. 4—Charge distribution on Koppers beads fluidized for two hours at 50 fpm.

Table 6—CHARGE DEVELOPED ON KOPPERS BEADS DURING FLUIDIZATION\*

Test No.	Time of fluidization, min	Average velocity of fluidization, fpm	Bed expansion, %	Average particle surface charge density, statcoulombs/cm <sup>2</sup>
1	5	13	0	0.021
2	15	24	12	0.054
3	25	28	16	0.049
4	120	50	40	0.298
5	Mechanical charging plus 10 min fluid.	22	10	0.086

\*t = 77°F, w = 68 grains water per pound dry air.

near the walls. The results of Table 6 show a trend for increasing charge per particle by increasing the time and velocity of fluidization, or in other words, the total air kinetic energy.

Test 4 shows the average charge throughout the bed after prolonged fluidization. Figure 4 represents how this charge is actually distributed throughout the bed. As expected, the charge is very high near the walls and descends to a very low value part way into the bed so that the central area of 0.4-in. radius is effectively at zero charge. Near the walls the maximum charge is roughly  $3.4 \times 10^6$  electron charges per particle or 1.30 statcoulombs/cm<sup>2</sup> which is comparable to the maximum charge attained mechanically with a high contacting surface to contacted surface ratio (see Table 1, test 4). Since all of the charging occurs at the walls then the decreasing charge density per particle is probably due to few particles of maximum charge (i.e.,  $3.4 \times 10^6$  e/part) having migrated towards the bed center. This comparatively poor charged distribution should be compared to that obtained with a matrix (Table 4). For the latter case a fairly uniform cross-sectional distribution results.

#### 4.2 Hindered Fluidization

In the columns, Fluidization Quality, of Tables 2 and 3, it will be noted that with the presence of the charging screen the quality of fluidization is very poor, most of the bed, in all cases, segregating above the charging screen, in spite of the fact that the fluidized solids flow through the screen quite easily in single passes. This segregation is due to the coating of the wires with several layers of particles which eventually prevent passage of more solids through the mesh openings. This wire coating phenomenon proved to be the most important single observation and can be attributed directly to "image forces" attracting the charged spheres to the conducting wires. These forces are due to the "bound" charges appearing in the conductor.

The wire matrix system introduced interferences throughout the bed. With 40 to 50 mesh Dylene spheres packed in a 1-in. bed it was found that the wire matrix prevented fluidization until a velocity of 69 fpm (roughly 5 times the theoretical point). At this point there was a sudden expansion to 50 per cent and a fall in pressure drop from 3.0 in. water to 0.39 in. water. Before fluidization the bed had acted as a packed bed with the pressure drop increasing linearly with velocity. The expansion then proceeded smoothly to 100 per cent at 87 fpm above which point channeling started to become apparent as indicated by a falling pressure drop. An indication of the effect of wire coatings was seen by slowly reducing the air velocity back to zero. About 37 per cent of the bed volume remained adhered to the matrix above the settled bed. Gentle rapping dislodged all but about 10 per cent of the total bed volume. It was obvious that for the system under test some form of gentle rapping should be employed to help promote uniform expansion by inhibiting the coating process. (It may be possible, however, that an experimentally determined combination of fluidized material, particle size, matrix arrangement and wire size, and fluidization velocity will produce uniform bed operation without the added mechanical aspect of "rapping.")

The bed (40 to 50 mesh Dylene) was observed again while gently rapping, by hand, the outside of the tube with a wooden stick. The observed bed behavior (expansion) under these

conditions: the bed first expands at about 11 fpm (extrapolated) which is very close to the theoretical value for an unhindered bed (13.6 fpm). It then expands very smoothly through the matrix up to an expansion of about 100 per cent (90 fpm). At this point the bed pressure drop, which had remained constant at 0.43 in. water began to fall indicating channeling and also, therefore, significant matrix coating. Once channeling started it proceeded rapidly with the pressure drop falling rapidly at the same velocity indicating a self-accelerating process. Eventually the wires became so heavily coated that the bed lost its identity as such even with violent rapping.

In the tests of Tables 2 and 3 no attempt was made to correlate actual fluidization velocities, expansions, and resistance with the theoretical, since the presence of the charging screen interfered with smooth fluidization. For rough comparisons however, the polystyrene material should fluidize at 13.6 fpm with a loss of 0.63 in. H<sub>2</sub>O/in. settled bed and Nylon spheres at 9.0 fpm with 0.77 in. H<sub>2</sub>O/in. settled bed. Fluidization velocities are determined by the Lowenstein method<sup>12</sup> and pressure drops by the Lapple method.<sup>11</sup> Measured pressure drops were lower than theoretical, perhaps due to some channeling, while fluidization velocities were kept above the critical points in all cases.

## 5 PERFORMANCE TESTS (COLLECTION EFFICIENCY)

### 5.1 Preliminary (Atmospheric Dust)

The whole value of this over-all study hinges on the effectiveness of the electrostatic aerosol collection mechanisms which may, or may not, occur in a triboelectricized fluidized bed. It is therefore important to determine, at the outset, whether any increase in filtration performance can be attained in this manner, and if such performance is attained, whether it is done so at an energy requirement and with advantages compatible with existing methods of air cleaning. The following tests were made to determine qualitatively whether the effectiveness of the proposed filtration mechanism warranted a full investigation.

A simple and rapid means of evaluating filter performance is by using atmospheric dust as the test aerosol and determining efficiency by the stain density technique.<sup>13,14</sup> The following tests were made in this manner on fixed and fluidized beds of Koppers Dylene-Polystyrene beads.

The equipment used consisted of the apparatus shown in Fig. 3, modified so that aerosol samples could be taken. All tests shown were made on the same day and aerosol characteristics were considered constant.

Table 7 shows the results of four tests made on similar beds: 14.9 g of Koppers Polystyrene, 1-in. bed. The charge shown is based on an average per unit weight of bed and therefore does not represent an equally distributed charge.

Table 7—PRELIMINARY STAIN DENSITY EFFICIENCIES OF TRIBOELECTRIFIED FLUIDIZED BEDS\*

Test No.	Superficial bed velocity, fpm	Bed expansion, %	Average unit surface charge, statcoulombs/cm <sup>2</sup>	N <sub>Re</sub>	Stain efficiency, %
1	13.4	0	0.021†	5.0	64
2	13.4	0	0.049‡	5.0	89
3	13.4	0	0.086§	5.0	96-100
4	30.0	18	0.086§	18.0	97-98

\*Koppers Polystyrene Beads, Mg = 200 μ, t = 70°F, w = 60 grains water per pound dry air.

†All charged particles at wall.

‡Most charged particles at wall—some distribution through bed.

§Most charged particles at wall—fair distribution through bed.

It is obvious that in a fixed bed even the limited charging attained can cause a very significant improvement in efficiency. For test 2 the charged filter cross section is probably less than one-half the total filter cross section (see Fig. 4) yet the increase in efficiency over an essentially uncharged bed (test 1) is very significant, i.e., nearly a 40 per cent increase in effectiveness. Albrecht<sup>15</sup> has shown that the flow distribution through such a bed is very uniform, each channel essentially having the same velocity profile despite the tortuous path. Therefore with only half the aerosol being exposed to comparatively small electric fields, a significant over-all improvement is observable.

When the average particle field strength is increased and better distribution through the bed is attained, the efficiency becomes very high in comparison to an uncharged bed (test 3). The importance of good distribution of charged particles through the bed is apparent. Finally, when the particles are separated due to fluidizing and the fields become correspondingly less intense, the over-all removal remains about the same (test 4), i.e., the attracting fields are still strong enough for very efficient performance. Therefore it may be assumed that during continual charging operation sufficient electrostatic effects still occur. Thus it appears that a highly effective electrostatic filter which may be continually charged in a simple manner is feasible.

## 5.2 Comprehensive

*Equipment and Methods.* Since the preliminary tests indicated that the triboelectric fluidized bed process showed promise, further development was indicated. In this work the control and measurement of aerosol and bed properties and variables were investigated under suitable conditions.<sup>16,17</sup>

Figures 5 and 6 show the experimental equipment in front and rear views, respectively.

The aerosol, gentian violet, was generated from an alcohol solution by a modified spinning disc method.<sup>18</sup>

At a point on the side of the generator drum the aerosol was drawn out by a controlled airstream. A significant vortical type flow was induced in the drum from the spinning disc. This was removed by passing the aerosol through a narrow throat Venturi section. Calculations show that at the minimum total volume contemplated for the unit, the Reynolds number at the Venturi throat > 2000 and thus turbulent mixing occurs.

The mixed stream was then passed through a 6-in. soda straw section to distribute the flow in the larger diameter glass tube, 1.5-in. I.D., which makes up the remainder of the test sections. At the end of the soda straw section the flow was split equally by 90° turns into two vertical sections. These constitute the upstream and downstream sampling tubes and consisted of rounded 90° turns leading to 18-in. vertical tubes. The joints of the system were made using cut bicycle tube sections which cause the glass tubes to butt firmly and also are essentially leakproof. Either section could house the fluidized bed for test.

The test system for this study was designed to preclude possible sampling errors. The entire air volume was sampled thus obviating aliquot percentage and isokinetic difficulties.<sup>19</sup> This method was possible because of the small total air volumes used. All that was required for accurate sampling was that the flow be split *exactly* at the tee-section and that inertial separation, if it did occur, be the same for each branch of the system. Initial tests showed duplication of sample concentrations within ±5 per cent.

The aerosol samplers are shown in more detail in Fig. 7. They are constructed from nominal 1-in. brass unions, specially machined. Type 1 is used for total volumes of 0.5 to 20 liters/min. Type 2 is used for higher volumes up to 200 liters/min if necessary.

The sampling pumps were two Leiman Brothers cycloidal type. A prefilter (1106B) medium was placed upstream of the test section tee and downstream of the aerosol generating tank. It was connected to the aerosol line by two pinch clamps so that prefiltered air or aerosol could be directed to the sampling sections. (See sketch, Fig. 8.)

A special rapping device was constructed so that bed agitation could be duplicated from run to run. It consisted of a weighted steel arm with a 1-in. diameter lucite hammer head

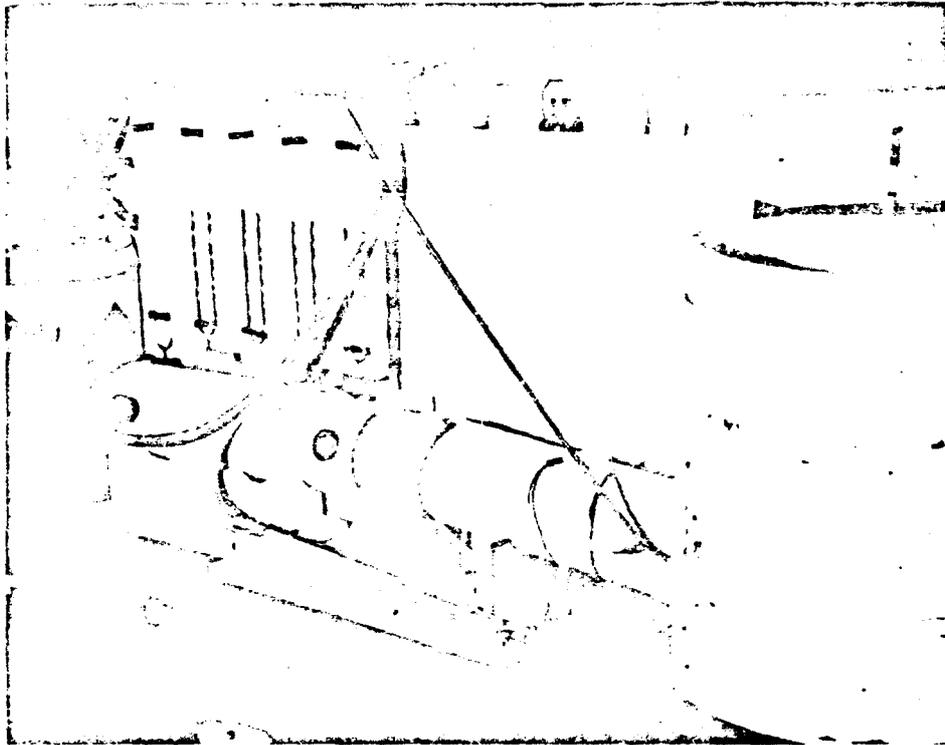


Fig. 5—Equipment for comprehensive tests, front view.

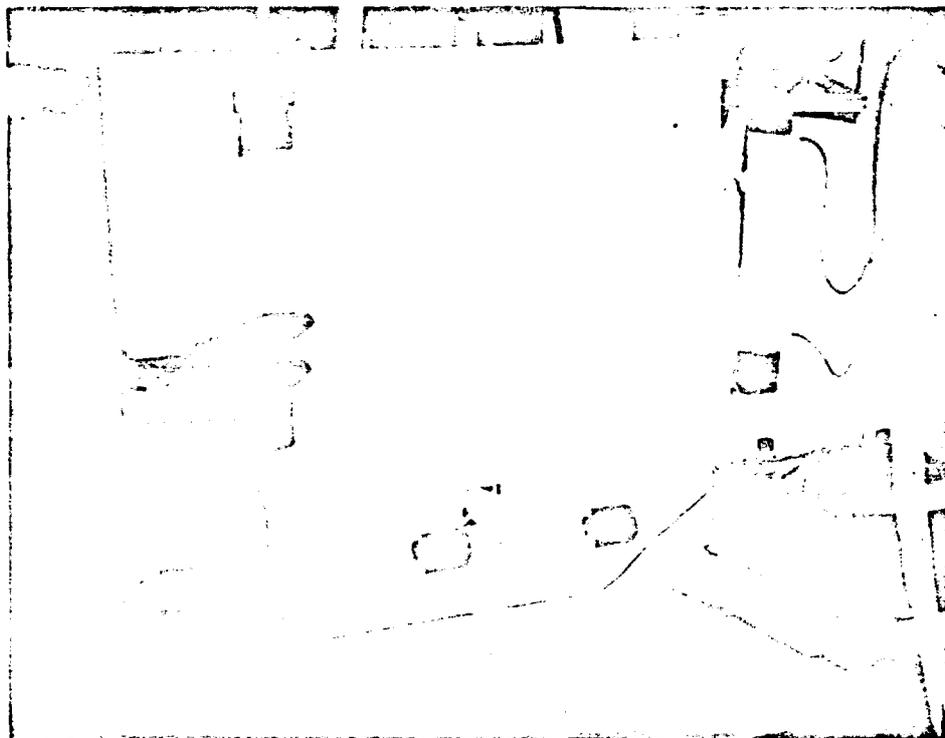


Fig. 6—Equipment for comprehensive tests, rear view.

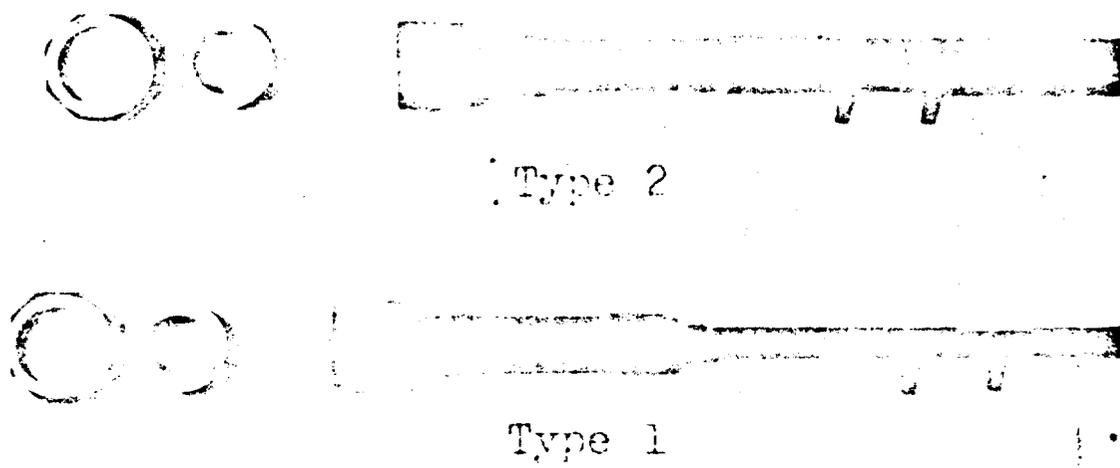


Fig. 7—Aerosol samplers.

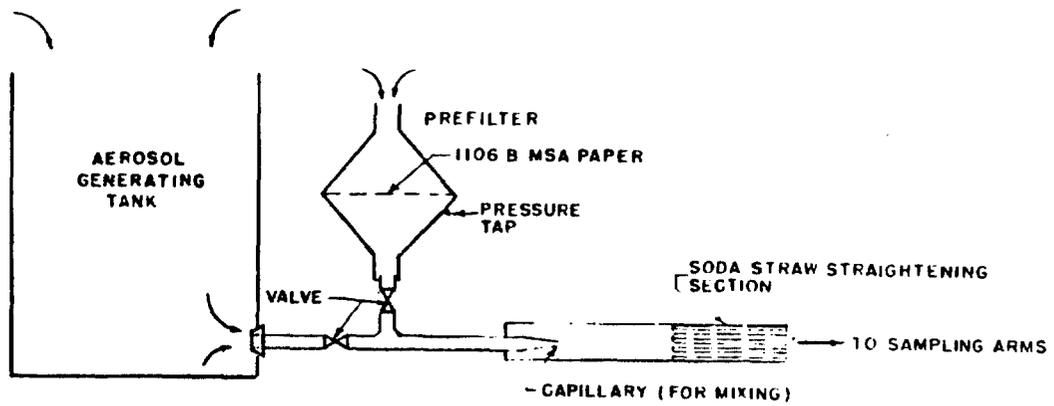


Fig. 8—Sketch of prefilter arrangement.

which was pivoted from the side of a special housing. A small EMC motor with a special gear reducer served to lift the hammer arm by means of an eccentric gear. The hammer fell back striking the side of test bed section with the lucite head. This action served to remove some particles from the matrix. In the following tests the hammer was geared to strike the tube 40 times/min. This device is subject to change.

The bed charge was measured by means of the matrix system itself. In some cases when the humidity is very high the only method of bed charge measurement is by pouring the bed into a separate Faraday cage at the end of the run. This is so because of extremely rapid charge leakage from the beads themselves and from the voltmeter-matrix-air capacitor measuring circuit.

The generating tank was opened to a 6-in. diameter duct system which withdraws several cubic feet per minute of dilution air and aerosol. This duct system served to measure net particle charge by the method developed by Rossano<sup>18</sup> (see Fig. 17, p. III-28a). A high efficiency filter paper is mounted in the Faraday cylinder of this apparatus. Upstream and downstream samples are taken isokinetically to determine the paper efficiency. Charge is induced on the cylinder, which, when corrected for efficiency, yields average net particle charge. The comparatively large volumes handled through this system are necessary to obtain accurate  $Q_p$  measurements.

Since high efficiencies are involved low downstream concentrations are encountered. To obtain greatest accuracy an accurate and sensitive spectrophotometer, the Beckman DU, was employed. It is essential to use an aerosol material with a high molar absorptivity index for colorimetric analysis. Gentian violet possesses the greatest index of available dyes. The absorptivity-concentration curve for GV is linear, with the equation,  $C = 4.06 A$  ( $C = \gamma/\text{ml}$ ,  $A = \text{absorbance}$ ).

In the following tests the weight fraction of GV was held constant at  $1.54 \times 10^{-4}$  (14  $\mu\text{g}/\text{ml}$ ) yielding an aerosol of  $M_g = 0.49 \mu$  ( $\sigma_g = 1.6$ ). This is equivalent to a mean volume diameter,  $D_v = 0.67 \mu$ . The specific gravity of the GV (Harleco, 96 per cent pure) was determined by a pycnometer technique using 50 centistokes Dow-Corning Silicone oil in which GV is insoluble, and found to be 1.16 g/ml. Thus numbers concentration of the generated aerosol could be computed:

$$N = 5.47 \times 10^6 \text{ particles}/\mu\text{g GV (using } D_v = 0.67 \mu)$$

*Experimental tests.* The efficiencies to be reported here were confined to one bed material, Koppers' Dylene "3", 40 to 50 mesh, and one operating velocity, 50 fpm, equivalent to a bed expansion of approximately 60 per cent. One-inch beds, 12.2 g of material were used throughout. Table 8 summarizes the pertinent data of these tests. Fresh bed material was used for each test.

The "uncharged" efficiency was determined at 10 fpm through the settled bed since it is impossible to have an uncharged operating fluidized bed. This zero charge level was obtained at the highest velocity before fluidization (13 fpm) and any contact charge generated in pouring the material was allowed to leak to ground for 4 time constants. It is to be expected that if no charge existed on the beads when fluidized, efficiency would fall, since targets become farther apart and velocities are increased. Thus, although not determined at the same velocity, the 10 fpm tests are considered zero charge levels for the 50 fpm tests.

1. *Charge levels.* Aerosol charge varied between 40 and 140 e/part, positive. It is believed that this is due to variations in  $\sigma_g$  of the aerosol both with regard to size and charge. Thus the mean size  $0.49 \mu$  might probably be represented by a mean charge of +90 e/part., or a surface density of 38 per cent max. Again when further data are available the variation  $Q_p$  will be taken into account by the use of dimensionless variables including  $Q_p$ ,  $Q_{\text{bed}}$ , bed size etc., as used by Kraemer.<sup>1</sup>

Bed charge (net) varied widely from zero to 35 esu/g (2.6 per cent max.). Leakage of charge from the bed also varied widely with some dependence on humidity. The charge generation rate was, on the average, quite low in comparison to that produced by fluidization at 100 fpm, 1.0 esu/g/min vs about 0.10 esu/g/min at 50 fpm. This is to be expected because of the lower kinetic energy involved. In tests 11 and 12 charge was generated at 100 fpm before

Table 8--SUMMARY OF PERFORMANCE TESTS ON FLUIDIZED POLYSTYRENE BEADS\*

Test No.	Absolute humidity, grains/lb.	Aerosol charge, elec./part.	Ave. total bed charge, esu/g	Aerosol conc. upstream, $\mu\text{g}/\text{m}^3$	Collection efficiency, %	Bed resistance, in. water
1	77	+46	0	29.4	71.5	0.65
2	77	+43	0	23.8	72.3	0.68
3	87	+71	< -1.2	16.6	94.6	0.59
4	68	+76	-1.6	15.6	97.1	0.51
5	68	+128	-2.8	18.1	96.2	0.47
6	68	+76	-3.6	12.5	96.4	0.49
7	68	+76	(-10.6)	13.0	90.6	0.55
8	83	+71	(-0.8)	17.7	98.1	0.55
9	51	+131	(-16.1)	17.9	93.5	0.41
10	82	+77	(-35.4)	27.2	94.1	0.45
11	43	+146	-14.7	17.2	96.7	0.51
12	43	+146	-16.9	17.9	95.0	0.46

Note: Tests 1 and 2 unfluidized at 10 fpm; all tests for 30 min operation; bed charge developed by fluidization before test at 50 fpm except for tests 11 and 12 were pre-fluidization at 100 fpm; charge values in parenthesis for free flowing fraction of bed not total bed ave.

\*Aerosol = Gentian Violet, Mg = 0.49  $\mu$ ; Bed = 12.2 gms, 40-50 mesh, Dylene 3, one-inch settled bed; Velocity = 50 fpm; Expansion = 60%.

filtration at 50 fpm to produce higher net charges and the generation rates here were more nearly those of the previous 100 fpm tests. The charge generation rate was, however, asymptotic indicating strong particle adhesion even at this velocity. It will be noted that the final average charge levels (total bed) are quite low (about 3.0 esu/g, ave.) when charging is accomplished only by fluidization at 50 fpm. Furthermore when this final charge is compared to initial bed charge (from pouring) in most cases particle charge leakage nearly obscures the generation rate. The data are not sufficient to attempt generation rate vs time constant correlations but this is the method to be followed in following tests.

The charge on the free flowing material in the bed is listed for several tests but is not too reliable since it is determined by pouring into a separate Faraday cage, an action which in itself produces charging. These values are useful as order of magnitude levels especially in runs where average total bed charge measurements are doubtful or missing.

Generally speaking charge generation is poor in comparison to levels possible, when operating at 50 fpm for this material. Nevertheless, efficiency tests were still made to determine the effectiveness of low charge levels on the bed material.

2. *Pressure loss.* Theoretical maximum  $\Delta P$  for unhindered fluidization is 0.63 in. water. The values in Table 8 of tests 1 and 2 are close. However, during fluidization it will be noted that pressure loss is less varying between 0.41 and 0.59 in. water. The resistance is lower due to the matrix coating process which reduces the amount of freely fluidized material by as much as 30 per cent. It varies due to the process of adhesion but for most cases becomes constant once an equilibrium is reached between adhesion vs "sluffing off" due to rapping. An average operating  $\Delta P$  for 50 fpm operation at equilibrium is 0.50 in. water.

3. *Aerosol concentration.* The upstream concentration of aerosol particles averages about 15 to 20  $\mu\text{g}/\text{m}^3$ . These levels are in the order of "background" dust loadings in air. The concentration for this particle size is limited to these values because of the aerosol generation process and the minute GV concentration of the feed.

4. *Bed efficiency.* It appears that even at very low particle charge (bed particles) values,  $-1.0$  esu/g, efficiency is quite high and, moreover, remains relatively constant despite increased surface charge. This indicates that coulombic attractive forces (negative bed particles, positive aerosol particles) are important. If they were not, and inductive forces predominated, there would necessarily be an increase in efficiency as bed particle charge increased. Another important effect is probably bipolar bed particle charging which is not reflected in net charge measurements at all.

Although these data are limited to one type bed and one operating velocity, it would not perhaps be remiss to compare this operating performance with competitive devices. Thus, for example, CC-6 paper will filter  $0.7 \mu$  methylene blue at 99.98 per cent efficiency (count) at 0.25 in. water/fpm. Cottrell precipitators will filter  $0.3 \mu$  DOP at 99.1 per cent (weight) at very low power requirements (roughly 0.001 in. water/fpm). This fluidized bed filters  $0.5 \mu$  GV at 94.5 to 98.5 per cent efficiency (weight) at 0.01 in. water/fpm. Thus, it now seems probable that filtration will approach that of high efficiency devices at power requirements close to those of precipitators and only a fraction of that of AEC type papers. Moreover the power requirements become even less as filtration velocity increases ( $\Delta P$  remains constant) and, if the high efficiency holds, the mechanism of collection now under study may be as effective as single stage precipitators at about the same operating power, without high capital cost.

Since humidity effect are of great interest in this work, the data of Table 8 are considered as a function of humidity alone. It is obvious that the high efficiency remains approximately constant up to absolute humidities as high as 90 grains per pound dry air. This is encouraging in view of previous work with fiber and fabric filters. Further data are necessary, however, before definite conclusions should be drawn.

## 6 FUTURE WORK

This study is being continued along the same lines. Contemplated variables are: bed material and particle size, fluidization velocity, (bed porosity and depth), and aerosol size. In addition, more efficient charging systems will be developed, if possible.

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