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UNITED STATES ATOMIC ENERGY COMMISSION

WASH-149

AIR CLEANING SEMINAR, AMES LABORATORY,
SEPTEMBER 15-17, 1952

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PREFACE

Second Air Cleaning Seminar for AEC Personnel

Institute for Atomic Research
Iowa State College
Ames, Iowa

September 15, 16, 17, 1952

This second seminar represents a continuing program based on the original seminar held in June, 1951 at Harvard University Air Cleaning Laboratory. Its purpose was to acquaint AEC personnel associated with national laboratories and AEC contractors with the fundamental aspects and problems involved in air and gas cleaning. Since the Atomic Energy Commission invests large sums of money through its divisions, laboratories, and contractors in air and gas cleaning equipment it is the intent of these seminars to discuss new problems and applications as well as to review developments and operating performance of equipment in this field with individuals responsible for selection on application of various devices.

It is also the intent of these seminars to provide basic information for those people who have not had a background in this field.

In the case of this second seminar the first half-day was devoted to a review of the properties of aerosols as related to air and gas cleaning as well as the basic principles and types of air cleaning equipment. The material covered is essentially that presented in the Handbook on Air Cleaning which was first available for distribution at this meeting. Since this material is readily available it is not included in this summary of papers presented at the Ames Meeting.

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Some of the papers included in this publication are condensed from the material presented at Ames and in other cases are complete manuscripts. The condensations, however, are complete enough to enable the reader to understand

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the intent of the project. It was the opinion of those present that the material given was valuable and should be available in document form for many other personnel. It is interesting to note that the technical papers presented represent a very broad attack upon all aspects of air and gas cleaning problems which confront the atomic energy industry. The successful solutions presented by many of these reports will contribute greatly to the practical application of nuclear energy to many problems.

The Ames Laboratory was made available for this meeting by Dr. Spedding and his group. They were most congenial hosts and provided an interesting facility for inspecting many air and gas cleaning applications. We are indebted to them for making this a successful meeting.

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INTRODUCTION AND WELCOME

Dr. F. H. Spedding
Director, Ames Laboratory

DR. SPEDDING: I would like to welcome you to this Laboratory, and I hope very much that your stay here will be pleasant. I might say that Mr. Fisher has been in charge of the arrangements. I hope he has done a very fine job. If he has, I hope you will praise him; and if he hasn't, I hope you will let me know and I will put the needle in and see that the next conference that is held goes off right.

In regard to anything you may want to do while you are here--if you want to know about reservations, or you may want to meet some particular individual or see something provided you are allowed to under the arrangements--get in touch with Mrs. Allen in the hall. She will see that you are put in contact with the right people to get answers to your questions.

I may also say I am particularly pleased to have this group meet here at Ames. You know, with the ordinary health and safety programs around the laboratory, looking at it from the laboratory director's viewpoint, there are certain aspects of such a program that ought to be welcomed with open arms, and there are certain aspects that we would like to bury. Two of them that we really need very badly--and I think this field represents one of them--are people to do work and to be able to tell us how to resolve these problems and what are the tolerances we can stand with regard to dust and radioactivity and other questions we are running up against.

This is an area of health and physics that I think badly needs much more help than we are getting today. I am very glad to see a conference being held where at least we can get some idea of the things we have to deal with.

The same thing is true of the tolerance level. I wish there were more work going on. You could get hold of something tough and you ask the experts outside, "Can you throw this away or can't you?" and you can't get anybody to give you an answer--particularly on radioactivity--within a factor of a thousand to ten thousand as to what you can do with it. We would like to have the answer as to what these tolerances are.

On the other hand, I must say in health and physics programs the thing I don't like is where somebody comes in, takes half an hour to look around the plant, makes some suggestions which you don't have the answer to yourself, then goes back and writes a report and says, "You want to follow this along; go ahead and do it this way." This gets us in such a position that I can't even get the boys to make any decisions because they are afraid somebody is going to write a report on them, and with hindsight they have got their neck out.

So I think this is a very bad aspect of the health and physics program. I think the things we should have are the experts who can tell us what to do, but not the ones who are going to make recommendations based on not having complete information. This is one reason I am very much interested in this group, because I think you fellows do have a program where you may not have the answers, but at least you are trying to get them as to how to handle these things. That is one of our major problems here.

My time is short. You have quite a program today. I can't tell you very much about the laboratory, but I think we have some booklets here describing what kind of work goes on and what the general setup is. Mr. Fisher and the men here have these booklets. If you care to take the time to read them, you can learn more about what we have done here during the war, which is unclassified. The classified part still is not in there. Also you can learn how the laboratory is set up at present.

Again I would like to welcome you. I hope you have a very successful conference.

REMARKS

THE CHAIRMAN: Dr. Leslie Silverman:

I would like to take this opportunity to introduce MR. Arthur E. Gorman of the Division of Engineering of AEC to say something about their activities in this field. I might say that we all appreciate his efforts in behalf of correlating and getting information on air cleaning. This conference like the others before it is the result of his pioneering in the field.

MR. GORMAN: The Division of Engineering, which is sponsoring the Harvard contract on air cleaning and other contracts in related fields, is anxious that those who are from the A.E.C. Operating and Research areas and those who are working for architect-engineer contractors for AEC know that this contract is not only for research and development work but also for service and educational activities. This meeting is part of the educational phase.

Therefore, if any of you have problems that you want to discuss with representatives of the Harvard Air Cleaning Laboratory, their services are available to you. If the service desired is an extended one running

into considerable cost some special arrangement would have to be made for covering the expense involved. I hope you feel free to tie into this service program which the AEC is directing through the Harvard Air Cleaning Laboratory.

I would suggest, as an initial contact, you might write to Mr. John C. Robinson, Acting Director of the Division of Engineering; or to me, and let us develop the arrangements for you.

The same holds true with our other Division of Engineering contracts. We have a contract for research on the properties of aerosols with the University of Illinois. Dr. Johnstone and staff are anxious to integrate their research with the real problems in various A.E.C. areas. We have another contract on development of an incinerator with the Bureau of Mines. This evening Dick Corey of their Combustion Engineering Laboratory, Pittsburgh, will discuss this work. If any of you have incinerator problems in which you want help; or if you have air filter problems in which personnel of the A. D. Little, Inc. can help, I hope you will feel free to let us know.

The Division has a contract with the Weather Bureau under which they are doing considerable work on micrometeorology, which is right around the corner from air cleaning. They have a representative here, Paul Humphrey from Idaho, who has done much work of this kind at the National Reactor Testing Station. If any of you have problems of air cleaning that are related to micrometeorology, the Weather Bureau will be pleased to help.

We all appreciate the fine program that the Harvard group put on for us this morning and the excellent arrangements the Ames Laboratory has made for our convenience and comfort. We are very appreciative of it. Thank you very much.

THE CHAIRMAN: Thank you, Mr. Gorman.

REMOVAL OF SOLUBLE GASES (AND PARTICULATES) FROM AIR STREAMS
(With Special Reference to Fluorides)

by

Edward M. Berly, Melvin W. First and Leslie Silverman

Presented by
Melvin W. First

1. Introduction

The wide use of hydrofluoric acid in process metallurgy for beryllium, uranium and other metals prompted the New York Operations Office of the Atomic Energy Commission to request the Harvard Air Cleaning Laboratory to investigate methods of removal of fluorides from stack gases.

Hydrofluoric acid as a gas can be absorbed in conventional packed towers filled with Berl Saddles, Raschig Rings or similar materials to provide intimate mixing and absorbing surface for the gas stream and the counter-currently flowing solvent. Hydrofluoric acid exhibits such a strong affinity for water that it may be absorbed also in simple spray chambers using water as a scrubbing fluid.

Tests at the Harvard Air Cleaning Laboratory⁽¹⁾ showed that wetted fiber cells give high efficiency with aerosols containing 1) soluble acid mists and 2) soluble gases with low vapor pressures. The large wetted area represented by the fiber surface of even large diameter fiber packs presents a favorable situation for gas absorption.

The removal of particulates, i.e. fluoride mists and fume, is not readily accomplished in ordinary spray chambers or in towers filled with conventional packings because effective separation requires fine droplets (50 microns) or fine fibers (< 5 microns). Mechanical features limit the use of fine fibers to dry operations.

When fluorides are present in air or gas streams as a mixed gas, mist and fume, it is desirable to collect them simultaneously in a single unit if possible. Previous experiments with the wet cell washer indicated that

series of wet and dry, fibrous, deep bed filters were a suitable means of cleaning effluent gases containing soluble or reactive materials.

Inert particulates which may accompany the mist or soluble fume in small or large concentration will likewise be captured by the packing and may adhere to it and eventually plug the bed. Therefore, provisions must always be made for removing inert particulates early in the cleaning process, or for periodically cleaning or replacing those sections of packing which become plugged and useless.

Cleaning requirements (i.e. degree of efficiency required) may be considered under two categories; First, removal of low concentrations from stack gas effluents; the primary purpose here is the elimination or prevention of atmospheric contamination, second, scrubbing of process gases or off-gases containing sufficient material to make recovery and re-utilization economically desirable. In many instances it may be necessary to meet both requirements although gases which cause problems of atmospheric contamination only are generally too lean for recovery, concentration and purification. High collection efficiency is not always needed for the removal of offending material from stack gases. Generally, the intent is to reduce the effluent below a concentration which can produce a nuisance.

On the other hand, high efficiency is generally required for collecting products from process gases to prevent stack gas effluents from becoming neighborhood nuisances. In some cases, it may be desirable to break the process into two operations. In the first, the rich gases are recovered at high efficiency in a relatively few absorption steps and in the second the clean gases are further cleaned for discharge to the atmosphere; the recovered material in the latter process being discarded.

2. Experimental Equipment

An experimental multiple-stage wetted-cell washer of the type shown in

Figure 1 was used in all the tests. The unit will receive a variety of fiber filters placed at a 45° angle to the air stream. The coarse fiber wetted cells were followed by a droplet eliminator and fine fiber pads. The interior of the cabinet, including the filter frames, was coated with protective paint to reduce corrosion. The scrubbing liquor in the sump was recirculated and the fluoride concentration was allowed to increase to approximately 2%. Air was drawn into the unit by an exhaustor on the exit side (washer under negative pressure). This type of equipment is not generally used for gas absorption, but has certain advantages over conventional tower construction. Increased capacity may be achieved by raising the number of filters in parallel in each stage.

For absorption of HF the selection of materials from which to make chemically resistant fibers is rather restricted. Fortunately, several plastics have excellent chemical resistance and are produced in a large number of fiber sizes. Saran and Dynel plastic fibers were investigated in this study. Both Saran and Dynel were obtained in the form of 2 to 6 inch long curled fibers which possess a degree of stiffness and resiliency not equalled by other synthetic fibers below 100 microns in diameter. At the time of this study Saran fibers were available in diameters of 27 microns and upward and for Dynel, 10 microns and up.

Previous work⁽¹⁾ with Fiberglas filters indicated that concurrent spraying permits higher gas velocities than are practical with countercurrent operation and reduced channeling results in better wetting of the packing. The absorption of high concentrations of HF from process gases can be accomplished directly by a system of countercurrent stages with concurrent spraying in each stage.

Wetting was accomplished with 6 suitably spaced flooding nozzles* per

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* Clarage Company, No. 0 Flooding Nozzles

20 x 20 inch cross-section wet cell placed 6 inches upstream of the cell face. It is thus possible to have a 4 inch deep pad with adequate area and free of channeling. In conventional countercurrent towers, by contrast, height is often 5 times the diameter of the column to assure proper distribution of gas and liquid throughout the packing.

In most tests the scrubbing liquor was recirculated at the rate of 8 to 9.6 gallons per minute per 20 x 20 inch cell. This quantity of liquid is large in comparison with the amount of HF to be absorbed, hence the concentration of fluorides in the absorbing liquor remains substantially constant during passage through the wet cell. Because of this high liquid rate there is no appreciable temperature change due to heat of solution of HF in the scrubbing liquid.

Fine-spray nozzles* were also substituted for the first wet stage in order to determine the comparative efficiency of wetted fibers and fine spray droplets for the absorption of HF gas. When scrubbing dirty gases, a wetted Rockwell "Neva-Clog"** screen was substituted for the first wetted fiber stage.

Water was chosen as the absorbing liquor (in preference to an alkali such as NaOH) because (1) it has excellent affinity for HF even with as much as 2% dissolved HF, (2) it is low in cost and (3) an aqueous acid solution lends itself to easier economical recovery and concentration than alkaline salts.

3. Absorption of Hydrogen Fluoride Gas

Loadings of HF (as fluoride ion) ranging from 25 to 4000 mg. per cubic meter of air were absorbed at >99% efficiency with two wetted fiber cells in series using water containing 0 to 2% of fluoride as the scrubbing liquor (Test A, Table I).

* Bete Company Nozzle No. P40.

** A stainless steel perforated double plate screen with 125 staggered 0.045" diameter holes per square inch. Sheet thickness is 0.010 inches and the space between sheets, maintained by dimpling the sheets and spot welding, is 0.05".

Efficiency was independent of air flow rate over the range tested (i.e. 108 to 216 feet per minute superficial face velocity). A final dry pad increased over-all collection efficiency only a few tenths of one per cent since a dry filter can collect only those droplets small enough to penetrate the 6-bend zigzag eliminator.

Substituting a concurrent water spray (i.e. 6 No. 0 Clarage flooding nozzles without the fiber cell) for the first wet cell resulted in a significant decrease in total wet stage absorption (i.e. water sprays plus wet cell) from 99% and over to 95 or 96% but, in all cases except one, over-all efficiencies were 99% or better, indicating that for this equipment arrangement the final dry cells assume greater significance in the over-all performance. When the nozzles develop their full spray pattern (as they do when the wet cell is taken out) some droplets small enough to penetrate the coarse fiber cell constituting the second wet stage and the zigzag eliminator plates are formed. These are removed in the final fine-fiber dry pad.

When fine misting nozzles are substituted for the flooding nozzles a larger per cent of the spray is represented by very fine mist droplets, which penetrate the wet cells and eliminator. Using 6 and 9 misting nozzles as the first wet stage and a one inch pleated Saran fiber filter wetted by spray carry-over as the second, over-all efficiencies (including the dry pad) were from 86.2 to 95.5%, indicating that a significant number of mist droplets fine enough to penetrate two inches of 44 micron dry fibers were formed by the fine spray nozzles.

For a given volume of scrubbing liquor fine droplets produce most rapid equilibrium, but the complete removal of these fine droplets of hydrofluoric acid presents an additional problem. In general, for the absorption of a material as readily soluble as HF, coarse flooding nozzles or other devices which do not produce fine droplets are to be preferred from the standpoint of simplicity of equipment and low air flow resistance.

When the first wet stage is 2.3 square feet of Neva-Clog filter screen wetted with 5 flooding nozzles, scrubbing efficiency was found to increase with increasing water rate up to 92% at 4.4 gallons per minute per square foot of screen.

With high loadings (0.1 to 2.0 grams per cubic meter) of two typical inert mineral dusts (talc and silica), efficiency of the Neva-Clog screen was 79.0 to 87.2% when wetted with 3 gallons per minute per square foot of screen (Table II).

4. Removal of Particulates. (Mists and Fumes)

An aqueous fluoride mist aerosol was prepared from a 10% solution of NH_4FHF by aspiration. It had a median size by weight of 4.4 microns and a geometric standard deviation of 7.9, indicating a wide range of sizes about the median.

A single stage of one wetted Neva-Clog screen collected 70.2% of the fluoride mist, at a superficial face velocity of 108 feet per minute and 91.2% at double this velocity, indicating that impaction is the principal removal mechanism for droplets in this size range. A Neva-Clog screen followed by a 78 micron diameter wetted Saran pad and a 44 micron diameter dry Saran pad gave over-all efficiencies of 92 and 94.4% at 108 and 216 feet per minute face velocity, respectively; again indicating by a greater collection efficiency at the higher flow rate that the principal collection mechanism for the mist droplets is impaction. Substituting 6 misting nozzles for the Neva-Clog screen reduced wet stage efficiency from 87 and 89% to 74 and 83% at 108 and 216 feet per minute face velocity, respectively, but efficiency of the over-all system was not affected by the change in the first wet stage indicating that the final dry pad was carrying a greater proportion of the load.

With 29 micron Saran fibers in the final dry pad over-all efficiency

increased to 96.3%; and with three Saran fiber stages (two wet cells containing 78 micron diameter fibers and a dry pad containing 29 micron diameter fibers) efficiency rose to 98.1%. (Test B, Table I)

Although glass fibers deteriorate rapidly under the action of HF it was felt that if placed following the final dry Saran pad they would last long enough to indicate what sizes and weights of fibers are required to give virtually complete removal of the fluoride mist. Therefore, the following glass fibers were added downstream of the 27 micron Saran pad: (1) 1/2 inch thickness of resin bonded 3 micron glass fibers (PF 105), (2) 1/4 inch of 1 micron fibers (XAA) and (3) a second 1/2 inch layer of 3 micron resin bonded fibers. This pad gave virtually complete removal of bifluoride mist but began to plug rapidly after a few hours of use. Nevertheless, these tests demonstrated that high efficiency removal of mist droplets can be accomplished with combinations of coarse wet and fine dry fiber beds. Fibers such as Dynel are commercially obtainable in diameters down to 10 microns and may be substituted for glass to give results comparable to those cited.

For tests with fluoride fume, crystals of NH_4FHF were evaporated on a hot-plate and the vapor condensed rapidly in the main air stream of the collector. The resulting fume had a median size by weight of 0.54 microns, a geometric standard deviation of 2.08 and it is very hygroscopic. In spite of its hygroscopic character, retention time in the scrubber is too brief to permit maximum growth of particles by adsorption of moisture. Consequently, fine diameter fibers are required for high efficiency collection. How much of an efficiency increase (when operating wet) can be attributed to growth of the hygroscopic fume particles and how much to moistening of the final dry pad by droplet carry-over was not determined, but wet operation appears to be of value in the treatment of hygroscopic fumes.

The most significant gains in efficiency are achieved by reducing the

size of the fibers in the final dry pad. As in the tests with fluoride mist virtually complete removal of the fume was obtained by the use of 1 to 3 micron glass fibers in the final dry pad. Using only HF resistant materials, >98% efficiency was obtained with 15 micron Dynel fibers in the final dry pad (Test C, Table I). When HF-resistant fibers such as Dynel, Saran, polyethylene, etc. are available in sizes below 5 microns they can be expected to produce results comparable to those obtained with the glass fibers. Efficiency of the wetted Neva-Clog screen was >80% for the fluoride fume indicating that it can be used effectively as a primary treatment stage when scrubbing gases containing large quantities of inert dusts.

An AlCl_3 fume, generated by heating crystals on a hot plate in the same manner as described above for fluorides and with particle size approximately the same, was removed at an efficiency of 67.2% for the wet stages and an over-all efficiency of 90.5% (Test E, Table I). Considerable improvement in over-all efficiency may be obtained by substituting all 3 micron glass fibers for the 29 micron Saran fibers in the final dry pad. However, for atmospheric pollution control an effluent concentration of $<40 \text{ mg./m}^3$ should be satisfactory.

H_2SO_4 mist was generated by evaporating acid on a hot plate and causing it to recondense in the main air stream of the collector. This gave a median size by weight of 0.6 to 0.7 microns. In addition, some tests were conducted using a dilute mist generated by atomizing a 10% aqueous solution of H_2SO_4 . This latter method produced a coarse mist having a median drop size by weight of 4.5 microns which is collected at greater than 98% efficiency with two 78 micron diameter Saran wet cells and a 3 micron glass fiber dry cell in series. This same arrangement of scrubbing stages gives 81.4% efficiency for H_2SO_4 generated by dropping and evaporating 10% sulfuric acid on the hot-plate (median size 0.7 micron) and 83.7% for mist generated from 96% acid

(median size 0.6 micron). The reason for the somewhat greater efficiency with the smaller size mist may be attributed to the greater rate of growth of the concentrated H_2SO_4 mist droplets while passing through the wet stages (the two wet stages together are less than 30% efficient in both cases). The dilute acid in contact with the evaporating water is presumed to be of greater initial size. Increasing the quantity of 3 micron glass fibers four-fold in the final dry pad increased over-all efficiency to 94.2%; while adding a 1/2 inch layer of ≤ 1 micron glass fibers to the final Saran fiber dry pad increased efficiency from 83.7 to 96.4% (Test D, Table I). However, the fine fibers had poor fluffing and packing characteristics and resistance rose from 4.5 to 8.5 inches of water gage in about 1 hour.

When efficiencies approaching 100% are required for the treatment of very fine fumes or mists, the fine fibers may be dispersed with sufficient coarse fibers to form a high efficiency bed (small diameter fibers) which will have excellent dimensional stability to resist matting and plugging (large diameter fibers). Such filters can be constructed by (1) carding large and small diameter fibers together to form a homogeneous batt or (2) flocking a preformed large diameter fiber bed with the finer fibers.

5. Absorption Efficiency of Packings

When (as in Table III) the heights of a transfer unit for various sizes of Raschig rings and Berl Saddles are compared with the HTU of a 4 inch deep bed of 78 micron diameter curled Saran fibers packed to a density of 3.6 pounds per cubic foot, it can be noted that 78 micron curled fibers are 5 to 10 times more effective than the Berl Saddles or Raschig rings for absorption. The explanation for the good results obtained with wetted fibers is the very large wetted surface available for absorption. Further, not only is a given height of fibers 5 to 10 times more effective for absorption, but the total weight of the packing, transfer unit for transfer unit, is 75 to 150 times as great for the saddles, (thereby requiring larger, stronger and

more expensive housing for the saddles). This is shown in Table IV.

The design of a scrubber for the concentration and recovery of high concentrations of HF should be based on a stage countercurrent system with concurrent wetting of the packing in each stage. The HF laden air or gas would enter the first stage and be scrubbed concurrently by a relatively concentrated solution of HF. It would then pass through successive stages to be scrubbed by successively weaker HF solutions. Clean water would be introduced at the final scrubbing stage and be pumped forward, stagewise, toward the initial scrubber. In this design concurrent scrubbing is used in combination with countercurrent flow through the apparatus to concentrate HF and strip the air or gas stream.

Design of equipment for the elimination of low concentrations of HF prior to discharge (as a means of preventing atmospheric pollution) can proceed along much simpler lines using the data accumulated in this study. Since only one or two stages would be required for scrubbing stack gases, this method of gas absorption is of general utility for the absorption of other gases as well as HF.

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- (1) First, M. W., et al, "U.S.A.E.C. Report No. NYO-1581, Waste Disposal," Boston, Harvard School of Public Health, (1952).

TABLE I

Some Typical Efficiency Results*

Description of Scrubber	Aerosol	Inlet Loading mg/cu.m.	Overall Efficiency % by weight	Overall Resistance in. w.g.
A.				
1) 3" depth 178 μ Saran fibers	HF	231	99.2	1.4
2) 4" depth 78 μ Saran fibers each cell wetted with 9.6 gpm of H ₂ O	gas	742	99.8	
B.				
1) 1" depth 78 μ Saran fibers wet- ted with 9.6 gpm water	10% NH ₄ FHF	925	98.1	2.6
2) 4" depth 78 μ Saran fibers wet- ted with 9.6 gpm water	mist			
3) 2" depth 29 μ Saran fibers (dry)				
C.				
1) Neva-Clog Screen wetted with 9.6 gpm	NH ₄ FHF	53	98.8	5.4
2) 4" depth of 51 μ Dynel (Dry)	fume			
3) 2" depth of 18 and 14 μ Dynel fibers (Dry)				
D.				
Same as B above with addition of 1/2" layer of 1 - 3 μ glass fibers to final dry pad	H ₂ SO ₄	231	96.4	5.2
	mist			
E.				
Same as D above	AlCl ₃	400	90.5	5.2
	fume			

* Air velocity = 108 fpm for all results cited.

TABLE II

Efficiency of Neva-Clog Screen for Collection of Inert Mineral Dusts

Aerosol	Inlet loading gms/cu.m	Water rate gpm/sq.ft.	Air rate cfm/sq.ft.	Mean weight Efficiency %
Atmospheric dust (0.5 μ)	.0001 - .001 (est.)	3.5	108	44.0
Silica (4.1 μ)	0.4 - 1.3	3.5	108	83.3
	0.1 - 0.5	3.5	216	87.2
Talc (1.4 μ)	0.2 - 2.0	3.5	108	79.0
	0.3 - 0.7	3.5	216	85.1

TABLE III
Absorption Efficiency of Packing Materials

Packing	Height of a Transfer Unit (HTU) Ft.
78 micron curled Saran fibers packed 6.2 lb./cu.ft.	0.14
Berl Saddles- 1/2 inch	0.8
1 inch	0.9
1 1/2 inch	1.5
Raschig Rings 1 inch	0.9
1 1/2 inch	1.5

TABLE IV
Physical Characteristics of Some Gas Absorption Packings

Packing Material	Weight lb./cu.ft.	Surface area sq.ft./cu.ft.	Porosity Fraction Voids	Approximate Cost	
				\$/cu.ft.	\$/lb.
1/2" Berl Saddles	45	141	0.68	6.75	0.15
1 " Berl Saddles	42	79	0.69	5.90	0.14
1/2" Raschig Rings	65	114	0.53	10.00	0.15
1 " Raschig Rings	45	58	0.68	6.30	0.14
178 μ Saran Fibers	6.2	278	0.94	6.20	1.00
78 μ Saran Fibers	3.2	470	0.97	3.20	1.00
50 μ Saran Fibers	3.2	736	0.96	3.20	1.00

Fig. 1 — Experimental scrubber.

PERFORMANCE OF REVERSE JET CLOTH FILTERS

by

Charles Billings, Melvin W. First and Leslie Silverman

Presented by
Charles Billings

A detailed description of the experimental reverse-jet filter used in this study appeared in a previous report (1) with resistance and efficiency data for clean wool felt bags filtering room air.

During the past year investigations have been conducted with a variety of test aerosols. Loadings ranging from 0.001 to 10 grains per cubic foot and air flow rates up to 25 cfm per square foot of filter cloth have been employed to determine the performance of (a) reverse jet construction, size, flow rate and per cent operating time; (b) filter bag diameter; and (c) types of filter media (i.e. resin- and silicone-treated and untreated felt bags).

a. Effect of reverse jet cleaning on performance.

Resistance and dust retention are influenced by (a) the amount of reverse jet air (b) speed of traverse of the reverse jet and (c) design of the slot. Since resistance and retention are also determined by filtration rate and dust loading, the effect of the reverse jet was investigated over a wide range of loadings and flows.

(1) Percent of time reverse jet operates.

Reverse jet action may be controlled by a pressure switch which turns on when the bag reaches a pre-set resistance and stops when the pressure differential falls below this value. The percentage of time the reverse jet is in operation can be varied to a considerable degree by setting appropriate "on" and "off" limits into the filter resistance-actuated switch. When the reverse jet sweeps only a fraction of the entire filter surface during each cycle that section of felt becomes too clean and

dust retention is lowered. Rapid, short cycling of the reverse jet mechanism is also poor from the standpoint of mechanical wear. Air flow rate and nature and concentration of the dust being filtered will determine the minimum and maximum resistance range over which filter operation is feasible.

The minimum resistance at which a reverse jet filter will operate for a particular aerosol and filtration rate may be determined by continuous reverse jet cleaning. Intermittent operation is possible with greater resistances and the smaller the fraction of reverse jet "on" time, the higher the resistance range will be. This is illustrated in Figure 1 which represents the behavior of untreated wool felt when filtering 1 grain per cubic foot of vaporized silica (mass median diameter = 0.6 microns) at a rate of 10 cfm per square foot of cloth. Velocity of the reverse jet was 4000 fpm and a constant pressure differential of one inch of water gage (i.e. between "off" and "on" switch positions) was maintained when the pressure settings on the reverse jet switch were changed. The right curve boundary represents the pressure at which the reverse jet starts and the left the pressure at which it stops. For these conditions the lowest operating resistance is 5.2 inches of water gage with 100% reverse jet operation and resistance increases exponentially as the per cent of reverse jet time is reduced.

The choice of continuous or intermittent operation of the reverse jet is a matter of convenience and economics. For specific situations the cost of increased maintenance and replacement which would accompany continuous or high reverse jet operational rates must be balanced by the cost of sufficient additional filter capacity to permit intermittent cleaning.

The cleaning action of the reverse jet affects collection efficiency by removing some of the material which accumulates on the dust side of the filter cloth. The effect on retentivity of disturbing the "filter cake"

is shown in Table I. The absolute amount of penetration is considerably influenced by the properties of the aerosol (i.e. particle size, shape, concentration, etc.) but, in general, maximum efficiency is associated with minimum reverse jet cleaning. For well plugged filters and dust loadings between 0.1 and 10 grains per cubic foot of air the differences in the weight of material penetrating are small but a significant trend is present.

(2) Effect on performance of reverse jet air velocity.

Resistance is affected by the amount of reverse jet air as well as by the frequency of application. The quantity of reverse jet air may be noted in terms of total volume, volume per inch of slot length or as average slot velocity. For a reverse jet mechanism of constant size, speed and operational "on" time, increases in reverse jet air volume result in decreased resistance as illustrated in Figure 2. When filtering flyash (MMD = 16 microns) resistance is considerably below that for vaporized silica (MMD = 0.6 microns) although this factor can only be quantitated approximately as different filtration velocities and loadings were employed for each series of tests. In spite of a wide diversity of loadings, flow rates and aerosols, the curves relating filter resistance to reverse jet air flow have a similar slope and within the limits of our observations resistance is inversely proportional to reverse jet air flow and tends to become asymptotic to some jet air volume at one extreme (i.e. as the reverse flow is increased a point will be reached where substantial increases in jet air volume produce only a negligible decrease in filter resistance) and to some pressure at the other extreme (i.e. as the resistance of the filter increases a point is reached where substantial decreases in jet air volume produce only a negligible increase in filter resistance).

Table II shows that when either air volume or jet velocity is held constant an increase in the width of the reverse jet slot produces a

decrease in filter resistance. This indicates that cleaning action is related to intensity of the jet (lower resistance with higher velocity) and to the total length of time during which the reverse jet cleans each section of cloth (lower resistance with longer treatment time).

Table III shows that increasing reverse jet velocity produces lower resistance (as noted above) but also results in a higher effluent dust concentration. With flyash, a doubling of the reverse jet volume produced a tripling of the effluent concentration.

(3) Effect of linear speed of travel of reverse jet.

Local overcleaning is likely to occur when speed of travel is too low while high speeds result in insufficient removal of dust accumulation. In both cases high resistances will result. Between these extremes, increases in jet travel speed produce slight decreases in resistance. For example, when filtering an aerosol containing 0.5 grains of vaporized silica per cubic foot of air resistance decreased from 5.5 to 5.2 to 4.6 inches of water gage as jet travel speed increased from 18 to 31 to 52 fpm, respectively.

b. Effect of inlet dust loading.

Filter resistance increases with dust load, the rate of increase is exponential with loading. The slope of the resistance-loading curves range between 0.1 and 0.3 for the dusts tested in our laboratory. Variations in filtration rate, jet velocity, etc., change the displacement of these curves but not their shape. Figure 3 shows typical results for three different aerosols. It may be noted that for loadings above 4 to 5 grains per cubic foot of air, increases in loading produce little change in overall resistance when the reverse jet operates continuously.

Outlet loadings of 10^{-5} to 10^{-3} were found for inlet loadings ranging

from 0.001 to 10 grains per cubic foot. Although higher inlet loadings were found to be associated with increased effluent concentrations, the relative rate of increase of dust in the outlet air is slow and a net increase in weight retained does occur. These tests, as well as others previously reported (1), indicate that effluent loading appears independent of inlet loading when the entering dust load is greater than approximately 0.1 grain per cubic foot.

c. Effect of filtration rate.

Over the range of flow rates investigated (7 to 31.4 cfm per square foot of filter cloth) there was a direct linear relationship between resistance and air rate indicating that flow through the felt bag and accumulated dust layer is in the laminar range. In order to keep the thickness of the filter cake constant, dust was fed at the same rate (i.e. grains per minute) regardless of air flow. In this way the amount of dust reaching the filter was maintained constant.

Higher velocities through the medium (in the range of 10 to 25 cfm per square foot) cause higher effluent concentrations. Doubling the velocity from 10 to 20 cfm per square foot, caused a 10 times increase in penetration in a typical case. Data on the retention of atmospheric dust with changes in air rate indicate that this same relationship also holds for light dust loadings.

d. Effect of filter size.

From comparative tests made on 18 inch diameter felt filters and 6 inch diameter bags of the same material it was concluded that three 6 inch bags have substantially the same resistance, retention and capacity as a single 18 inch diameter bag of equal length.

e. Effect of filter cloth treatment.

Tests with treated and untreated wool bags indicated that a silicone

impregnated felt (designated "HCE") has a higher resistance (3.5 inches of water gage) but yields higher efficiency (99.997%) than the same wool, untreated (i.e. 2.8 inches of water gage and 99.93% efficiency). Tests were conducted over a twelve hour period on well-plugged filter cloths using Cottrell precipitated flyash at inlet loadings of 3.8 to 3.9 grains per cubic foot of air. Another type of felt cloth, treated to produce a resin coating on the wool fibers, was intermediate between "untreated" and "HCE Treated" in both resistance and efficiency at equal capacity.

REFERENCES

- (1) First, M. W., et al., Performance of Reverse Jet Cloth Filters, "USAEC Report No. NYO-1581, Waste Disposal", Boston, Harvard School of Public Health. (1952).

TABLE I

EFFECT ON COLLECTION EFFICIENCY OF REVERSE JET OPERATION TIME

Air Flow Rate cfm/sq.ft.	Test Dust	Filter Start	Resistance - Stop	in. w.g. Average	Reverse Jet Velocity fpm	Dust Grains/1000 in	Loading cu.ft. out	Reverse Jet Operation Time	Dust Penetration % by weight
24.2	Atmospheric Dust	---	---	1.48	----	.0022	.00020	0	6.6
23.8	Atmospheric Dust	---	---	1.40	2200	.0022	.00030	100	12.6
11.5	Talc	5.6	4.8	----	1620	140	.00025	45	0.0019
11.5	Talc	---	---	4.72	1620	160	.00125	100	0.0078
10.0	Vaporized Silica	8.0	7.1	----	4000	1070	.001	10	0.00093
10.0	Vaporized Silica	---	---	5.1	4000	1260	.018	100	0.0014
9.5	Fly Ash	2.4	1.7	----	4200	1120	1.0	7	0.023
10.0	Fly Ash	---	---	1.06	4200	1240	0.25	100	0.082

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TABLE II
EFFECT ON FILTER RESISTANCE OF REVERSE JET SLOT WIDTH

Slot Width in.	Reverse Jet Air Volume cfm	Reverse Jet Air Velocity fpm	Filter Resistance in. w.g.	Ratio of Reverse Jet Air To Filtration Volume
0.030	74	7200	5.7	0.36
0.030	42	4000	9.0	0.20
0.046	69	4000	5.8	0.35
0.055	74	4000	5.1	0.36
0.055	42	2300	6.3	0.20

TABLE III
EFFECT ON FILTER EFFICIENCY OF REVERSE JET AIR VELOCITY

Reverse Jet Velocity fpm	Dust Loading Grains per cubic foot		Penetration Percent by weight
	in	out	
4250	11.9	.00136	0.0114
3200	13.4	.000607	0.0046
2100	11.2	.000437	0.0039

Fig. 1—Effect on filter resistance of reverse jet operation time.

Fig. 2—Effect on resistance of reverse jet air velocity.

Curve no.	Test Dust	Filtration velocity	Reverse jet slot width
A	Fly ash	10 fpm	0.055 in.
B	Silica	10 fpm	0.055 in.
C	Silica	15 fpm	0.030 in.
D	Silica	15 fpm	0.055 in.

Fig. 3—Effect on resistance of inlet dust concentrations.

Dust	Air rate cfm/sq. ft.	Reverse jet velocity fpm	% time reverse jet operates
Silica	10	8,000	100
Talc	8	2,000	100
Fly ash	10	4,250	100

FIELD STUDIES OF COMMERCIAL DUST COLLECTOR PERFORMANCE

by

Richard Dennis, Melvin W. First, and Leslie Silverman

Presented by
Richard Dennis

1. Objective and Methods

Field testing of commercial dust collectors provides information covering a wider range of aerosols and operating conditions than can be investigated conveniently in the laboratory. In addition, the effects upon efficiency and resistance of average plant maintenance and normal deterioration of equipment under typical industrial applications can be observed.

Results of our studies of commercial cloth collectors (utilizing bag shaking or the reverse jet cleaning principle) and dry mechanical and inertial types have been reported previously (1) (2). Tests have since been made on representative models of two-stage, low voltage electrostatic precipitators and on a variety of wet collectors embodying a fairly representative group of the many designs now available.

Sampling and analytical procedures followed closely the methods and principles described at length in our Annual Report for 1950-1951 (1). High volume sampling with type S pleated filters and low volume sampling with molecular filters were used for determining weight collection efficiency and particle size distribution, respectively, when dealing with low dust loadings (i.e. ≤ 0.1 grain per cubic foot of air), and our stack sampler with paper or all-glass thimbles (for high temperature gases) was used for higher dust concentrations. Impinger tubes were used where excessive moisture caused filter plugging.

2. Test Results

a. Electrostatic precipitators. Operating principle and general construction of all models tested are basically identical. An adequate description

may be found on page 42 of the Handbook on Air Cleaning (3). Ionizing wires maintained at a positive potential of 12 to 13.5 KV preceded collecting plates charged to 6 or 6.5 KV. Plate depth in the direction of air flow varied from 10 to 12 inches and the spacing between the alternately charged and grounded collecting plates was approximately $3/8$ inch.

Collectors from three different manufacturers (Westinghouse "Precipitron", American Air Filter "Electromatic", and Trion "Electric Air Filter") were tested. The units differed in methods employed to clean the plates, the use of adhesive coatings and the location and construction of auxiliary filters. After-filters were employed in all units to guard against power failers, blow-off of accumulated dust and to eliminate carry-over during cleaning.

Table I is a summary of our test data. No significant performance variations were observed among the three models studied but efficiency varied inversely with flow rate as shown by tests 1, 2, 3, and 5, 6, 7. Other factors beside air flow rate may have influenced these results since they represent six different collectors, but so far as could be determined they were all operating properly at the time of the tests. Manufacturers rate these units as 90 per cent efficient at 350 FPM and 85 per cent at 400 FPM by the NBS discoloration test (4). The relationship between "blackness" and weight efficiency tests is not easily determined but our results seem to indicate that weight efficiency is a more severe test of the air cleaning effectiveness of these precipitators.

Because of improper location of return air ducts there was considerable variation in air velocity over the face of some of these units (in some instances maximum velocities nearly twice average were observed). Maldistribution of air tends to overload some sections of the collector and permits little or no air to reach other locations. This undoubtedly lowers efficiency. Flow resistance of these units is so low, i.e. 0.05 to 0.10 inches water gage, that there is little tendency for air to straighten and

enter into all sections and special straightening devices should be employed upstream of the precipitator for this purpose when air distribution is abnormal. In the field it was not possible to determine quantitatively what part poor air flow distribution plays in lowering the efficiency of these units.

Tests 4a and 4b of Table I indicate greater efficiency for adhesive-coated plates although power pack fluctuations may have exaggerated the apparent advantage of the sticky plates.

b. Wet collectors. The units tested may be divided into two main categories; (1) mechanical-centrifugal scrubbers in which dust collector and air exhauster are incorporated into a single unit, i.e. type W Rotoclone (American Air Filter Company) and Hydro Volute Scrubber (Buffalo Forge Company) and (2) inertial types in which the dust laden air is caused to flow over or around wetted baffles and vanes which impart a spinning motion to the gases. Both types of wet collectors are described and illustrated in the Handbook on Air Cleaning (3, p.26).

Both mechanical-centrifugal scrubbers employed an involute scroll as a pre-cleaner. For the type W Rotoclone, sprays are used in both pre-cleaner and impeller sections, while in the Hydro Volute Scrubber, sprays were used in the entry to the pre-cleaner section and in the droplet eliminator section to keep the bent plates washed clean. Nozzle pressures of 80 to 90 psi are used in the type W Rotoclone and 5 to 15 psi in the Hydro Volute Scrubber. Table II lists the results of tests on these two wet scrubbers. Five type W Rotoclones (capacity 5,000 to 10,000 CFM) gave weight efficiencies ranging from 97.2 to 99.6 per cent on foundry dusts having mass median diameters of 40 to 47 microns. Inlet loadings ranged from 0.75 to 7.29 grains per cubic foot. A 1,000 CFM Hydro Volute Scrubber gave 97.8 per cent efficiency on a re-suspended flyash with a mass median of 16 microns and a loading of 1.35

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grains per cubic foot. As the equipment gets larger, inertial forces tend to decrease and give lower efficiencies, but these results are a good indication of the useful range of this type of equipment, i.e. efficiency 95 per cent or better on particles greater than 10 to 15 microns for units ranging in capacity from 1000 to 10,000 CFM. Because of the dual role of the impeller it cannot be designed for maximum aerodynamic efficiency and power requirements for units of this type are high.

Table III lists the results of tests on a variety of inertial wet collectors. Type N Rotoclones employing a water curtain and abrupt changes in direction to capture dust appear to be approximately as efficient as the mechanical-centrifugal type when applied to similar dust (i.e. 37 to 140 micron mass median diameter). (Had dust loadings been more nearly like those found in the type W Rotoclone tests, efficiency probably would have been somewhat improved). These units are not suitable for dusts one micron in size (MMD) or less as shown by Test 2b, Table III, but have about the same useful range as the mechanical-centrifugal types and may have somewhat less air flow resistance.

A 3,500 CFM Air Tumbler unit (wetted-wall spiral tube of four turns) removed 76 per cent of Al_2O_3 dust having a MMD of 25 microns, (Test 3). Air flow resistance was 1.9 inches water gage. With maximum gas flow (unit is rated up to 5,000 CFM) resistance would double (approximately) and efficiency might increase somewhat.

Five different impingement type scrubbers were tested. All have tangential entries (to produce a cyclonic air motion) plus guide vanes and impingement plates wetted by low-pressure water sprays. Efficiency ranged from 73 to 96.8 per cent, increasing with increase in size of dust and decrease in size of scrubber. Only the smaller units (1000 to 3000 CFM) appeared to be as efficient as the mechanical-centrifugal types.

A Buffalo Forge Company high-pressure-spray tower is representative of several such designs now available commercially. Their distinguishing feature and principal cleaning mechanism is multiple rows of 300 to 500 psi water sprays. Test 9, Table III, indicates that a 2,000 CFM tower removes 75 per cent of a dust having a mass median diameter of 0.9 microns. It is not possible to compare these results with those discussed above since the particle size is so different but it may be concluded that this type of scrubber will do at least as well on dust of a comparable size. Air flow resistance is low but the cost of pumping 400 psi water is a significant factor. High pressure nozzles are easily plugged and scrubbing liquor cannot be recirculated. A comparison of temperature reduction of hot gases passing through a low-pressure spray Ducon collector (2 gpm per 1,000 CFM at 20 psi) and a high-pressure spray Buffalo tower (3 gpm per 1,000 CFM at 400 psi) is as follows: from 230° to 120°F for the Ducon and from 329° to 72°F for the high pressure nozzle Buffalo unit, indicating that high pressure sprays may have some advantages where intimate contact between air and water is desired.

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TABLE I—PERFORMANCE OF LOW-VOLTAGE ELECTROSTATIC PRECIPITATORS WITH ATMOSPHERIC DUST

DUST DESCRIPTION												
Manufacturer	Test ¹ and Unit ⁶	Method ² of plate Cleaning and Coating	Inlet			Outlet			Air Flow Rate (S.T.P.) ⁵ cfm	Face Velocity (Average) fpm	Per cent Air Recirculated (Estimated)	Collection Efficiency by Weight per cent
			Loading ³ Grains per 1000 cu. ft.	Median Size Microns		Loading ⁴ Grains per 1000 cu. ft.	Median Size Microns					
				Count	Mass.		Count	Mass.				
Westinghouse	1 (A)	Manual	0.0254	0.44	0.90	0.00638	0.39	0.48	21,900	780	50	74.9
	2 (A)	Washing	0.0302	0.44	0.85	0.00803	0.40	0.46	27,150	565	50	76.4
	3 (A)	and	0.031	---	---	0.0034	---	---	15,700	154	65	89.4
	4 _a (A) ⁸	Water	0.0224			0.011			15,700	253 ⁷	50	50.9
	4 _b (A)	Soluble Adhesive	0.061	0.45	0.74	0.0221	0.39	0.47	15,700	253 ⁷	50	63.7
AAF	5 (B)	Automatic	0.0584	0.44	0.54	0.0171	0.42	0.47	22,000	389	50	70.8
	6 (B)	Cleaning	0.0632	0.45	0.52	0.0058	0.42	0.48	4,580	255	50	90.9
	7 (C)	by Oil Dipping	0.0307	0.43	0.58	0.00107	0.39	0.48	7,370	140	50	96.6
Trion	8 (D)	Built-in	0.0302	0.51	0.63	0.0032	0.46	0.56	1,800	322	45	89.5
	9 (D)	Water Sprays No Adhesive Coating	0.00902	0.42	0.62	0.00228	0.41	0.51	2,200	297 ⁷	90	74.7

¹Cell voltages: ionizer 12 - 13.5 Kv, plate 6 - 6.5 Kv.

²Total plate depth = 12 in. (Westinghouse); 10 in. (AAF); and 10.75 in. (Trion).

³Outside air in units 1 through 4 pre-cleaned with coarse Fiberglas filters.

⁴Loading refers to concentration downstream of coarse metal fiber after filters (integral parts of units 5-9).

⁵S.T.P. = 70 deg. F., 760 mm. Hg.

⁶Letters in parenthesis indicate different designs: (A,D) fixed vertical plates; (B) moving vertical plates, 2 rev. per 24 hrs.; (C) moving horizontal plates, 2 rev. per 24 hrs.

⁷Voltage fluctuation during tests. Arcing in unit 4, low plate current in unit 9.

⁸No adhesive on plate.

Note: Pressure losses across all units varied from 0.05 to 0.1 in. water.

TABLE II—PERFORMANCE DATA FOR MECHANICAL - CENTRIFUGAL WET COLLECTORS

DUST DESCRIPTION																	
Type Unit	Test No.	Operation	Inlet						Outlet			Air Flow Rate (S.T.P.) cfm	Water Flow Rate gpm	Entry Velocity fpm	Pressure Loss. In. Water	Collection Efficiency by Weight Per cent	Overall Unit Dimensions. Feet L x W x H
			Loading Grains per Cu. Ft.	Median Size Microns			Loading Grains per Cu. Ft.	Median Size Microns									
				Mass	Count			Mass	Count								
Type W Rotoclone	1	Castings	5.07	47	9.5	0.022	7.2	1.7	10,400	9	3,750	3.2	99.6	8.8 x 8.0 x 15.3			
	2	Cleaning	0.75	40	10.5	0.0052	6.7	2.1	4,150	9	1,490	4.4	99.3	8.8 x 8.0 x 15.3			
	3	by Metal	5.98	47	5.4	0.045	6.0	1.0	10,000	14	2,500	3.0	99.2	10.2 x 9.6 x 17.8			
	4	Shot and	7.29	43	1.1	0.029	2.7	0.6	5,220	7.5	2,830	3.3	99.6	7.0 x 6.6 x 13.2			
	5	Sandblast, & Tumbling	1.12	45	---	0.031	--	--	5,440	7.5	3,060	4.2	97.2	7.0 x 6.6 x 13.2			
Hydro Volute Scrubber	6	Flyash	1.35	15	4.0	0.030			1,000	6.5	2,800	5.1	97.8	3 x 2.5 x 8			

TABLE III—PERFORMANCE DATA FOR INERTIAL AND CYCLONIC WET COLLECTORS

DUST DESCRIPTION														
Type	Test	Operation	Inlet			Outlet			Air Flow Rate (S.T.P.) cfm	Water Flow Rate gpm	Entry Velocity fpm	Pressure Loss. In. Water.	Collection Efficiency by Weight Per cent	Overall Unit Dimensions Feet L × W × H
			Loading Grains per Cu. Ft.	Median Size Microns		Loading Grains per Cu. Ft.	Median Size Microns							
				Mass	Count		Mass	Count						
Type N Rotoclone	1	Foundry Tumbling	0.28	140	10.1	0.0025	9.0	2.4	10,100	3.2	3,370	2.6	99.1	8.2 × 8.1 × 16
	2a	Machine Shop-- Grinding	0.0114	37	21	0.001	7.8	4.4	28,000	2.2	2,800	2.9	91.2	19.6 × 8.1 × 18
	2b	Machine Shop Gen- eral Air	0.0056	1.0 ¹	0.6	0.002	---	---	28,000	2.2	2,800	2.9	64.5	19.6 × 8.1 × 18
Air Tumbler	3	Steam Dry- ing Al ₂ O ₃	0.525	25	1.0	0.126	10.7	0.9	3,350 (176-140°) ²	0.3	3,350	1.9	76.0	9 × 3 × 8.5 Diam. × H
Schneible	4a	SiC	0.076	20	7.6	0.0024	5.0	3.1	895 (142-88°) ²	4.5	1,350	0.7	96.8	3 × 13
	4b		0.127	---	---	0.0066			1,900	4.5	2,880	3.2	94.8	3 × 13
Ducon	5	Stone and Sand Drying	5.8	4.3	1.7	1.5	1.2	0.6	9,200 (230-120°) ²	20	1,300	2.5	74.0	6 × 16.7
	6	Banbury Mixer	0.0052	---	---	0.00077			16,600	16	3,200	5.2	85.2	5.3 × 13.5
Warren Bros.	7	Sand and	3.6	4.3	1.7	0.3	1.2	0.59	3,200	10	2,050	--	92.0	3 × 10.5
	8	Stone Drying	6.4	---	---	1.7	---	---	10,000 (275-145°) ²	12	2,000	--	73.0	4.5 × 18
Buffalo Forge Company	9	Ferro- Silicon Furnace Fume 90% Amorphous Silica	0.972	0.89	.35	0.243	0.82	0.31	2,800 (329-72°) ²	10	4,000	1.1	75.0	4 × 16

¹Estimated Size - Machining Operations Suspended During Test.²Inlet and Outlet Air Temperature, deg. F.

ELECTROSTATICALLY CHARGED AEROSOL FILTERS

by

August T. Rossano, Jr.,* E. W. Conners, Jr. and Leslie Silverman

Presented by
August T. Rossano, Jr.

Introduction

It is recognized that electrostatic forces may represent a significant factor in the filtration of aerosols but comparatively little attention has been given to this aspect of the problem.

Electrostatically charged filters are those in which aerosol removal is accomplished in part by electrostatic forces from fields naturally occurring within the fiber mass. By contrast, in electrostatic precipitators, separation is accomplished by means of electrical power supplied by external electrical apparatus.

Much of current knowledge on electrostatically charged filters is related to the resin-wool filter, a product of European research and development, notably by the British Experiment Station at Porton. It was found that the addition of resin powder to a permeable wool pad would transform it into a highly efficient smoke filter without appreciable effect on resistance. Subsequent research led to the conclusion that improved performance was due to superimposition of electrical forces on the other removal forces normally associated with fibrous filters.

Mechanisms for Producing Static Electrification

Methods which are of most interest in the study of aerosol filters are as follows⁽¹⁾:

- (1) Contact or Volta electrification can occur between clean dry metallic surfaces or between the surface of a metal and a semi-conductor.

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*U. S. Public Health Service Officer on assignment to Harvard Air Cleaning Laboratory.

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- (2) Spray electrification is the production of charge as a result of disruption of liquid surfaces such as by atomization, bubbling of liquids or shattering of high energy liquid jets by solid surfaces.
  - (3) Frictional or tribo-electrical charging is the most frequently observed mechanism of electrification, and paradoxically the most obscure. This charge is created when two materials are brought into intimate contact and then separated.

Mechanisms of Charge Reduction

Electrostatic charge can be dissipated in several ways⁽²⁾;

- (1) Grounding. Direct leakage to ground by means of solid conductors (such as metallic strips or wires) or through the medium of a conducting gas.
- (2) Humidification. In atmospheres high in humidity a thin film of water vapor collects on solid surfaces. Although pure water is not a good conductor, water in equilibrium with atmosphere contains CO₂ or other air-borne impurities such as salts. This plus the contaminants normally existing on solid surfaces provides a conducting film which permits the charge on the object to leak to ground.
- (3) Chemical Agents. There are a large number of antistatic compounds which may be applied to surfaces on which undesirable or dangerous levels of charge may accumulate. Many antistatic agents function by adsorbing a greater than normal conducting film of water onto the charged surface.
- (4) Charge Neutralization by Ionization. Ions produced in various ways either by thermal and electrical means or by ionizing radiations are attracted to a charged body and neutralize it.

Measurement of Charge

The gold leaf electroscope is the basic instrument for measuring static electricity. Mutual repulsion of like charges induced on the leaves causes

them to diverge in proportion to the amount of charge at the terminal. Readings are only semi-quantitative, however. More precise instruments include fiber electrometers in which the gold leaves are replaced by a quartz fiber suspension. One type, the Lindemann-Ryerson Electrometer, which we use in our laboratory can indicate potentials as small as one hundredth of a volt.

The operation of the usual type of voltmeter requires an appreciable and sustained flow of current which seriously affects, if not completely dissipates, the charge to be measured. There are a few suitable commercial electrostatic voltmeters available which satisfy our requirements. We use a Rawson electrostatic voltmeter in our laboratory for high voltages and have found it light weight and rugged. It has a direct-reading scale and low current drain. To calculate charge, the capacitance of the entire system must be known, so an accurate instrument for making extremely low capacitance measurements is required.

Resin Wool Filter

There is evidence to indicate that Hansen selected calophony resin to powder his wood pads because he sought to add to the filter miniature electrets for attracting aerosol particles⁽³⁾.

The mode of action and electrical structure of these filters was reported by the British Experiment Station at Porton⁽⁴⁾ to be as follows:

- (1) The high efficiency of resin-wool filters is due to the attraction of aerosol particles to resin particles covering the fibers.
- (2) This attraction arises from electrostatic forces existing in the field between the fiber and the charged resin particles.
- (3) The resin particles acquire their charge by friction generated during the manufacturing process.
- (4) Although the filter as a whole is electrically neutral, the resin particles are negatively charged and a positively induced charge resides on the wool fibers. The resulting field is non-homogenous

so that uncharged or positively charged aerosol particles are impelled toward the resin.

- (5) The long storage life of these filters is attributed to the high electrical resistivity.
- (6) Breakdown of these filters is caused by oil mist, carbon smoke and ionizing radiations. These agents remove charge from all good insulators.
- (7) High efficiency can be restored by carding or handling. Evidently the resin particles are re-charged by frictional electrification.
- (8) Prolonged passage of air or low concentrations of smoke particles through the filter does not increase its efficiency. Apparently, frictional electrification by passage of air and suspended particles through the filter does not occur to any significant degree.
- (9) Hansen's idea that the electrical forces were due to the formation of electrets in the filter was discarded following a comprehensive series of tests which failed to support this theory.

Resistivity measurements made at Porton by means of improved apparatus in which the effect of air conduction was eliminated yielded values for resin as high as 10^{21} ohms-cm. Long charge-retention time is correlated with the extremely high resistivity of the resin-wool system, a figure higher than can be measured with present techniques. The possibility of high contact resistance between the resin particles and the fibers may also account for the high charge retention of the impregnant.

Billington and Saunders⁽⁵⁾ have shown that with use, there is a gradual drop in efficiency of the resin-wool filter followed by a gradual increase. Resistance varies in a similar manner. Initial high efficiency is due in part to the electrostatic effect, but after this is diminished by gradual loss of charge, plugging comes into play and efficiency begins to increase

by the mechanical action of plugging (as in the case of ordinary fiber filters).

As evidence of the fact that improved performance of resin-wool is due to electrostatic forces a filter impregnated with Beckacite (a para-tertiary butyl phenol-formaldehyde modified resin) was exposed to x-rays. Figure 1 from Billington and Saunders⁽⁵⁾ indicates that penetration of a methylene blue aerosol increased in proportion to the degree of exposure. From this it may be concluded that ionizing radiations cause diminution of charge on the filter, and consequent decrease in filtering efficiency.

These results were confirmed by tests performed by Thomas⁽⁶⁾ in which the passage of tricresyl phosphate smoke through the filter caused a progressive lowering of efficiency. The liquid aerosol was able to wet the fibers and cause the charge to leak off (somewhat the same effect as radiation).

Although initial penetration through a resin-wool filter is low, subsequent low penetration is achieved at the expense of increasing resistance. In industrial applications where the loading is relatively high the resistance increase with time may be so rapid as to seriously shorten the effective life of the filter. The most practical application of resin-wool at the moment therefore, seems to be its use in respirators where filtration velocity and loading are both low.

Current Studies on the Role of Electrostatic Charge in Filtration of Aerosols

The development of new synthetic fibers with good dielectric properties and low moisture regain (making them easily susceptible to static electrification) suggested their possible use in aerosol filtration.

Among the fibers under study are Saran^a, polystyrene, polyethylene, Nylon^b, Dacron^c, Orlon^d, Dynel^e and Vinyon^f.

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a. Vinylidene chloride polymer

b. Polyamid resin

c. Polyester polymer

d. Acrylonitrile polymer

e. Vinylchloride-acrylonitrile co-polymer

f. Vinyl acetate-acrylonitrile co-polymer

Our preliminary activities, of necessity, have been concerned chiefly with selecting methods for filter testing and for measuring electrostatic charge on fibers and aerosols. Evaluating charge on fibers is difficult and a lack of reliable instruments is a serious limitation to research in this field. Equipment has been constructed and standardized and an appreciable amount of preliminary data collected.

In electrostatics, materials generally considered good insulators of current electricity are worthless. For instance, hard rubber, glass, porcelain and bakelite are not adequate for static electricity as they do not provide a high enough degree of insulation. We found it necessary to rebuild some commercial components (generally considered of high quality) with superior dielectrics such as polystyrene and Teflon - which have resistivities of 10^{18} to 10^{21} ohm-cm.

Brush discharge from needle points, sharp edges and other prominences of small radius of curvature was found to be an important source of error in charge measurement. Brush discharge was greatly reduced by "streamlined design" and the use of reduced operating voltages. These measures, with extensive electrical shielding to reduce the effects of stray capacitance and stray electric fields, reduced charge leakage to an acceptable level.

A reliable method for measuring fiber charges utilizes the Faraday effect. With this apparatus, Figure 2, the charge to be measured is placed in a metallic cylinder insulated from ground, and the cylinder, or "Faraday Cage" is connected to an electrostatic voltmeter having a range of 0 to 500 V.

Initial tests were made on 70 micron diameter Saran fibers. A charge could be generated by merely handling the loose fibers briskly after which they were dropped into the Faraday Cage, and the voltmeter read. The mean of ten

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g. Tetrafluoroethylene resin

such identical tests was deemed statistically reliable. Knowing the capacitance of all parts of the system the net charge was calculated in terms of microcoulombs per gram of fibers.

Measurements were made with different quantities of fibers to determine the relation of charge to weight. It was found that charge did not increase in proportion to the increase in weight. The relationship between the ratio of charge-to-mass and fiber mass approximated a straight line having a slope of minus 0.3 on log-log paper (Figure 3).

The charge-to-mass ratio on the surface of a sphere having a uniform charge density is a function of the cube root of the mass, i.e. a log-log plot of these variables would have a slope of minus 0.33, a figure remarkably close to our experimentally obtained value. From this, it was concluded that the Faraday Cage measured the net charge residing on the surface of the wad of fibers. This was later confirmed by the observation that the total net charge varies as the square of the radius of the fiber wad.

From the outset it was apparent that atmospheric humidity had an important effect on charge measurements. On days of high humidity the rate of charge leakage from the apparatus was so high as to make it impossible to perform tests. Even moisture from the breath causes a significant discharge. Although it was obvious that control of atmospheric conditions (mainly humidity) in the test area was essential⁽⁷⁾, it was not clear what the desirable operating level should be. Over a period of two months we made observations of the rate of leakage of our Rawson meter alone for a variety of dry and wet bulb temperatures. Figure 4, a plot of charge leakage (measured in volts per minute) and humidity, indicates the following:

- (1) Leakage is a function of absolute humidity rather than of relative humidity.
- (2) Above an absolute humidity of 90 grains per pound of dry air charge

leakage becomes excessive. (This corresponds to a relative humidity of about 58% for a dry bulb temperature of 80°F.). These results are in good agreement with experiences cited in the textile literature in which humidities of 55 to 70% were found to be effective in preventing accumulation of static electricity during the processing of synthetic fibers. By this method the maximum leakage resistance of the meter was found to be 10^{15} ohms. A 150% increase in absolute humidity caused leakage resistance to decrease by a factor of 500, clearly indicating that humidity control is an essential in studies involving electrostatic charge measurements.

Electrostatic Filters

A commercial "self-charging electrostatic filter" consisting of shredded polyethylene sheet was found to have a removal efficiency of 10% based on the National Bureau of Standards discoloration test, and 58% based on the ASHVE weight efficiency test. A comparable ASHVE test of a filter containing a 1/2 inch layer of FG-25 or PF 314 media showed 80% efficiency.

A related investigation is the development of electrostatically charged filters constructed from woven cloth or felt. Since the rubbing of two fabrics causes their electrification, it may be possible to construct a filter of a combination of fabrics which combines mechanical filtration through a cloth medium with precipitation by electrical forces.

A number of synthetic and natural fibers were tested against each other to construct the Tribo-electric series(8) shown in Table 1. Materials are positive to those below them in the series.

A Faraday Cage connected to a Rawson electrostatic voltmeter (Figure 2) was used to make these determinations. A calibrated variable air capacitor was connected in parallel with the voltmeter as a range extender.

A charge of known polarity was placed on the cylinder to obtain a half

scale (approximately) meter deflection. Two test samples were vigorously rubbed against each other and one of them dropped into the cylinder. The direction in which the meter needle moved indicated the polarity of the charge on the specimen. This procedure was repeated placing the second specimen in the Faraday Cage, as a check.

An alternate method (used to confirm our results) uses a cathode ray oscilloscope with a direct connection to a beam deflection plate, Figure 5. The upper vertical deflection plate was connected to a Faraday Cage and the procedure followed was similar to that described above. With no sample in the Faraday Cage a spot of light appeared in the center of the screen. If the charged sample caused the spot to move downward it was evident that the specimen was of negative polarity since it caused a repulsion of the electron beam. A positively charged sample produced an upward deflection of the cathode ray.

Based on this information Vinyon, Saran, Dynel and Orlon fabrics were selected as potentially suitable materials for an electrostatic cloth filter, using wool as the charging material. Because of the availability of Orlon, the first filter constructed utilized this fabric, Figure 6a. Orlon cloth travels over rollers on top and bottom of a Lucite box perforated on two opposite faces. The aerosol passed through the cloth into the box and out through a metal duct emerging from one end. The Orlon belt was electrified by the rubbing of a wool-covered paddle geared to the same drive as the belt.

During early tests it was observed that the exit duct became electrically charged with the same polarity as that of the Orlon belt. Since the duct was not grounded, it was deduced that it was being electrified by aerosol particles negatively charged during passage through the Orlon. It was thought that these particles might be collected by the use of a positively charged filter medium. Accordingly, a two-stage unit, Figures 6a, b and c was constructed

in which an Orlon screen charged by a wool-covered windshield wiper blade acts as an ionizing stage. The collection stage which follows consists of a wool belt charged by an Orlon-covered paddle. This combination represents an electrostatic fabric filter analogous in many ways to a commercial two stage, low voltage electrostatic precipitator.

The method used to determine the relative magnitude of the charges on the fabric consisted of an aluminum plate suspended near the fabric face and connected to an electrostatic voltmeter with a range extender. With this arrangement it has been possible to measure potentials as high as 15,000 volts on the fabric.

The effect of humidity on the generation and maintenance of charges on fabrics is under investigation. It was observed that the charge on Orlon is much more slowly generated when the absolute humidity is in the vicinity of 90 grains of moisture per pound of dry air. Wool behaves similarly, and appears to be even more sensitive to humidity changes. We are in the process of determining whether charge dissipation is a function of (a) adsorbed or absorbed moisture, (b) decrease in leakage resistance of the measuring system or filter assembly, or (c) some other factors. Results from efficiency tests indicate some benefits are obtained from charging, and this filtering technique will receive further investigation and development.

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TABLE I

TRIBOELECTRIC SERIES OF SEVERAL FIBERS

Positive End

Glass
Wool
Cotton
Nylon
Dacron
Orlon
Polyethylene
Polystyrene
Dynel
Saran
Vinyon

Negative End

Fig. 1—Effect of radiation on performance of resin-wool filter.

Fig. 2—Apparatus for measuring fiber charge.

Fig. 3—Relation between charge to mass ratio and mass - saran fibers-70 μ .

Fig. 4—Effect of atmospheric humidity on charge leakage. Rawson electrostatic volt-meter polystyrene insulation.

Fig. 5—Oscilloscope for measuring polarity of charge.

Fig. 6a—Diagram of electrostatically charged filter.

Fig. 6b—Right side of electrostatically charged filter.

Fig. 6c — Left side of electrostatically charged filter.

WET CLEANING INVESTIGATIONS

by

Glenn A. Johnson, Sheldon K. Friedlander, Melvin W. First and Leslie Silverman

Presented by
Melvin W. First

The simplest and perhaps the most common type of wet collector is the centrifugal scrubber in which air or gas is introduced tangentially or is given a rotating motion by deflecting vanes after entering the scrubbing chambers. Spray nozzles are usually located on an axial water main to spray radially outward, although they may be placed at the scrubber wall so as to spray tangentially in the direction of air flow.

A simple wet cyclone scrubber with a tangential inlet was constructed from 55 gallon oil drums and provision made for introducing hydraulic and pneumatic spray nozzles at different locations in the cyclone body, Figure 1. Basic performance data were obtained with a finely divided talc dust having a median size by count of less than one micron.

1. Effect of wet operation.

Weight efficiency was determined for wet and dry operation over a wide range of dust loadings. The results obtained were approximately straight lines on log-log paper, Figure 2.

Efficiency of the collector when operated wet ranged from 78% at a loading of 0.03 grains per cubic foot to 94% at 18 grains per cubic foot. Efficiency of the collector when operated dry varied from 46% at a loading of 0.5 grains per cubic foot to 75% at 10 grains per cubic foot. The wet runs were made with a water rate of 6 gallons per 1000 cubic foot of air using two 400 psi hydraulic nozzles. It is apparent that the dust loading is important in the performance of this type of device.

Since the slopes of the "Efficiency-Loading" curves are nearly equal, the relative effect of water is nearly constant in terms of reduction of effluent loading. The dry effluent is 2.8 times that obtained for the wet

unit at a loading of 0.1 grains per cubic foot and 3.6 times at a loading of 10.0 grains per cubic foot. In terms of relative performance the effect of the sprays is slightly greater at higher loadings. This indicates, as predicted from theory, that there are a greater number of possible collisions as the number of dust particles increases. With dry operation an increase in efficiency with loading can be attributed to greater probable collision and subsequent agglomeration between particles. The rise in efficiency under wet conditions is a result of the increased collisions between particles and droplets.

2. Effect of wetting the cyclone walls.

Since many wet centrifugal dust collectors use only wetted walls or baffle plates as a means of increasing dust retention, the relative efficiency of the cyclone when dry and with walls wetted by means of a circular drip tube located around the upper edge of the cyclone body was investigated. The wetted wall tests were made with a water rate of 4.5 gallons per 1000 cubic feet and loadings about 1 grain per cubic foot. At low entry velocities wet and dry efficiencies were substantially equal (Figure 3) but at 4000 feet per minute entry velocity the difference was small but significant, indicating that even with small particles there is a dynamic equilibrium in dry cyclones between deposition on the walls by centrifugal force and re-entrainment by (1) rebound and (2) eddy formation at irregularities on the collector surfaces. The differences between dry and wetted wall operation would doubtlessly be greater if there were larger particles (i.e. more nearly in the usual particle size range for equipment of this nature) in the test dust.

From these tests it was concluded that the wetted wall surfaces accounted for only a small part of the increased efficiency noted when the cyclone was operated with high pressure sprays located at the inlet.

3. Effect of entry velocity.

The efficiency of a centrifugal collector is a function of entry velocity, i.e. higher entry velocities give higher efficiencies (as well as greater power requirements). A series of runs, wet and dry, was made to study the effect of velocity on efficiency. For the wet runs the water rate was 8 gallons per thousand cubic feet of air. The maintenance of constant water rate per volume of air was accomplished by maintaining constant water pressure but varying the number of nozzles in order to be certain that droplet characteristics would not change. For all these runs dust loading was approximately 1 grain per cubic foot of air.

Both wet and dry efficiency increased with increasing entry velocity (Figure 4), although the increase was more apparent on the dry than the wet runs. Relatively, dry efficiency improved at twice the rate of wet over the range tested. Other results indicate that when the wet cyclone is operating in a lower region of the efficiency curve, wet efficiency increases with increased inlet velocity in the same manner as dry efficiency.

4. Effect of water rate variation.

One of the basic considerations in the study of any wet collector is the amount of water required to give satisfactory performance. Figure 5 shows a series of tests using 2, 3, and 4 high pressure nozzles to study the effect of water rate variation. Dust loading was held close to 1 grain per cubic foot and an entry velocity of 3500 feet per minute was maintained during all of these tests. The portion of the curve between 0 and 4 gallons per 1000 cubic feet of air has been shown with a dotted line to indicate its expected position. The optimum water rate for use in the collector can be selected from curves of this type. As the water rate is increased above 6 gallons per 1000 cubic feet of air the curve rapidly approaches an asymptote indicating that further increases in water rate do little or nothing to

enhance the performance of the collector and only serve to increase the power requirements as well as contribute to waste water disposal problems.

Figure 6 shows the effect of water rate and inlet velocity on scrubber efficiency for low pressure hydraulic nozzles located near the cyclone entry at right angles to air flow. Efficiency increased with increasing nozzle pressure (i.e. water rate). This was also true for the high pressure nozzles.

Efficiency with the nozzles in place but the water turned off was 52% at an entry velocity of 3900 feet per minute. This is considerably below the dry efficiency of the cyclone when tested with no spray nozzles installed. The wet efficiency of the cyclone at 8 psi is also less than the dry efficiency of the empty cyclone. This peculiar result is probably due to the entry vane effect of the nozzles placed in the path of the incoming air. This is in agreement with studies on conventional cyclones which show that entry vanes decrease the velocity of the spinning gases in the cyclone body.

5. Effect of spray droplet size.

The effect of spray droplet size was investigated with coarse spray, low pressure hydraulic nozzles and fine-spray pneumatic nozzles operating at the same total water rate (Figure 7). The coarse spray gave higher efficiencies for the same entry velocity and dust loadings, indicating that the fine hydraulic nozzle spray droplets were too small to sweep or penetrate the area involved in front of the inlet (instead they were carried away with the air stream). The coarse flooding nozzle spray droplets were large enough to penetrate the air stream and reach the outer cyclone wall; but in comparison with high pressure sprays (dust collection efficiency approximately 90%) too few droplets were formed for effective dust removal. As a matter of interest, it may be noted that wet efficiency with the fine spray pneumatic nozzles was not appreciably superior to efficiency using an empty, dry cyclone although it was higher than dry efficiency with the spray nozzles in place.

6. Location of sprays.

Effect of nozzle location on wet cyclone performance for a low pressure pneumatic spray is summarized in Table I. The nozzles noted in the first item in the table were placed one foot above the inlet and directed downwards in an attempt to direct the spray toward the wall where the dust concentration is highest. Efficiency and resistance were both low. Efficiency was increased 16% by placing the nozzles at right angles to the inlet but resistance also increased (test 2). When the nozzles were placed countercurrent to flow in the cyclone inlet duct (test 3) efficiency increased another 11% and the resistance of the system doubled.

From this table it may be seen that highest efficiencies (and resistances) occurred with the nozzles placed in the inlet duct. With two nozzles placed countercurrent to flow, a water rate of 14.5 gallons per 1000 cubic feet of air and a water pressure of 50 psi, an efficiency of 84.7% was obtained (test 4). This compares favorably with 90% obtained with 400 psi nozzles at the same inlet velocity, but cyclone resistance with nozzles in the entry duct was about an inch higher and water rate 6 gallons per 1000 cubic feet greater. With low pressure nozzles, however, pumping requirements are less and water can be recirculated with less danger of plugging the nozzle orifice than with the high pressure ones.

Several runs were made with 1/8 inch mesh Saran screens inserted in the inlet duct downstream of a nozzle spraying concurrently (test 7). The screens were included to break up large water droplets and spread the water by surface tension effects. The insertion of two screens increased efficiency 8% (from 72 to 80.2%, test 6) but also resulted in a somewhat greater resistance. Water rate was relatively low (7 gallons per 1000 cubic feet) and there was no accumulation of material on the screens.

The design of the experimental scrubber studied is not a practical one

since it has an unnecessarily high resistance. This particular design was chosen primarily for convenience and ease in construction and was purposely underdesigned in order to give low efficiency so that the effect of the addition of sprays, etc. would be readily apparent. Other investigations have indicated those factors which produce low energy loss in cyclone collectors and when the present studies of wet collection demonstrate the optimum methods of applying a scrubbing fluid, a practical, low-loss, high-efficiency scrubber will be constructed and tested.

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TABLE I

Effect of Nozzle Position on Wet Cyclone Performance

Test No.	No. Nozzles	Position	Water Pressure psi	Water Rate gals/1000CF	Cyclone Resistance " H ₂ O	Dust Loading grains/CF	Efficiency % by weight
1	3	Directed down at inlet near entry wall	25.5	15.9	2.6	1.17	54.8
2	3	Right angles at inlet	25.5	15.9	4.6	1.09	70.9
3	3	Countercurrent to flow in inlet duct	25	15.3	9.2	1.00	82.0
4	2	Countercurrent to flow in inlet duct	50	14.5	9.5	1.11	84.7
5	1	Countercurrent to flow in inlet duct	45	7.0	---	1.09	76.3
6	1	Concurrent with flow in inlet duct	45	7.0	---	1.22	72.0
7	1	Concurrent in inlet duct followed by 2 Saran screens supported by a coarse wire screen	45	7.0	---	0.951	80.2

Fig. 1—Arrangement of spray nozzles.

Fig. 2—Effect on efficiency of inlet dust loading.

Fig. 3—Efficiency of cyclone with wetted walls.

Fig. 4—Effect of entry velocity on efficiency.

Fig. 5—Effect of water rate on efficiency.

Fig. 6—Performance with low pressure hydraulic nozzles.

Fig. 7—Effect of size of spray droplets.

DISSOLVER OFF-GAS FILTRATION

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I. INTRODUCTION

In the Separations process the irradiated metal, after a suitable "cooling" period is charged to the dissolver, or the first processing vessel. Here the jackets are removed and the uranium is dissolved. The dissolver vent gases during actual metal dissolution and the agitation and transferring of the prepared solution constitute the most highly contaminated gas stream in the Separations Plants. From the health-hazard viewpoint there are two principal contaminants, radio-iodine and an aerosol composed of other fission products. One of the primary problems in the decontamination of the stack gases at Hanford Works has been the development of methods and equipment to remove effectively the radio-active iodine and particulate contamination from the dissolver off-gas streams. The investigation has led to the development and adoption of the silver reactor and Fiberglas filter for iodine and particulate matter removal respectively. Today's discussion will be concerned primarily with the filtration of these process gas streams.

II. BACKGROUND

(A) Collector Requirements

The first slide presents the specifications which were established as representing the development and design goals for a dissolver off-gas filter.

FILTER SPECIFICATIONS

1. A collection efficiency of 99.99% for sub-micron particles present in low concentrations.
2. A life expectancy in terms of years.
3. A minimum of maintenance in the continuous operation of the unit.

4. No subsequent problem caused by the disposal of the collected material.

(B) Development Program

The success of the sand filter installations at Hanford led to the investigation of employing the same filtration mechanism, but with filter media of more desirable properties. It was suggested by Mr. C.E. Lapple, a consultant at Hanford from the Du Pont Company, during the summer and fall of 1948, that the substitution of glass fibers for sand might lead to some improvements in filter design and operation. Since the results of preliminary tests were favorable, an extensive investigation of the filtration characteristics of glass fibers was initiated.

This investigation consisted of three parts: (1) The correlation of collection efficiency and pressure drop under startup conditions with superficial air velocity, the bed depth, and the packing density of the various types of glass fibers; (2) A study of the manner in which the pressure drop of glass fibers increases with accumulative amount of smoke particles passing to the unit; and (3) A study of the physical characteristics of the glass fibers.

The investigation of the filtration characteristics of glass fiber beds was made under fixed conditions by employing the radioactive aerosol discharged from the process cells. It was determined that the two dependent variables, collection efficiency and pressure drop, could be mathematically expressed by the transfer unit concept. The efficiency equation is presented in the next slide:

Slide No. 2

TRANSFER UNIT EQUATION FOR FIBERGLAS FILTRATION

$$\text{Efficiency} = \frac{1 - \text{Wt. Passing Through Collector}}{\text{Wt. to Collector}}$$

$$= 1 - e^{-Nt}$$

$$= 1 - e^{-KL^a p^b / V^c}$$

where: L is bed depth, inches
 p is packing density, lbs/ft³
 V is superficial velocity, ft/min
 K is proportionality constant
 a, b, c, are empirically determined exponents

The constants a, b, and c, must be obtained experimentally for each fiber.

This was done by varying only one parameter at a time and obtaining the corresponding change in collection efficiency. The manner of handling the data is indicated on the next slide.

Slide No. 3

DATA CORRELATION

$$\text{Eff} = 1 - e^{-KL^a p^b / V^c}$$

$$1 - \text{Eff} = e^{-K'L^a}$$

$$\log (1 - \text{Eff}) = -K'L^a \log e = -K'L^a$$

$$\log (-\log (1 - \text{Eff})) = a \log L / \log K''$$

If the "one" in the basic filtration equation is transposed and then the logarithm of both sides of the equation is taken twice, an expression is obtained stating the variation of efficiency with bed depth only. The "K" prime lumps the logarithm of all the constants in the equation. In the log-log plot of log (1 - efficiency) against the bed depth, the constant "a"

is then the slope of the line obtained. The other constants "b" and "c", can be obtained in the same way by varying only the velocity or packed density respectively. The more promising glass fibers were thoroughly evaluated in this manner and the data assembled for each type of Fiberglas in nomograph form. A typical nomograph is shown in the next slide. This represents a compilation of the data for the so-called "Owens-Corning No. 55 Fiberglas". The nomograph makes it possible to predict the initial filtration efficiency of any filter bed of No. 55 Fiberglas at all packing densities and over a wide range of air velocities. In a composite filter bed where more than one grade of Fiberglas may be used, the initial efficiency of the part of the filter consisting of No. 55 Fiberglas can be readily predicted from the nomograph.

A couple of examples will show how this nomograph is used. Suppose we want to know the filtration efficiency of a 24-inch bed of 55 Fiberglas packed to a density of three pounds per cubic foot and operated at 25 feet per minute. You connect 3 on the fiber density scale with 25 on the velocity scale. The point where this line crosses the auxiliary line "A" is then connected to 24 on the bed depth scale. The efficiency of the unit, 96%, is then read off the efficiency scale. Another example would be to find what depth of 55 Fiberglas packed at six pounds per cubic foot is required to get a filtration efficiency of 96 per cent at a velocity of 25 feet per minute. Again a line is drawn from 6 on the packing density scale to 25 on the velocity scale. The point where this line crosses the "A" line is then connected to 96 on the efficiency line and extended to the bed depth line. We find that a bed depth of 11 inches is required.

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70

WASH-149

DF	%
4.00	99.99
3.00	99.9
2.30	99.5
2.00	99
1.39	96
1.17	93
1.00	90
.696	80
.522	70
.400	60
.300	50
.222	40
.156	30
.100	20
.048	10

V - fpm

L - INCHES

Nomograph of the Efficiency Characteristics of No. 55 Fiberglas

$$DF = \frac{C_{55} L^{0.9} \rho_p^{1.1}}{V^{0.4}}$$

Where

- DF = Decontamination Factor
- C_{55} = Constant
- L = Bed Depth, inches
- ρ_p = Packing Density pcf.
- V = Superficial Velocity, fpm.

Nomographs were also prepared for the various fibers relating pressure drop to the same variables. The nomographs are sufficiently accurate within the indicated ranges to be of particular value in the design of fibrous filters for the removal of particles similar to those at Hanford. These charts should also be of considerable use in any application where the particle loading is low.

The second phase of the investigation was concerned with the expected service life of glass fiber filters. The tests were conducted with a methylene blue smoke having a particle size distribution similar to that of the radioactive aerosol and a dust loading ten to twenty times that of the process cell air. Studies were made on several small depths of fibrous materials to investigate the course of the pressure drop increase which occurs with the passage of smoke particles to a fixed bed filter. By including a less efficient filter that effectively protects the more efficient material the life expectancy of the composite filter can be extended. In the series of methylene blue tests, a comparison was made of the useful filtration life to be expected from the various types of fibrous units. At the same time suitable fore-filters were developed for the more efficient glass fibers.

The final phase of the investigation was primarily concerned with the weatherability of glass fibers; that is, the degree to which the various types of fibers can withstand the effects of water, alkali, or acid present in the gas stream passing through the filter bed. This information was assembled to permit the specification of glass fibers having the maximum weatherability for particular service conditions.

III. PLANT INSTALLATIONS

(A) Equipment Description

The development and design of the silver reactor for iodine removal proceeded concurrently with the filtration studies. Silver reactors and Fiberglas filters were installed in the dissolver cells as integral

20 50

decontamination units. The first assembly was placed in operation on October 26, 1950. The next slide presents a schematic representation of the equipment. The assembly consists of a heater, a reactor tower containing a silver bearing material, and a Fiberglas filter. The dissolver vent gases after leaving the reflux column are passed through the heater where the temperature is adjusted to the value desired for the reaction between the iodine in the gas stream and the silver bearing packing. The iodine reacts with the silver to form silver iodide and is retained within the bed. The gases then pass through the Fiberglas filter for particulate decontamination and are discharged to the stack. Monitoring of the gases downstream from the reactor has established that the plant silver reactors are removing iodine from the dissolver vent gases with an efficiency greater than 99.99 per cent.

The dimensional details of the dissolver cell Fiberglas filter are presented in the next slide. The unit is 2-1/2 feet by 5-1/2 feet with an overall height of 4.3 feet. The cross-sectional area, 12.5 square feet, results in a superficial velocity of approximately 20 feet per minute under conditions of maximum gas flow. Weatherability data indicated that the chemical resistivity of the 115K and AA Fiberglas would be satisfactory under the service conditions. The depth and packing densities of the various strata were selected to provide a maximum service life, a filtration efficiency in the order of 99.99 per cent, and a pressure drop of 4 inches of water at the rated air velocity.

Performance Data

To obtain accurate efficiency data for the Fiberglas filter, monitoring equipment was installed in the Canyon Building pipe gallery. The system is schematically represented in the next slide. Aliquots of the upstream and downstream gases were drawn through the filter pressure lead lines, through the canyon wall and passed through CWS Type 6 monitoring filters. The system used short, well-sloped lines and permitted reliable sampling. The data which were

Slide No. 5—Schematic diagram of silver reactor — fibreglas unit.

SECTION - AA

SECTION - BB

PLAN

Slide No. 6—Dissolver cell fiberglass filter.

Slide No. 7—Fiberglass filter monitoring equipment 221-B pipe gallery.

obtained with this apparatus are presented in the next slide.

Slide No. 8

FIBERGLAS FILTER MONITORING DATA

<u>Date</u>	<u>Upstream Monitor</u>		<u>Downstream Monitor</u>		<u>Efficiency (%)</u>
	<u>Flow (cfm)</u>	<u>Mrep/hr.</u>	<u>Flow (cfm)</u>	<u>Mrep/hr.</u>	
12-19-50	1.0	6000	1.0	< 5	> 99.92
12-19-50	1.0	1500	1.0	< 5	> 99.67
12-21-50	1.0	4250	1.0	< 5	> 99.88
12-21-50	1.0	33000	1.0	8	99.97
12-21-50	0.5	9750	1.5	< 5	> 99.98
12-22-50	0.5	6000	3.0	< 5	> 99.98
12-22-50	0.5	135	3.0	< 5	> 99.39

In this efficiency range, with only approximately one part in 10,000 passing the filter it is quite difficult to obtain definitive efficiency values. Even with the expedient of using different flow ratios through the two monitors it is difficult to obtain a set of monitoring filters for which the upstream sample is not too "hot" or the downstream sample too "cold" for accurate activity readings. Consequently, a majority of the efficiency determinations can be expressed only as "greater than" values. The data demonstrate, however, that the efficiency of the Fiberglas bed is greater than 99.9 per cent and probably near 99.99 per cent. The efficiency values obtained agree well with the calculated design figures.

The first filter units have been in operation for slightly less than two years. There have been no maintenance requirements nor has there been any change in operating characteristics.

EFFICIENCY OF REVERSE-JET FILTERS
ON URANIUM REFINING OPERATIONS

by

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Mallinckrodt Chemical Co.

INTRODUCTION

The efficiency of reverse-jet filters is a very interesting subject and is one on which it is difficult to gather reliable data on applications other than radioactive. Added to this complexity is the fact that for the most industrial applications, it makes little difference whether the collection efficiency is 99.9% or 99.99%, and therefore little efficiency data is forthcoming from users other than those handling radioactive materials.

In considering the data presented here, it should be kept in mind that the plant from which it originates is primarily a high-volume production unit, not a laboratory or research unit. Although the control of dust in the plant and the proper and efficient collection of that dust are of prime importance, there is little "research time" available for investigations on the fine points of control systems that are doing a satisfactory job. Thus investigations which were started, or begun on a pilot basis, sometimes have not yet been carried through to completion, and one finds places in the data where there are more questions than there are answers. Nevertheless, much data gathered here is invaluable because it represents actual production operation conditions, and could not be duplicated on a research basis without excessive expense. At

least, it indicates trends and provides a basis for further work and thought on the part of those interested in this question.

The statement is frequently made, and is in conformance with filtration theory, that the higher the flow rate through a filter, the lower the efficiency will be for the small particles (1.0 or 0.5 micron and less) which are trapped by diffusional and electrostatic forces rather than screening or impingement. This statement, to the best of our knowledge, is true, but it applies only to a given filter medium. It may not be true, in a quantitative sense, for one filter medium as compared with another. One factor deserving consideration is the fact that the chance of entrapment of a particle due to the random process of diffusion is proportional to the surface area of the filter fibers. Thus small fibers comprising a thick, dense filter medium of high specific surface (such as wool felt) will aid in collection of small particles by the mechanism of diffusion, and will permit higher gas velocities than could otherwise be tolerated.

Quite a variety of dense filters of various special and synthetic fibers have been made, which give quite exceptional efficiencies and which usually operate at low flow rates. The reverse-jet filter is to date, as far as we know, the only mechanism permitting the use of such a dense, fine-fibered filter on heavy dust loads where it is necessary to maintain the porosity of the filter, instead of throwing the filter away when it is plugged.

METHODS AND PROCEDURES

All effluent stack samples were taken by means of an isokinetic sampling head, usually at flow rates between 0.5 and 1.0 cfm, using Whatman No. 41 filter paper. Samples obtained were counted either in parallel plate alpha counters or in scintillation counters. With a few rare exceptions, at least three and frequently many more samples were taken, covering an appreciable operating period on the order of eight to twenty-four hours.

The amount of dust entering the filter was determined by weighing the collected dust. Where indicated, chemical analyses were performed on the collected dust to determine the Uranium content (or content of other alpha emitters), and the assumption was made that the effluent dust was of the same percentage composition as the entering dust. With few exceptions, this should be a fairly safe assumption for the products and processes involved. Thus the reported effluent concentration figures are calculated on the basis of total dust by weight from alpha activity determinations.

DISCUSSION OF RESULTS

The summary of test results reported on units in this study is tabulated in Table 1. It will be noted from the Performance Data columns that almost all of these units are operating under industrial, rather than laboratory, conditions. Effluent concentrations range from the order of 7×10^{-4} to 2×10^{-8} grains per cubic foot. Some of the lower concentrations are based on non-typical operations, or on

a few number of samples; accordingly the average, with units 5a and 6 omitted, is 2.0×10^{-4} grains per cubic foot. Some of the values for Unit No. 7 have been omitted, for reasons that will be discussed. Average efficiency, on this basis, is 0.0135% passed, 99.986% retained.

Unit No. 7 in Table 1 is one duty that has been very troublesome. The dust which it is handling is known in the slang of the reverse-jet filter as a "seeper." In field experience with approximately 1000 reverse-jet filters on industrial applications, about a half-dozen "seepers" have been encountered. After considerable experimentation, the troubles with this unit were cured, or at least minimized, by the use of HCE-treated felt. From one point of view, the difficulties with Unit No. 7 in Table 1 is one duty that has been very troublesome. probably hold true for the general application are easier to determine on this Unit. The fact that the dust is a "seeper" gives larger effluent concentrations, and this plus the fact that the dust is radioactive makes effluent concentrations easier to assess.

Table II presents a history of the efficiency tests on Unit No. 7. It will be noted that with plain felt, collection efficiencies were on the order of 99.2%, and this was regarded as unsatisfactory. The average of all efficiency tests using resin treated and HCE felt was 99.946% as shown in Table 1 previously. Figure 1 shows a chronological plot of the history of Unit No. 7. Points labelled A and B are seriously questioned, although what back-checks are possible on the original data reveal no apparent error.

Sections of Figure 1, expanded, are plotted in Figure 2. For the resin-treated felt, 5 points form an almost perfect straight line when the time scale is logarithmic; and for HCE felt, 4 points form the same type of straight line. The resin-treated felt data covers a service period of from 1 to 20 days, and the HCE from 10 to 200 days. Since the lines have approximately the same slope, the increment in effluent concentration per day is approximately ten times greater for the resin-treated than for the HCE felt.

The straight lines obtained are very impressive when it is remembered that these various samples were taken over a year apart and by different persons; and that each point represents from 3 to 14 samples, over periods of 6 to 10 hours total sampling time for each point. Thus it is apparent why points A and B are puzzling; surely they cannot be the fault of randomness of the data. On the other hand, no other apparent factors affecting these results were observed, or at least recorded, and the answer is probably lost in history.

During the course of the experimenting with Unit No. 7, the data shown in Figure 3 were obtained. It is reasonable to assume that undisturbed felt should be a more efficient filter medium than felt which is "worked," by the blow-rings in order to maintain porosity. Although the notation in the figure shows blow-ring operation "normal" at the beginning of the test, this is open to question, as the data would suggest that the blow-rings were operating continuously rather than on pressure-switch actuation as would be really "normal." The ratio of the last two points on the curve is about 45/1 greater for continuous blow-

ring operation than for non-operation. Presumably the same type of effect, although lesser in magnitude, would be noted with any dust.

SUMMARY

In the Uranium refining operations reported, the overall average effluent concentration from reverse-jet filters is 0.16 grains per 1000 cubic feet, representing 0.0135% passed or 99.986% retained.

One dust was found to be a "seeper", and as the result of experiment HCE felt is now being used on this filter. Detailed testing showed that effluent concentrations apparently first decrease, then increase in a logarithmic fashion with respect to time. The rate of increase in effluent for resin-treated felt was about 10 times that for HCE felt.

On the basis of a single series of tests, effluent concentrations were found to be as high as 45 times greater with continuous blow-ring operation than with no blow-ring operation. This effect is magnified in this instance but the same type of relationship probably is true for any dust. Thus it is postulated that pressure control operation should be more efficient than continuous operation, but there is no data to substantiate this point.

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TABLE I
SUMMARY OF TEST RESULTS

UNIT	PERFORMANCE				EFFICIENCY							
	DUTY	FILTER RATIO CFM PER SQ. FT.	DIFF. PRESS INCHES W.G.	INPUT GRAINS PER CU. FT.	NO. SAMPLES	TOTAL SAMPLING TIME MINUTES	EFFLUENT GRS. PER 1000 CU. FT.			% PASSED	% RETAINED	REMARKS
							MIN.	MAX.	AVG.			
No. 1	LF-9 HANDLING	16.2	3-4	0.389	5	407	0.00277	0.0817	0.0380	0.00978	99.9902	LF-9 Basis
No. 2	QM-2 HANDLING	20.5	3-4	0.202	5	405	0.0161	0.0705	0.0469	0.0232	99.9768	QM-2 Basis
No. 3	(a) Q-11 and Other Feeds	34.2	6-7	1.89	11	325	0.023	0.735	0.286	0.0146	99.9854	Alpha Activity Basis- Actual Analysis
No. 3	(b) Q-11	27.7	6-7	32.4	2	20	0.200	0.622	0.411	0.00127	99.9987	Alpha Activity Basis- Theoretical Equilibrium
No. 4	QM-2 Final Fil- ter Pneu. Conveyor	17.2	4-10	14.0*	7	321	0.294	0.645	0.380	0.00272	99.9973	QM-2 Basis
No. 5	(a) D22	18.3	3-4	0.00425	1	1440	--	--	17×10^{-6}	0.0004	99.9996	D22 Basis
No. 5	(b) D22	16.0	3-4	0.0456	6	360	0.00326	0.0415	0.0234	0.0515	99.9485	D22 Basis
No. 6	D22	17.5	3-4	0.0021	1	1425	--	--	0.0001	0.0048	99.9952	D22 Basis
No. 7	D20	21.3	3-4	0.418	63	12 Tests over 18 Mo.	0.0498	0.876	0.226	0.054	99.946	D20 Basis

AVERAGE 0.16 0.0135 99.986

AVERAGE, 5A & 6 EXCLUDED 0.20 -- --

WASH-149

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TABLE II

HISTORY OF UNIT NO. 7

DATE	BAG TYPE	DAYS SERVICE (AVG.)	CFM PER SQ. FT.	ΔP INCHES W.G.	LOADING GRS/CU. FT.	EFFLUENT GRS/1000 CU. FT.	EFFICIENCY %	NO. SAMPLES
10/18/50	Plain	110	19.6	2.5-3.5	0.355	2.63	99.259	8
4/19/51	Type D	123	19.6	2.5-3.5	0.352	2.44	99.305	9
5/7/51	Resin	1	19.7	2.0	0.345	0.100	99.971	2
5/8/51	"	2	"	"	0.350	0.199	99.943	6
5/9/51	"	3	"	"	0.354	0.219	99.938	5
5/18/51	"	11	"	"	0.350	0.411	99.883	7
6/1/51	"	23	21.7	2.5-3.5	0.355	0.495	99.860	8
6/5/51	"	26	21.7	"	0.352	0.216	99.939	7
9/6/51	HCE	12	19.8	2.5-3.5	0.861	0.0498	99.994	4
9/27/51	"	20	"	"	0.500	0.109	99.978	3
9/28/51	"	21	"	"	0.391	0.102	99.974	3
2/20/52	"	158	20.3	2.5-3.5	0.463	0.372	99.920	3
8/27/52	"	5	26.2	3.0-4.0	0.316	0.080	99.975	14
9/ 5/52	"	10	22.9	3.0-4.0	0.327	0.050	99.982	5

Fig. 1 — History of efficiency tests on unit no. 7.

Fig. 2 — Variation of effluent with length of bag service for unit no. 7.

Fig. 3 — Variation of effluent with blow ring operation, unit no. 7 with plain felt.

REMOVAL OF BACTERIA AND BACTERIOPHAGE FROM THE AIR
BY GLASS FIBER FILTERS

by

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Demands are increasing steadily for highly effective air filtration systems in research laboratories where air must always be relatively free of biological organisms.

High speed photography as well as air sampling has shown that common operations such as pipetting, pouring, and vigorous agitation of tubes containing fluid cultures of bacteria often produce bacterial contamination of the surrounding air and nearby surfaces. Mixing broth cultures with a pipette by alternate suction and blowing, making microscopic slide agglutination tests, autopsy of infected animals, and other bacteriological manipulations also release bacterial aerosols. A survey of laboratory acquired infections in the United States reported in 1951 by Sulkin and Pike (1) tabulates a total of 1,334 infections presumably acquired in the laboratory.

The purpose of the present investigation was to determine the effectiveness of glass fiber filters in removing bacteria and viruses from the air. Advantages of spun glass air filter pads are that they (1) can be decontaminated economically by heat, (2) do not disintegrate when moist, and (3) have a low resistance to air flow.

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The initial studies were conducted on 3 types of commercially available spun glass filter pads. The test organisms used were Serratia indica and Escherichia coli T-3 bacteriophage. S indica is a harmless small bacterial organism about 1 micron in length and one-half micron in thickness. E coli T-3 bacteriophage is also a harmless virus organism, somewhat spherical in shape, which ranges in size from 0.02 to 0.05 microns.

The three types of spun glass material initially tested possessed the nomenclature of 25, 50, and 100 FG: Number 25 FG had a pad thickness of one-half inch and a fiber diameter of 2.75 microns; Number 50 FG was 0.5 inch thick and had a fiber diameter of 1.25 microns; Number 100 FG was 1 inch thick and had a fiber diameter of 2.75 microns. Respective pad resistances to air flow at 20 fpm were 0.12, 0.48, and 0.22 inches of water (Figure 1).

The spun glass pads were installed in a filter unit containing wedge shaped pockets supported in a grid type frame. Each frame could hold one to five pockets. In the standard type frame holding 5 pockets, the total net filtering area was approximately 50 sq. ft. and the normal capacity was 1000 cfm. The pockets were so designed that filtering material from one-half inch to one inch in depth could be placed in them (Figure 2).

Initial tests were conducted on a surface area of 20 sq. ft. with an air volume of 400 cfm, equivalent to 20 fpm through the filter. After the data were assembled and analyzed, it was decided to test a larger filter with a capacity of 2,800 cfm at the same linear flow of 20 fpm. Unless otherwise noted, results refer to the 400 cfm filter.

A Chicago type nebulizer (2) was used to create the aerosol. Biological material from this nebulizer is not always unicellular, because agglomeration of organisms may occur during or after release of the aerosol.

Figure 3 shows the method of air sampling used to determine the bacterial efficiency of the filters. Two sieve type air samplers were placed in the duct work before the filter and two after it. The concentration of organisms before the filter was so adjusted that there were 85 to 240 organisms per cu ft of air. This low concentration was used to approximate the order of magnitude of bacteria in the air under the actual conditions encountered in schools and hospitals, where counts of 23 per cu ft have been reported. Air was drawn through each sampler for three minutes at the rate of 1 cfm. The organisms entering the sieve sampler were impinged on a growth medium of corn steep agar. After incubation at a temperature of 30°C (86°F) for 24 hours, the bacterial colonies were counted. The efficiency of the filter was calculated by comparing the bacterial count of the air before and after filtration. In addition to using low concentrations of S. indica, the filters were tested with much higher concentrations through the use of a cloud of bacteriophage having an average count of 3.1×10^6 particles per cu ft.

The results are summarized in Figures 4 and 5.

1. The bacterial arrestance of the 25 FG material varied from 23 to 90 per cent. The average bacterial efficiency was 60 per cent for 23 tests.

2. The arrestance of the 50 FG material was much higher. With the 400 cfm filter and a single half-inch layer of spun glass, the range of efficiency in 20 tests was 88 to 97 per cent, with an average of 94.

When two layers of spun glass were used, the efficiency in 14 tests was 93 to 100 per cent, with an average of 97 per cent. These results indicate considerable variation. Later work indicated that higher and more consistent efficiencies can be expected. The greater early variation

was caused by poor sealing of the filters in the filter frames.

With the 2,800 cfm filter (Figure 5) and a single layer of 50 FG spun glass, the average efficiency in 45 tests was 99 per cent; with a double layer, it was also 99.

3. The 100 FG material was 73 to 88 per cent effective, and the average of 10 tests on the 400 cfm filter was 81 per cent (Figure 4). With the 2,800 cfm filter, the average arrestance was 89 per cent for 44 tests (Figure 5).

The 2,800 cfm filter had a higher efficiency in removing bacteria than the 400 cfm unit, but this variation likewise is attributed to the poorer sealing of the filter in the original 400 cfm filter frame.

FILTRATION OF BACTERIOPHAGE

Viruses are much smaller than bacteria. E coli T-3 bacteriophage virus was used in these studies, which ranges in size from .02 microns to 0.05 microns. The quantitative assay of bacteriophage particles recovered was determined by the plaque count method. Three types of air samplers were used. These were: (1) liquid impingers in which air was passed through a suitable collecting liquid, (2) sieve samplers with a solid growth medium as previously described, and (3) sieve samplers which used a liquid growth medium.

In each test, samplers were placed directly in front of and also behind the spun glass filter being tested.

A suspension of 1.8×10^8 to 7.5×10^9 bacteriophage particles per cubic centimeter of liquid was atomized from a nebulizer. This produced

a concentration of 3.1×10^6 particles of bacteriophage per cu ft of air in front of the filter. Samples of air were taken before and after the air entered the filter.

Results of counting the bacteriophage particles collected by the air samplers are shown in Figures 5 and 6. The work summarized in Figure 5 represents a 2,800 cfm filter, while Figure 6 represents the results of initial tests on a 400 cfm filter. The 25 FG spun glass filter had an efficiency of only 30 to 38 per cent. One layer of 50 FG spun glass removed 98 to 99 per cent of the organisms, while two layers removed 99 per cent. The 100 FG material rated about 90 per cent.

These studies show that it is possible to set up a spun glass air filtration system having a bacterial and viral filtration efficiency of 99 per cent.

In addition to the use of spun glass as filter material for building ventilation systems, tests were conducted to determine its practicability for use as a filter for bacteriological cabinets, animal cages and shaking machine containers. The readily available supply of spun glass, the low pressure drop across the filter pad, low cost, and the ease with which the spun glass can be installed in a filter frame suggested its use for such laboratory equipment.

A practical compactly arranged spun glass filter unit having a capacity up to 300 cfm and an overall resistance of 2 inches of water was designed, developed and tested (Figure 7). The unit is about 2-1/4 by 3-1/4 ft by 8 inches in size. The results of tests on this filter compared favorably with the original data collected. The weighted average efficiency of the filter for an average S indica concentration of 350 organisms per cu ft

2-3

of air was 99.68 per cent, while for a concentration of 69,650 organisms per cu ft the filter efficiency was 99.95. Concentrations of phage particles varying from 30,870 to 298,000 per cu ft of air were removed with an efficiency of 99.74 per cent. It is believed that these efficiencies are sufficient to permit use of this filter in all situations in which air containing minor aerosols incidental to common laboratory techniques is to be filtered and discharged to the air outside a building.

Consideration also had to be given to protective measures required in changing the spun glass filter pads. To avoid exposure of personnel to the contaminated filter, it was desirable to decontaminate the filter in place. Accordingly, the filter unit was designed with strip heaters capable of heating the interior of the filter cabinet to more than 200°C.

Time and temperature studies showed that after the interior of the filter reached 200°C, an exposure of 20 minutes was sufficient to destroy Bacillus globigii spores.

USE OF SPUN GLASS IN ANIMAL CAGES

It has been reported in the literature that some pathogenic organisms can be isolated from the feces and urine of infected animals. This would indicate the possibility of airborne infection from animal cages. One way to minimize this danger is to ventilate cages in such a manner that the air is filtered as it enters and leaves. Use of a filter serves several purposes: (1) it protects personnel in the animal room; (2) it lowers the possibility of cross contamination between cages; and (3) in the event of a failure of the mechanical air supply system, contaminated air does not

escape but the animals still receive enough circulation of air through the filters to prevent suffocation. The filter for incoming air consists of a bored rubber stopper with a grooved section into which are fitted a true arc inside retaining ring, a 32 mesh screen, two layers of spun glass, a second 32 mesh screen, and a second true arc ring. (Figure 8) This preliminary model now is under further development. The arrangement provides a tight fit which prevents leakage of organisms between the spun glass and the sides of the rubber stopper. The air leaving the cage may pass through a similar filter or be piped to a larger filter unit.

USE OF SPUN GLASS IN A SHAKING MACHINE

The breakage of cultured flasks on a mechanical shaker is a problem which becomes a hazard in laboratories working with pathogenic agents. Loss of plugs from the culture flasks being shaken has also been reported. The possibility of accidentally dropping a flask during transfer to or from the shaker must not be overlooked. To avoid the danger in these possibilities, a shaking machine container has been constructed, which completely encloses the flask yet provides sufficient air through the spun glass filter for satisfactory bacterial growth (Figures 9 and 10).

The shaking machine container is cylindrical and equipped with a spring device which securely holds a 250 or 500 ml flask in place. The head is made of pyrex glass and aluminum. A circular opening in the center of the head houses a spun glass filter held in position by pyrex glass secured in a groove with a true arc retaining ring. Several tests were conducted to determine whether inclosure of a culture flask would affect the growth rate of bacteria. All results indicated that there was no effect upon the growth rate of the bacteria.

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NEW DEVELOPMENTS IN FILTER MATERIAL

In the past, a commercially available asbestos and cellulose paper filter has been used. This filter is easily combustible and disintegrates when exposed to water or air saturated with moisture for any considerable time. To overcome these difficulties, several research laboratories and paper mills are developing a glass paper that will be equivalent or better than present air filter papers. One such glass paper possessing glass fibers between 0.2 and 1.5 microns in diameter has been produced commercially by a paper mill and is undergoing adaptation to non-combustible frames. Preliminary tests in our laboratories of the filter material with bacteria showed penetration of 0.01 to 0.001 per cent with most of the data falling near 0.001 per cent. It is evident that it is only a matter of months until there will be available a paper-thin noncombustible filter which is not affected by moisture or chemicals. The glass paper filter will have an efficiency equivalent to or better than that of asbestos paper filters.

It is encouraging to witness the rapid progress that is being made in research laboratories throughout the country as well as by industry in developing high efficiency filters.

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	NO. 100 FG	NO. 50 FG	NO. 25 FG
THICKNESS	1"	0.5"	0.5"
FIBER DIA.	2.75	1.25	2.75

Fig. 1—Spun glass filter material.

Deep bed filter unit—air-entering side—showing spring latches that hold pockets securely in frame against heavy sponge rubber seals to prevent air leakage.

Fig. 2—Spun glass air filter unit front view.

Fig. 3—Air filtration test unit.

Fig. 4—Comparison of average arrestances when removing serratia indica with spun glass filters (400 cfm filter).

Fig. 5—Comparison of average arrestances obtained in removing serratia indica and E. coli bacteriophage T-3 with spun glass filters (2800 cfm filter).

TYPE OF FILTER	NUMBER OF TESTS	EFFICIENCY-%	
		TESTED BY LIQUID IMPINGER	TESTED BY SIEVE SAMPLER
25-FG SPUN GLASS	1	30	38
50-FG SPUN GLASS	1	98	99
50-FG + 50-FG	1	99	99
100-FG SPUN GLASS	1	90	90

Fig. 6—Approximate efficiency of various filters removing E. coli bacteriophage T-3 from the air.

Fig. 7—Air filter for bacteriological safety cabinets.

Fig. 8—Mechanically ventilated animal cage.

Fig. 9—Shaking machine container.

Fig. 10—Container with spun glass air inlet for shaking machine flasks.

DEEP-BED SAND AND GLASS-FIBER FILTERS

by

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Introduction

Filters employed for removing small amounts of radioactive particles from large volumes of gas may be classified into two types, thin-bed and deep-bed filters. Thin-bed filters comprise units employing such filter media as paper (e.g., CWS, Type 6 or AEC, Type 1), wool felt (as used in the Hersey cloth collectors), and thin glass mats (e.g. AAF Type 50, Fiberglas Type AA). Deep-bed filters on the other hand, involve packings of granular (sand or coke) or fibrous materials (such as "Fiberglas") that are up to several feet deep. In this service, the total aerosol concentration is usually on the order of or less than normal atmospheric dust concentrations.

Both types of units have a so-called "life," which is reached when so, "much dust has accumulated in the filter medium that the resistance of the medium to air flow is increasing rapidly. The filter medium must then be cleaned or replaced. It is in this connection that the distinction between thin-bed or "paper" filters and deep-bed filters is closely related to a philosophy of application in decontamination of radioactive aerosols. With the thin-bed filters, the intent is usually to replace or clean the filter medium periodically. The deep-bed filter, on the other hand, usually has as its objective the installation of a unit which will have a long

"life," in the dust capacity sense, of say five to twenty years, corresponding to either the life of the process or the mechanical life of the system. Thus, when the resistance starts increasing rapidly, the entire filter installation will be abandoned and replaced with a new unit rather than replacing or cleaning the filter medium.

The above distinction is rather arbitrary and applies to the types of units as now used. For example, the paper filters could be installed on an abandonment basis by providing enough filter area so that the "life" would be of the same magnitude as for the deep-bed types.* On the other hand, deep-bed filters could be operated at higher capacities and the medium replaced at intervals. There would, however, be no practical objective in this, since the primary advantage of deep-bed units is that they can be made maintenance-free.

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*This is in fact, a potential unexplored manner of using paper filters. The current design velocity for many of these "high efficiency" papers, such as C.W.S. Type 6, is 5 ft./min.. At these medium velocities a "life" of on the order of 1 to 3 years is experienced. The writer feels that, by going to medium velocities in the range of 0.3 to 1 ft./min., there is a very definite potential of obtaining a more economical installation from the standpoint of total annual cost. While the first cost might be somewhat higher than in current design practice, the unit should be maintenance free. In this reduced range of velocity, the paper filters might be competitive or economically superior to deep-bed filters, which have as their only justification the fact that they are maintenance-free. Before such potentials can be evaluated, however, further data are required on the "life" characteristics of paper filters at the reduced velocities.

It is the purpose of this paper to present the various practical and economic aspects involved in the design and application of deep-bed filters for the decontamination of radioactive aerosols.

Development of Deep-Bed Filters

Deep-bed aerosol filters have been used for many years in industry in the form of so-called coke beds. These employ a packing several feet deep consisting of graded-coke ranging from 1/2-in. to 40 mesh on size. They are employed at superficial bed velocities in the range of 1 to 10 ft./min. to remove sulfuric acid mist from burner gases in contact sulfuric acid systems.

In 1948 a high activity level was detected at Hanford and traced to particulates from the chemical processing ventilation stacks. Because of the urgency of the problem, it was decided, on the basis of theoretical predictions plus the precedent of the coke filters, that a deep-bed sand filter would offer the most expedient means for eliminating this particulate contamination. While it was recognized at this time that filters employing a fibrous medium would probably have a greater merit from the standpoint of economics, it was felt that the time required for the necessary development work would be considerably in excess of that required for the sand filters. This time factor was the main basis for the selection of a sand filter for this application. It took only 3-1/2 months from start of experimental work to prove theoretical predictions of sand filter performance to the time that the first large-scale unit was in operation. All the experimental evaluations, design, procurement, and construction of the full scale unit were carried out in this period.

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Since that time, further work has been carried out, especially at Hanford, to develop more complete information on the performance characteristics of deep-bed filters with emphasis on fibrous media.

Principles of Operation

When an aerosol is passed through a packing, the suspended particles are caused to deposit on the surface of the packing by one of a number of mechanisms: 1) by direct interception of the aerosol particle due to its size; 2) by interception of the particle due to its inertia; 3) by diffusional or Brownian migration; 4) by gravity settling; 5) by electrostatic attraction; and 6) by migration due to a thermal gradient. In the applications under consideration here, there is substantially no thermal gradient and, to date, there has been no positive evidence that any electrostatic effects are involved.

In sand filters which normally operate at superficial velocities of 5 to 10 ft./min. and employ granules graded from as large as 2-in. diameter down to 40 mesh, the deposition mechanisms are primarily those of diffusion and gravity settling. Collection efficiency increases appreciably as superficial velocity is reduced. With fibrous filters, on the other hand, interception, both direct and inertial, may be a controlling factor, depending on the size of the fiber relative to that of the aerosol particle. Beds of coarse fibers, larger than 100 microns in diameter, normally operate at superficial velocities in excess of 30 ft./min. and generally show improved collection efficiency as the velocity is increased. Beds of fine fibers are usually operated at velocities of 5 to 50 ft./min. and show a reduction in efficiency as velocity is increased. These ef-

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fects of velocity on efficiency reflect the predominant deposition mechanism in each case.

While a detailed discussion of deposition and build-up in packed beds is beyond the scope of this paper, it should be noted that most deep-bed filters are made up of a grading of sand or fiber sizes. This is done because of structural considerations in the case of sand filters but, more importantly, for increased life in the case of both sand and fibrous filters. The aerosol will deposit throughout the depth of a given layer of the filter, but the amount deposited will be the greatest at the upstream face, becoming gradually less toward the downstream face. The greater the collection efficiency of any single layer, the greater will be the concentration of deposit on the upstream end and the shorter the filter life. A coarser layer used ahead of a fine layer will remove the coarser aerosol particles and minimize the extent of aerosol concentration at the upstream edge of the fine layer. Since accumulation of deposit in the coarser layer will have less effect on resistance than it would in the fine layer, this will serve to increase filter life. Needless to say, for every aerosol particle-size distribution there is an optimum fiber or sand-size distribution from the standpoint of filter life. At the present time, however, the fundamentals of deposition and resistance build-up are not sufficiently developed to permit direct specification of these optimum distributions. Also, in most applications, the aerosol size distribution is not known well enough to permit the use of the fundamentals if they were available.

Design of Deep-Bed Filters

The factors that must be considered in the design of a deep-bed filter are collection efficiency or penetration, pressure drop, filter size, filter life, and available packing media. Fundamentally, the most important design specification should be the maximum tolerable activity level in the exhaust gases from the filter. In practice, however, this has been a secondary consideration. In many cases, especially in new installations, neither the quantity nor the particle size of particulate activity in the gas stream is known. Even if these were known, the tolerable concentrations have not been established in most cases. Thus, in the absence of such information, what has actually taken place in practice is to provide as high a degree of clean-up as is reasonably possible. Unfortunately, in a number of cases, the degree of clean-up that has been achieved in one application has been taken as a criterion for all other similar applications without re-analysis in terms of the specific conditions involved in these applications.

Pressure drop across a filter is controlled by the design of the filter and the amount of air passed through it. The pressure drop for which a unit is designed is determined by essentially two considerations. First, the pressure drop must not exceed that which ordinary commercial fans can develop. This sets an upper limit on pressure drop of 30 to 50 in. water without getting into multi-stage fans. More important, however, are the conditions imposed by straight economic considerations. The economics of a filter installation may, according to one system of accounting, be measured by the total annual operating cost. This operating cost may be considered in three parts: 1) power costs, which are directly related to pressure drop; 2) those fixed charges, such as

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maintenance and earning power of the funds invested, which are directly related to the investment cost; and 3) depreciation, which is related to the investment cost and to the life of the filter. Considering a given type of filter and packing arrangement and a given air handling capacity, a high air velocity through the packing will mean a high pressure drop, a small unit, and a short filter life. The effect of air velocity on total annual operating cost and on the components thereof is shown diagrammatically in Figure 1. It is apparent that there exists an optimum velocity at which the total annual cost is a minimum. This is the velocity for which the filter should be designed. Unfortunately sufficient information is not available on the life characteristics of such filters to evaluate this optimum velocity accurately. For the conditions at which deep-bed filters have been used, this optimum velocity is probably in the range of 5 to 10 ft./min. for the sand filters and 15 to 30 ft./min. for the fibrous type. Actual designs have been based on 6 and 25 ft./min. for sand and fibrous filters, respectively, with a corresponding pressure drop in the range of 4 to 8 in. water for both types. It would probably be more economical to operate at higher velocities and pressure drops but this could not be considered until a more complete knowledge of filter life is developed. It should be noted that the optimum velocity is dependent on both the aerosol size and concentration. A finer aerosol and a higher aerosol concentration would probably call for a lower optimum velocity with a given type of packing arrangement. It should also be noted that the relatively simple economic picture given above, in which a given type of packing arrangement is considered at different velocities, becomes considerably more complicated when, in addition, an attempt is

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made to arrive at an optimum packing arrangement for a given application. In this connection, the actual degree of clean-up required should have little effect on the optimum design velocity although a higher degree of clean-up will increase the total annual operating cost. The higher degree of clean-up would usually be obtained by additional depths of fine sand or fiber with a corresponding increase in pressure drop.

The filter area is, of course, determined by the air handling capacity and the superficial velocity. The filter depth is usually determined by the collection efficiency required. Deep-bed filters are inherently relatively large units. Most units to date have been of the horizontal type with gas flowing up through the packing. This results in a large floor-space or area requirement. While such units could be built in other arrangements to conserve on floor space, this normally increases the initial cost.

The filter life, as mentioned previously, is determined by the aerosol concentration and the packing grading as related to the aerosol size distribution. From the standpoint of maximum filter life it would be desirable to have a continuous graded packing, with the coarsest material at the upstream end and becoming continuously finer toward the downstream end. In all cases the maximum life would correspond to the most porous packing. In the case of sand, bed porosity is essentially fixed since it can be varied over only a small range. With fibrous packings, however, porosity can be varied over as much as a ten-fold range. From the standpoint of filter depth, however, it is desirable to maintain as high a porosity as possible. With fibrous packing, therefore, the actual porosity employed in any layer should be the maximum consistent with long filter life.

While an ideal packing would be continuously graded, in practice we are limited to a relatively narrow range of available sizes and densities. In addition the fundamentals of pressure build-up in packings due to dust deposition have not been developed to a point where they may be employed quantitatively; nor are the operating data on aerosol concentration and size distribution, necessary for any such application of fundamentals, usually available. Consequently, all packing arrangements to date have been somewhat arbitrary, governed primarily by available materials. With granular materials, such as sand, the limitations are imposed by the sizes available in quantity in the specific geographic area. In the case of fibrous materials, we are limited to the range of materials currently manufactured as standard products. Any attempt at specifying special sizes or materials will usually result in a marked increase in cost. The packings have been made by using layers of successively finer material, with the coarsest at the upstream end. In the case of sand, the successive layers have differed in nominal size by a factor of approximately two. In the case of glass fiber, the successive layers also vary in nominal size by a factor of two. As an alternate to a variation in size, however, a variation in packing density by a factor of two has also been used, with the more open packing at the upstream end. In most of the units to date, the gas flow has been up through the packing because of the possible presence of condensate or entrained liquid. In this way the liquid drops will first meet and be removed by the coarsest packing at the bottom or inlet end. If down-flow were used, without other special arrangements, all the liquid would eventually reach the fine packing and cause a marked increase in resistance to air flow.

It should be apparent from the above that the overall design of a deep-bed filter involves a balance of a large number of items. Because of a lack of both fundamental and operating information and various practical limitations, it is not yet possible to provide a rigorous design for a specific application. Instead it has been necessary to resort to engineering judgement to balance the various factors and thereby to arrive at reasonable designs. The final choice of type of deep-bed filter, sand or fibrous, rests purely on economics, aside from special considerations in some applications. While this paper deals solely with the deep-bed filter, it should be noted that, in any actual design comparison, the thin-bed filter should be included. In most cases, any one of these units, a deep-bed sand filter, a deep-bed fibrous filter, or a thin-bed or paper filter, can be designed to do a given job. The one that involves the lowest total annual operating cost is the unit to use.

Cost and Performance of Deep-Bed Filters

Cost and performance data on deep-bed filters are relatively meager. In Table I are shown comparative data for both a sand filter and a glass-fiber filter designed to handle 35,000 cu. ft./min. of air. The sand filter contains 9-1/2 ft. of graded gravel and sand ranging in size from 3 in. down to 50 mesh, as indicated in detail in Table I. The successive layers of gravel and sand rest directly upon each other, all being supported by a ceramic tile air distribution system at the bottom. The fibrous filter contains a total depth of 3 ft. of graded glass-fiber layers as specified in detail in Table II. Since these layers were specified for a predetermined packing density, each layer was supported separately on a screen, with an additional screen above the layer of Type AA "Fiberglas." In both

the sand and the glass-fiber filter units, the filtering medium was horizontal with the air flowing vertically up through the medium. The filter size given in Table I is for the entire unit including, besides the filter housing proper, the inlet and outlet air manifolds, but not including the space occupied by lead-in or exhaust ductwork.

The cost estimates for the sand filter are based on actual construction costs of a comparable unit corrected to the specified capacity of 35,000 cu. ft./min. The cost data for the glass-fiber unit are estimates based on a specific design for this capacity. The performance data, pressure drop and collection efficiency, for the sand filter are based on field measurements made on a unit of almost identical design operated at the same velocity in an identical service. The performance data for the glass-fiber unit are estimated from the experimental results reported by Blasewitz et al ("Filtration of Radioactive Aerosols by Glass Fibers," Parts I and II, Hanford Works Report No. 20,847, April 16, 1951, unclassified) for a substantially identical service. The magnitude of the collection efficiency has also been checked by entirely separate tests made at Ohio State University on various types and densities of "Fiberglas," using a condensed dyestuff of the same order of particle size (0.4-micron diameter) as the radioactive aerosol.

At least one sand filter of the type indicated in Table I has now been in operation for a period of over 4 years with no indications of any build-up in pressure drop due to solids accumulation. It is safe to say that this unit will have a life in excess of 5 years in this service although its life may be over 20 years. There is no sound basis on which the actual life may be estimated more accurately. As to the glass-fiber filter, there is no large scale unit that has been in service long enough

to obtain any reliable life data. Based on the comparative experimental data obtained by Blasewitz et al, it is estimated that the glass-fiber filter should have a life of 2 to 3 times that of the sand filter in this service.

In Table I the cost data have been presented on the basis of \$/(cu. ft./min.) of air handled for convenience of generalization. The housing cost includes excavation, concrete structure, roofing, drains, painting, duct connections, etc.. For the sand filter this cost is \$3.86/(cu. ft./min.) whereas, it is only \$0.94/(cu. ft./min.) for the glass-fiber filter because of its much smaller size. The graded sand and gravel for the sand filter cost \$1.71/(cu. ft./min.) in place. This includes the cost of the distributor tile blocks, which constitute only a small fraction of this item. The glass-fiber filter medium cost \$0.76/(cu. ft./min.). However, with the designed involved here, the aluminum screen supports cost \$1.16/(cu. ft./min.) or 1-1/2 times as much as the filter medium. Thus, the total installed cost of the sand filter is \$5.57/(cu. ft./min.) as compared to \$2.86/(cu. ft./min.) for a glass-fiber unit of the specified design.

The cost data given in Table I for sand and fibrous filters are actually not directly comparable. They represent merely what information is currently available. For a true picture, it would be necessary to compare the cost of a sand filter having the same pressure drop, collection efficiency, and life as a fibrous unit. In the case of the glass-fiber unit for which data are given in Table I, the pressure drop is lower and both the collection efficiency and life higher than for the sand filter. To make the results comparable would mean to approximately halve the size of

the glass-fiber unit and also eliminate some of the finer fibers. On this basis, the cost comparison would be considerably more favorable for the glass-fiber unit than it already is. However, because of the meager information on filter life and the fact that considerably more data are available on large sand filter installations, it would be conservative to neglect these corrections for the present when using these data for design comparisons or decisions.

If stainless steel were used in place of aluminum for the screen supports, the cost for the glass-fiber filter would be increased approximately \$1/(cu. ft./min.). For many applications, it is felt that, considering the maximum quantity of acidic components that may be present in the air handled, ordinary steel would be adequate for the supports and thereby permit an appreciable reduction in cost of this item. However, noting the large cost associated with the supporting screens, it would seem logical to reconsider the design of the glass-fiber filter with the objective of eliminating this major item of expense. In the glass-fiber filter design referred to in Table I, a fixed density and a fixed depth was specified for each layer of the packing. In order to insure that the density would be maintained and not changed due to the compressive effects of the weight of fibers on top or because of the pressure drop through the unit, the intervening screen supports were required.

Both the data obtained at Hanford and those obtained at Ohio State University indicated that, for a given aerosol, a given superficial velocity, and a given fiber, the collection efficiency depends on the total weight of fiber in the packing, independent of the density of the packing. In other words, if a given filter pad is compressed, the effect

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on collection efficiency will be negligible in the range of densities involved in these filter units. It should be noted that, in considering this independence of collection efficiency on packing density, we are not considering the same depth of packing with different densities; we are considering the same weight of fiber at different densities, and hence a smaller depth of fiber is involved at the higher density. While collection efficiency depends only on the total weight of fiber, pressure drop will increase as the density increases. In the range of density involved, for a given weight of fiber, the pressure drop will vary approximately as the square root of bed density. Thus, compressing a given pad to half of its original thickness, will result in approximately a 40% increase in pressure drop.

In view of the above, it would seem that packing density is not a critical factor. In order to eliminate the need for the supporting screens, it is only necessary to distribute the fiber uniformly insofar as weight per unit of filter area is concerned since the actual packing density is not a critical factor. The density influences only pressure drop and is not too great a factor at that. Thus it should be possible to take layers of fiber and lay them in the filter bed, one on top of the other, covering the entire filter bed with a grid or gravel to compress the filter layers to some pre-determined average density.

In Table II are given proposed specifications for such a packing arrangement in which density of each layer is not controlled, together with a typical specification currently used at Hanford for a packing of controlled density. It will be noted that the total amount of fiber has been increased from 6.85 lb./sq. ft. of filter in the current specification to

18 lb./sq. ft. in the proposed specification, in addition to changes in the grades of fiber employed. The layers of Type 800 and 450 "Fiberglas" have been added to increase filter life. While these layers will remove only a small percentage of the total aerosol, say 10%, they will collect the coarser particles that may be present. Such large particles, if not removed, could materially reduce filter life by forming a so-called "interface block" at the upstream edge of the fine glass wool layers. It should be remembered in this connection that most of the available performance data on collection efficiency and life have come from operations at Hanford and, as such, apply only to the specific aerosol concentration and size distribution existing in the Hanford ventilation air. At another site the aerosol may be different. At the present time in the absence of actual comparative data, we can only assume that the aerosol in similar operations at other sites is of the same order of magnitude. However, a small amount of coarser aerosol particles at other sites could materially reduce the life of a filter below that experienced at Hanford.

In the proposed specification a deeper layer of Type 28 "Fiberglas" has been substituted for the current thin layer of Type AA in order to eliminate the problems of edge-sealing, puncturing of the medium, placement and chemical deterioration, associated with such a thin fragile layer of extremely fine fibers. The deep layer of Type 115K "Fiberglas" has been provided to give adequate protection to the layer of Type 28 from the standpoint of life.

While the proposed specification calls for considerably more filter medium than does the one in current use, a large portion of this is associated with the coarse layers of Types 800 and 450 for purposes of in-

creased filter life. While the cost of the filter medium will be greater; the over-all cost of the filter should be lower because of the simpler method of installation and the fact that the screen supports will not be required.

To design a unit with the proposed specifications given in Table II, it is necessary to have available information on the corresponding properties of fibers in order to be able to estimate the filter depth and pressure drop. Blasewitz et al give such data on Type 115K "Fiberglas" but no other such data are currently available. The depths on the proposed packing specifications given in parenthesis in Table II are purely arbitrary, in order to give an order of magnitude value. They are based on an assumed density of 3 lbs./cu. ft.. Actually this density will be different for each layer, dependent on the compressive properties of each layer and on the top grid or gravel location and arrangement.

When a pad of fine glass fibers is wetted with liquid, the resistance to air flow will mount rapidly and the fibers will tend to be matted together. This, as well as the possible deterioration of fine fibers by moisture and other chemicals, has been a question of no small concern in the use of fibrous filters. Unfortunately, there has been little practical experience to date with any large glass-fiber filters. There is in existence only one large installation and this is a relatively recent one. There is, however, a fair amount of background on smaller glass-fiber filters. Numerous such units with metallic housings are located on the tank-farm vents at Hanford. In the winter difficulty was experienced with condensation, with resultant high pressure build-up, presumably in the layer of Type AA "Fiberglas." When the unit was dried out by passing air through

it, the resistance returned to normal; the "Fiberglas" had not matted together and had not given any permanent increase in pressure drop. Since then, this condition has been avoided by heating the units in the winter. It should also be noted that condensation should not be a problem with large filters, especially those housed in concrete. Because of the small relative area for heat transfer and the high heat capacity of the packing itself, the amount of water vapor that is capable of condensing in such large units is negligible.

At Oak Ridge a glass-fiber filter on the dissolver off-gas vent system showed a large permanent increase in pressure drop. This unit, however, was operated at many times the gas-handling capacity for which it was originally designed. The resultant extremely high pressure drops coupled with probable large quantities of liquid or solid entrainment from the vessels preceding the filter has presumably resulted in a permanent compression of the bed. This is, however, an abnormal operating situation.

Reports emanating from Hanford indicated that, on one occasion, moisture accumulation in one of the large sand filters, due to an accidental discharge of a steam vent into the ventilation gases, had resulted in a marked increase in pressure drop. What actually happened was that some of the steam condensate had accumulated in the lines to the manometer used for measuring filter pressure drop. This caused the manometer to show a fallaciously high pressure drop. Actually the pressure drop across the sand filter had not increased as shown by the fact that the manometer reading returned to normal when the water was blown out of the lead lines.

While the above discussion had been limited primarily to sand and glass-fiber filters, the synthetic fibers (such as "Dynel," "Orlon,"

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"Saran," etc.) offer great promise for achieving more economical installations. Temperature considerations, of course, constitute limitations on the synthetics but in atmospheric installations synthetics may be less expensive than glass fibers. In filters, the controlling item is the cost of the fiber per cu. ft. of fiber. Since the density of the synthetics is roughly one-half that of glass, the cost of the synthetic fibers on a weight basis could be as much as twice that of the corresponding glass fibers and still be competitive.

Table I--Typical Deep-Bed Filter Data

	Filter Medium	
	Sand ^X	"Fiberglas" ^{XX}
Air handling capacity, cu. ft./min.	35,000	35,000
Filter Size (width x length x height), ft.	85 x 85 x 14	28 x 70 x 9
Filter Medium Velocity (superficial), ft./min.	6	25
Pressure Drop, in water	8	5
Collection Efficiency, % activity	99.7	99.99
Life	>5 years	>10 years [§]
Installed Cost, \$/(cu. ft./min.)		
Housing	\$3.86	\$0.94
Filter medium	1.71	
Supports		1.16 ^{§§}
Fibers		0.76
Total	\$5.57	\$2.86

[§]Estimated as 2 to 3 times that of sand filter

^{§§}For aluminum supports. This would be approximately twice as much for stainless steel.

^XFilter medium consisted of the following approximate depths and sizes of gravel or sand. These were supported on a molded ceramic distributor tile.

Depth of Layer, in. (In order, bottom layer listed first)	Sand or Gravel Size
12	1" to 3"
12	1/2" to 2"
12	1/2" to 4 U.S. mesh
12	4 to 8 U.S. mesh
24	8 to 20 U.S. mesh
36	20 to 50 U.S. mesh
6	4 to 8 U.S. mesh

^{XX}Filter medium consisted of the packing arrangement designated in Table II as "Typical Hanford Specification."

Table II--Typical Deep-Bed Glass-Fiber Packing Specifications§

"Fiberglas" ^X Number	Approx. Fiber Diameter, microns	Approx. Fiber Cost, §§ \$/lb.	Typical Hanford ^{XX} Specification			Proposed Specification	
			Depth in.	Density		Density lb./sq. ft.	Depth ^{\$\$\$} in.
				lb./cu. ft.	lb./sq. ft.		
800	200	0.80				3	(12)
450	110	0.80				3	(12)
115 K	30	2.00	18	1.5	2.25	6	(24)
115 K	30	2.00	6	3.0	1.5		
55 P	15	0.25	12	3.0	3.0	3	(12)
28	7	1.00				3	(12)
AA	1	4.00	1	1.2	0.1		
Total			37		6.85	18	(72)

§Designed for an activity collection efficiency of 99.99%. Pressure drop for Hanford specification is 5 in. water; for proposed specification it should be 4 in. $\pm$ 1 in. water, depending on degree of compression.

§§Approximate purchase cost as of June 1952.

§§§Will depend on degree of compression. Values given are for a 3-lb./cu. ft. density.

^XFiber layers listed in order, bottom or upstream end being specified first.

^{XX}Similar to that given by Blasewitz et al., "Filtration of Radioactive Aerosols by Glass Fibers," Part I, p. 121, Hanford Works Report No. 20,847, April 16, 1951, unclassified.

Fig. 1—Economic filter velocity.

PROPERTIES OF AEROSOLS

FOREWORD

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Many of the problems in the atomic energy program involve the handling of small particles. Some of the operations produce radioactive wastes in the form of dust, fume, and mist which would create hazards if considerable quantities were released in or near the installation. Much progress has been made in the methods of handling these materials to prevent contamination of the atmosphere, but there is still much more to be learned about the fundamental properties of finely divided material suspended in gases and the practical application of this field of science to industrial problems. The problem of waste disposal is not unique to the atomic energy industry. Many large industries must dispose of obnoxious gases and aerosols created in the course of their operations. This industry differs from others, however, in that permitted tolerances must be lower when the waste materials are radioactive. Careful monitoring must be maintained at all times to cope with accidental releases, and operations can be carried on only with the full realization of the effect of the meteorological conditions in the dispersion of stack gases.

The objective of the aerosol work at the University of Illinois is to make fundamental studies of the properties and behavior of aerosol particles and aerosol systems as they are related to practical problems in air pol-

lution and in air cleaning operations. The program was initiated June 1, 1949. A series of technical reports and publications have been issued on the progress of the work. Theoretical studies that have been completed include:

Calculation of the Size Distribution of Aerosol Particles from Tranquil and Stirred Settling Data. Technical Report No. 1, Serial No. SO-1000, April 30, 1950.

Effect of Temperature, Density, and Velocity of Gases on Dispersion from Stacks. Technical Report No. 2, Serial No. SO-1001, June 30, 1950.

Impaction of Aerosol Particles on Cylindrical and Spherical Collectors. Technical Report No. 3, Serial No. SO-1004, March 31, 1951.

Some Aspects of the Physical Behavior of Atmospheric Aerosols. Proc. Second Nat. Air Pollution Symposium, Pasadena, Calif., May 1952.

Five experimental programs have been completed and the results reported as follows:

Impaction of Dust and Smoke Particles on Surface and Body Collectors. Technical Report No. 3, Serial No. SO-1004, March 31, 1951; published in Ind. Eng. Chem. 44, No. 6 (June, 1952).

Jet Impactors for Determining the Particle Size Distributions of Aerosols. Technical Report No. 4, Serial No. SO-1005, July 31, 1951; published in Arch. Ind. Hyg. Occup. Med. 5, 464 (1952).

Collection of Aerosol Particles by Atomized Sprays. Technical Report No. 5, Serial No. SO-1006; October 31, 1951.

Thermal Force on an Aerosol Particle in a Temperature Gradient. Technical Report No. 6, Serial No. SO-1007, December 31, 1951; published in J. Applied Phys. 23, 917 (1952).

Homopolar Electrification of Aerosols. Technical Report No. 7, Serial No. SO-1008, September 30, 1952.

An annotated bibliography on aerosols containing 1936 references was issued as a report, Serial No. SO-1003, February 1951.

The three papers which follow represent progress reports on the current work. The report by H. F. Kraemer is included because this work is a part of the general program on aerosols although it is not being done on the contract. Much credit for the success of the work should be given to the graduate research assistants. Special acknowledgment is made of the contributions of Dr. William E. Ranz, who has helped direct the work on the contract and has made many outstanding contributions to the theory of aerosols.

HYGROSCOPIC AEROSOLS

by

G. R. Gillespie, Research Assistant

Aerosols, such as smoke, dusts, and fume, present important problems in industrial operations. In metallurgical processes, dusts and fumes are collected and recovered for economic reasons or for the protection of the health of the workers; in chemical manufacturing, waste gases containing injurious aerosols must be cleaned before discharge to the atmosphere.

Filters, scrubbers, cyclones, electrostatic precipitators and other devices are used for cleaning gases. Since hygroscopic aerosols often exist as droplets in the submicron range, their collection becomes difficult. For these, filtration through porous media, impaction at high velocities and agglomeration by means of sound waves have been used, in addition to electrostatic precipitation which has been standard in the past. The selection and design of these devices depend to a large extent on knowledge of the particle size distribution in the aerosol. It is seldom that such information is available. Even in the case of sulfuric acid mist, no accurate information exists on particle sizes, or on the effect of the operating conditions and the nature of the source.

Recently the high velocity jet impactor has been developed as a reliable and convenient instrument for measurement of the particle size distribution in non-homogeneous aerosols. This device was used to determine the effect of various factors on the distribution of droplet size in several hygroscopic aerosols. The mists were made under closely controlled conditions in the laboratory. Some data, which corroborate those obtained in

the laboratory, have been taken from measurements on stack gases from a commercial sulfuric acid plant.

Sulfuric Acid Aerosols

In the laboratory sulfuric acid aerosols were produced by reacting sulfur trioxide vapor with moist air to form sulfuric acid vapor which immediately condensed into small liquid droplets. A schematic diagram of the equipment used to carry out this reaction is shown in Figure 1. The concentration of the aerosol was varied from 0.05 to 2.9 grains per cubic foot, and the moisture content of the air was varied from 10 to 90 per cent relative humidity. After formation, the aerosol entered a horizontal lucite tube 14 feet long and tapered from 1 inch to 6 inches in diameter, in which it was allowed to age for a period of time up to five minutes. At various intervals along the tube were placed ports from which samples of the aerosol could be withdrawn through an impactor for particle size determination.

The four-stage cascade impactor used was patterned after that of Ranz and Wong (3) and was equipped with 12 interchangeable jets giving nearly any particle size cut desired between 0.2 and 3.0 microns diameter. At each stage the largest droplets were impacted in a glass cup, and the smaller droplets still entrained in the gas stream were carried to the following stage where the next largest size range of droplets was collected. The droplets not impacted in any of the four stages were collected in a three-stage glass wool filter train. Sampling was continued until a weighable quantity of acid was collected in the small cups at each stage. The concentration of the acid samples was determined by titration against standard base.

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From the data the weight fraction smaller than the characteristic diameter of each jet was calculated and the results expressed as a particle size distribution curve on log-probability paper. Representative plots for sulfuric acid aerosols of concentration of 1.2 and 0.3 grains per cubic foot are shown in Figures 2 and 3, respectively. On these graphs each line represents the particle size distribution of the aerosol at a given time after its formation.

The most apparent conclusion to be drawn from the data is the increase of the droplet size with time. This growth in size may occur in two ways: (1) by condensation of water vapor on the surface of the droplet until chemical equilibrium exists between the particle and the surrounding air, and (2) by coagulation of the particles formed. That any growth of the particles by condensation of water vapor must take place before the aerosol could be sampled (that is, within 0.2 seconds after its formation) is shown conclusively by the experimental data. If, for example, growth of the particles in the retention chamber were by condensation, then the larger droplets would necessarily show a lower acid content than the smaller ones. Also the weight per cent acid of the aerosol would decrease with time. Analysis of the acid in each size range showed that the acid content did not vary appreciably with size nor did the average acid content in the aerosol decrease with time.

Further evidence against condensation is shown by the fact that the weight of the aerosol per unit volume of air did not increase with time as would be expected if the droplets were absorbing water vapor from the air. Finally, it was found that, even at the earliest sampling point, the aerosol was already nearly in equilibrium with the surrounding air. Therefore,

it must be concluded that within a fraction of a second the reaction of SO_3 and H_2O takes place, the sulfuric acid vapor condenses into primary particles, and these particles absorb sufficient water vapor to come into equilibrium with the air.

Having ruled out condensation as a growth mechanism in the tube what support is there that the growth is by coagulation? Recalling that the coagulation theory of Smoluchowski and Whytlaw-Gray states that the change in the number of particles per unit time is directly proportional to the square of the particle concentration, a plot of the reciprocal of the number of particles per unit volume against time should result in a straight line, the slope of which is called the coagulation constant.

Although number concentrations of the aerosols were not determined directly in this work, a method exists for calculating them. Since the size distributions fell on straight lines on a log-probability plot, they can be represented mathematically by the log-probability distribution function which permits the calculation of various mean and median diameters. Thus the number median diameter may be calculated by

$$\ln D_{nmd} = \ln D_{vmd} - .3 \ln^2 \sigma_g$$

and the mean volume diameter by

$$\ln D_v^3 = \ln D_{nmd}^3 + 9/2 \ln^2 \sigma_g$$

The volume of a droplet having this mean volume diameter when divided into the total volume of the aerosol gives the number of particles, N , per unit volume of air. The total volume of aerosol collected per unit volume of air may be determined from a knowledge of its weight and density.

Having thus obtained a value for the particle concentrations at various points in the retention chamber, plots of the reciprocal of this value against time were then made. These data are shown in Figure 4; the curve drawn represents the average slope, $K = 16 \times 10^{-10}$ cc. per second, obtained from experiments with varying concentrations of aerosol and relative humidities of the air stream. This value compares favorably with that of 15×10^{-10} cc. per second predicted by Fuchs (1).

After obtaining satisfactory results in the laboratory, measurements were made on the exit stack gases of two commercial contact acid units. The particle size and particle size distribution of the mists contained in these gases were nearly identical with those produced under similar conditions in the laboratory. A mass median diameter of 0.6 microns and a standard geometric deviation of 1.3 were found. We believe that this is the first time that accurate measurements have been made on the particle size of sulfuric acid mist from a commercial plant.

Phosphoric Acid Aerosols

An aerosol of phosphoric acid was produced by vaporization of solid phosphorus pentoxide into a stream of nitrogen which was then mixed with moist air. The P_4O_{10} molecules reacted with the water vapor to form H_3PO_4 which then condensed into small liquid droplets. As in the case of sulfuric acid, the aerosol immediately came into chemical equilibrium with the surrounding air.

The particle size was more than twice as large as that of sulfuric acid when produced under similar conditions of mist loading and relative humidity. This fact, resulting in a large decrease of the number of

particles per unit volume, reduced the rate of coagulation of the aerosol. In fact, even after seven minutes, no growth in the particle size could be detected by the impactors. These results are shown in Figure 5.

- A partial explanation of the differences in size of these two aerosols may be found in their relative self-nucleating powers: sulfuric acid and sulfur trioxide have been reported as strongly self-nucleating by LaMer (2). An indirect verification of the relative nucleating powers of sulfuric and phosphoric acid has been carried out in the laboratory. Foreign nuclei in the form of sodium chloride ions were added to the moist air stream. In the case of sulfuric acid no change in the particle size or number was found, indicating that additional nuclei had no effect on the physical properties of the aerosol. In the case of phosphoric acid, however, the addition of foreign nuclei increased the number concentration and decreased the size of the droplets. This fact indicates that phosphoric acid does not supply an excess of nuclei from which the droplets grow, which results in fewer but larger droplets. Figure 6 graphically represents these experiments.

Work on other hygroscopic aerosols is in progress, including those of hydrochloric acid, nitric acid, titanium tetrachloride, and silicon tetrachloride.

Conclusions

1. The high velocity cascade impactor has been shown to be a convenient instrument for determining the particle size distribution of hygroscopic aerosols in the micron and submicron range in both laboratory and field work.

2. Data have been presented showing the effect of aging on the particle size distribution of sulfuric and phosphoric acid mists.

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Nomenclature

D_{mmd} = Mass median diameter

D_{nmd} = Number median diameter

D_v = Mean volume diameter

N = Number of particles per cc of air

K = Coagulation coefficient, cc per second

Fig. 1—Schematic diagram of equipment.

Fig. 2—Particle size distribution of sulfuric acid aerosol.

Fig. 3—Particle size distribution of sulfuric acid aerosol.

Fig. 4—Rate of coagulation of droplets sulfuric acid.

Fig. 5—Particle size distribution of phosphoric acid aerosol.

Fig. 6—Effect of foreign nuclei on particle size.

COLLECTION OF AEROSOLS ON FIBER MATS

by

James B. Wong, Research Assistant

The object of this work is to obtain a correlation between the collection efficiency of a fiber mat and the pressure drop across the mat. The mechanisms involved in the collection of aerosol particles in filters include gravity settling, inertial impaction, finite size interception, electrostatic attraction, and Brownian diffusion. At present, we are interested in isolating the inertial mechanism for study. Consider a fiber mat consisting of a large number of cylindrical fibers. If the aerosol particles passing into the mat have small diameters compared to the fiber diameters, the interception mechanism can be neglected. Electrostatic attraction can be eliminated by dealing with uncharged particles and fibers. Gravity settling is negligible for particles of the order of one micron moving at relatively high velocities. Brownian diffusion can be made insignificant if the particles do not have diameters smaller than half of a micron.

A fiber mat can be pictured as consisting of numerous cylinders randomly oriented. For cases where the volume occupied by the fibers is small compared with the overall volume of the mat, the collection efficiency should be the sum of the inertial impaction efficiencies of the single cylinders and the pressure drop should be the total drag force on these cylinders per unit area of the mat surface. For cases where the fiber volume is appreciable, a correction should be applied to the volumetric velocity of the aerosol stream if the inertial impaction efficiencies and total drag force on the single cylinders are to be used to

predict the collection efficiency and the pressure drop, respectively, of the mat. Undoubtedly, in either case, there is a mutual effect of the fibers on each other, both in regard to the collection efficiency and the pressure loss. This may be expressed by modifying the Reynolds Number so that it includes a mutual interaction constant which depends on the geometry of the fiber mat. By defining a parameter representing the ratio of the velocity inside the fiber mat to the upstream volumetric velocity, we have worked out equations relating the collection efficiency to the pressure drop of the mat based on the drag coefficient and the inertial impaction efficiency for single cylinders. This parameter is unity when the fibers occupy a negligible volume. In deriving these equations, several simplifying assumptions were made.

Equipment is now being designed to measure simultaneously the inertial collection efficiency and the pressure drop of fiber mats specially made for the purpose of testing the validity of the basic assumptions. At this time, it suffices to note that the theoretical equations contain all the essential constants of the mat, such as fiber diameter, bulk density, fiber density, and mat thickness and that the parameter representing the velocity inside the mat to the upstream velocity can be evaluated by experimental measurements. The parameter for inertial impaction is assumed to be the same as that for pressure drop. If these equations are valid, a measurement of the pressure drop across a fiber mat can be used to predict the inertial collection efficiency of the mat, or vice versa. What is more, since the inertial mechanism is the only one that is directly related to the pressure loss, the correlation, in theory at least, should represent the minimum collection efficiency at a given pressure

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loss across the mat. To this correlation, the contributions of the other mechanisms, such as interception, Brownian diffusion, etc., to the collection efficiency of the mat can be added one by one.

We need to have reliable experimental data on inertial impaction efficiencies and drag coefficients of single cylinders. As far as the inertial impaction efficiency of single cylinders is concerned, experimental data are meager although the problem has been investigated rather extensively from the theoretical standpoint. The results expected from different theories are not always in agreement, and some experimental investigation is necessary. With regard to the drag coefficient on single cylinders, we have again found it advisable to take data in a range of the Reynolds Number where neither theory nor experiment has been adequate.

Inertial Impaction Efficiency on Cylindrical Collectors

Figure 1 is a schematic diagram of the experimental equipment used to establish the efficiency curves for inertial impaction on cylindrical collectors (1). A condensation aerosol was produced in a generator similar to that described by LaMer (6). The air at 90 pounds per square inch pressure and saturated with water vapor was filtered, but not dried, and metered through a pressure regulator to the humidifier and the salt nuclei generator; a side stream was used to dilute the dense aerosol from the reheater of the aerosol generator.

Concentrated sulfuric acid was used as the aerosol material. The concentration of acid in the aerosol droplets was nearly constant with a mean of 50.5 weight per cent in equilibrium with the moisture content of the expanded supply air. Although the moisture content of the supply air was

relatively low, there was a great excess of moisture over that needed to form the fog. As a result, the aerosol particles did not change in size when additional air of practically the same humidity was added, and the aerosol velocity through the test section could be varied without changing the particle size.

A 3-mil platinum wire was used as the cylindrical collector. The wire was wound on a drum which could be rotated by a knob attached to it. Below the drum, a Venturi-shape nozzle having a throat diameter of 0.125 inch and fabricated of polystyrene was installed with its center line in a horizontal plane. The wire passed vertically downward across the mid-section of the throat into an 8-mm. glass wash tube about 4 feet in length. To facilitate introduction and removal of wash water, a side arm was attached near the top of the glass tube, and a stopcock was connected to the lower end. A filter train consisted of three separate filters, each containing about 1 inch of tightly packed No. 800 Pyrex brand glass wool, was used to collect the aerosol particles which escaped impaction on the wire. The filters could be removed and weighed. As all, or nearly all of the weight increase appeared in the first two sections, complete removal of the particles was assumed.

The aerosol stream could be directed through the equipment by five different paths: (1) discarded through the aspirator when the generator was being adjusted to produce a steady flow of a homogeneous aerosol of the desired particle size, (2) discarded into the vacuum system filter so as to establish steady conditions at the two-way quick-opening valve, (3) sent through the jet impactor for analysis for acid concentration, (4) sent through the optical system (the "Owl") for measurement of the particle size, and (5) during test runs, directed by the two-way valve

through the nozzle passing the cylindrical collector into the filter train. The amount of aerosol collected on the wire was determined by washing with a measured amount of conductance water and finding the change in conductivity.

Figure 2 shows in graphical form the results of the experimental measurements. Here C is Cunningham's correction for small particles, ρ_p is the density of the particle, v_0 is the volumetric velocity of the fluid stream, μ is the viscosity of the fluid, D_c is the diameter of the cylindrical collector, D_p is the diameter of the aerosol particles, and η is the target efficiency of collection. The ranges of variables studied are: particle diameters, 0.36 to 1.30 microns; relative velocity of the aerosol stream, 2000 to 7000 cm. per second; and particle concentration, approximately 10^5 to 10^7 particles per cc. As the ratio of particle diameter to collector diameter was never greater than 0.02, collection by interception was considered negligible. Brownian diffusion had little effect under the existing velocities and particle sizes. Since the particles were not charged, collection by the electrostatic mechanism was also improbable. The results, therefore, should represent collection by the inertial impaction mechanism alone.

The experimental data confirm the general shape and relative position of the inertial impaction curves for cylindrical collectors predicted by the theoretical curves reproduced in Figure 3 (1). Because the experimental variables were difficult to control, it is perhaps more accurate to consider the curve as a confirmation of the theoretical calculations, which were based on assumed ideal flow around the cylindrical collector. The theoretical equations for impaction on a cylinder indicate the exist-

ence of a critical value of ψ below which impaction cannot occur. The calculated value of the intercept depends on the model assumed for the flow lines. While extrapolation of the experimental curve indicates that such an intercept may exist, there is no definite evidence of what the critical value of the parameter may be. Since this is a region of considerable practical importance, the studies are being continued with improved equipment in the hope that a more complete curve may be obtained and the existence or nonexistence of the critical value of ψ can be established definitely.

Drag Coefficient of Circular Cylinders

The drag coefficient of a small circular cylinder placed in a stream of fluid with its axis normal to the flow may be predicted for viscous flow by a theoretical equation derived by Lamb (2). Because of the simplifying assumptions made in its derivation, however, the equation can be applied only when the Reynolds Number is less than 0.1. In contrast to the corresponding Stokes equation for spheres, the Lamb equation has not been verified by experiment.

White measured the terminal velocity of wires falling through liquids, but the drag coefficients which he found did not agree with the Lamb equation because of wall effects (9). The drag coefficients have been measured directly at relatively high velocities by a number of workers (4,5,8). The data of Wieselsberger extend to a Reynolds Number as low as 4.1 but between 4.1 and 0.1, the values of the drag coefficient are uncertain. Consequently, when presenting graphs of the drag coefficient versus the Reynolds Number for cylinders, the usual practice has been to draw a smooth curve connecting the data of Wieselsberger with the line representing the

Lamb equation. Tomotika and Aoi have recently refined the derivation of Lamb so as to allow the prediction of drag coefficients up to a Reynolds Number of 4, but no data were available to confirm their calculations (7).

The experimental technique used in our laboratory in the determination of drag coefficients for cylinders was similar in principle to that used by Wieselsberger (8). A fine wire with a weight attached to its lower end was suspended as a pendulum in a uniform stream of air flowing at a known rate. The drag force was calculated from the measured deflection of the pendulum. Since the weight itself hung outside the air stream, the deflection was due entirely to the drag of the cylindrical wire.

The flow chamber consisted of a short Lucite tube having an inside diameter of 1.90 cm. A standard flow nozzle was connected at the upstream end of the chamber and the downstream end was open to the atmosphere. In order to make the measurements with a uniform velocity profile, the wire was suspended to a point only 2 mm. downstream from a 200-mesh screen placed across the throat of the nozzle. Ranz has shown that such an arrangement gives uniform velocity for a variety of flow conditions (3).

The top of the test wire was soldered onto a steel needle which served as a support, and which passed through a small hole at the top of the Lucite tube. The wire itself extended down through a hole in the bottom of the tube and its lower end, weighted with a drop of solder, was protected from stray air currents by a small Lucite box. The essential parts of the apparatus are shown in Figure 4.

Deflections of the wire were observed with a microscope equipped with a 32 mm. objective and a calibrated micrometer eyepiece. The point

of observation was either at the bottom of the Lucite tube or just below the tube where the wire entered the Lucite box. From the deflection of the wire, d , the length exposed to the air stream, L , and the weight of the solder, W , it was possible to calculate the drag force, F , from the formula.

$$F = \frac{2Wd}{L}$$

This equation is based on the fact that the wires were flexible and therefore exerted no residual moment of force at the point of suspension. The drag coefficient C_D is defined by the equation

$$C_D = \frac{2Fg_c}{\rho v^2 D_c L}$$

where g_c is Newton's Law conversion factor, ρ is the density of the fluid, and other symbols have the same meanings stated previously.

Three sizes of wires were used: tungsten wires, 4.1 and 6.5 microns in diameter, and chromel wire, 12.6 microns in diameter. The wires were examined under an electron microscope to determine their size and uniformity. The operations of cleaning, copper plating, and soldering the test wires were facilitated by the use of a jig which had been built to make probes for a hot-wire anemometer.

The range of air flows was from 20 to 730 cm. per second, and the observed deflections varied from 36 microns to 1 mm. The weight of solder attached to the wire was in every case so much greater than the weight of the wire that the latter could be considered negligible.

The experimental data of this study are shown in Figure 5, together with the data of Wieselsberger; also shown are the theoretical lines pro-

posed by Lamb and by Tomotika and Aoi. The Lamb equation is confirmed for the upper region of viscous flow. At higher Reynolds Numbers, the present data lie slightly below the predictions of Tomotika and Aoi, but there is a smooth fit with the experimental results of Wieselsberger.

The scatter of the data is not considered excessive in the light of the experimental difficulties. Some of the abnormally high values of the drag coefficient may be accounted for by a slight kinking of the wire or by surface roughness, although efforts were made to avoid such interferences. Since the diameter of the flow chamber was 1500 times the diameter of the largest wire used, any influence of the wall can be considered negligible.

Acknowledgment

The work on the drag coefficient of single fibers was performed by Professor R. K. Finn. The author wishes to extend his thanks for the use of the data.

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Fig. 1 — Experimental equipment, impactation on body collectors.

Fig. 2 — Experimental impactation efficiencies, cylindrical collectors.

Fig. 3—Theoretical impaction efficiencies, cylindrical collectors.

Fig. 4—Equipment for drag coefficients.

Fig. 5—Experimental data, drag coefficients.

ELECTRIFICATION OF AEROSOLS

by

Herbert F. Kraemer*

The main object of this research was the design and construction of a device which would produce an aerosol with particles of uniform size, bearing electric charges of the same magnitude and of the same sign. A secondary objective was the derivation of theoretical equations that would explain the phenomena occurring in the charging device and permit intelligent design of such equipment. Finally, it was desired to devise a method of measuring the charges on the aerosol particles and of detecting any non-uniformity in size or charge.

A representative aerosol produced as a result of this work is shown in Figure 1 in terms of frequency distributions of charge and diameter, the measurements being made with a Millikan cell. The average diameter of the particles in this case was 1.43 microns with a geometric standard deviation in diameter of 1.28. The average electrical charge on the particles was 230 electron units, with a geometric standard deviation in charge of 1.25.

It can be seen that several problems are encountered in producing a uniform aerosol for test purposes. Firstly, one must produce a monodisperse or homogeneous aerosol. Secondly, one must place an electrical charge on the aerosol in as uniform a manner as possible, yet without causing excessive electrostatic precipitation of the particles. Thirdly, a satisfactory method of measuring the properties of the test aerosol must be available.

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Production of a Homogeneous Aerosol

Reasonably uniform aerosols of glycerol were produced in a generator similar to the one described by LaMer and Hochberg (4). The glycerol was heated by an air temperature bath to about 120°C. Air was bubbled through the liquid and superheated in a second chamber. Salt nuclei were generated in the air stream by vaporization of sodium chloride in contact with a red hot wire. The vapor-laden air was then conducted through an insulated chimney wherein condensation of the glycerol into small droplets occurred. The resulting aerosol was then transferred through a glass tube to the corona charging device. Aerosols of about one micron diameter were produced in concentrations of 10^6 to 10^8 particles per cc. Particle sizes were measured from the angle of the scattered light (the "Owl") and by means of a high velocity cascade impactor. The aerosol coming from the generator was essentially uncharged, at least insofar as Millikan cell and "charge-spectrometer" measurements could detect.

Theory of the Electrical Charging of Aerosols

An electrical charge may be placed on aerosol particles by friction, by radioactive radiation, by corona discharge, by thermionic emission, or even by contacting the particles with a highly charged surface. Charged aerosols are also known to be formed in the process of atomization and during certain chemical reactions such as the oxidation of magnesium and the combination of hydrochloric acid and ammonia. The simplest technique of placing a high yet uniform electric charge on the aerosol particles appears to be the exposure of the particles to the ionized field of a corona discharge.

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In this work, an unique property of a corona discharge between two concentric cylindrical electrodes was utilized to insure that the charges on all the aerosol particles would be identical. First, it is known that the field intensity between two such electrodes during the discharge is practically constant at all radial positions except very close to the central electrode (1). Secondly, the maximum charge developed on an aerosol particle is proportional to the field intensity, and to the particle diameter squared (6). If the particles are of uniform size, and the field intensity acting on all of the particles is the same, then the maximum charges on all the particles in the aerosol are identical. Naturally if the retention time of the particles in the corona is insufficient for the maximum charge to be attained the particles will not all have identical charges. On the other hand, if the particles are permitted to remain in the corona field for too long a time, they will be precipitated on the walls of the corona device in a manner similar to the Cottrell precipitator.

It can be seen from the above discussion that a device for the electrical charging of aerosol particles with a corona has several diverse requirements. The corona charging device must charge the particles uniformly yet without causing an excessive amount of particle precipitation. In order to design a corona charging device properly, the differential equations of motion of an aerosol particle in the corona device were solved (3). After determining the trajectories of the aerosol particles as they travel axially between the two concentric corona electrodes, it is possible to calculate the average amount of charge on the particles leaving the corona device, the statistical variability or lack of uni-

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formity of charges on the effluent particles, and the extent of particle precipitation within the corona charging device. The results of these calculations are shown in Figure 2 as lines of constant charge, constant per cent precipitation and constant geometric standard deviation of the charges on the particles. The isograms are plotted as functions of the two dimensionless parameters N_ϕ and N_β , which describe the operating conditions and size of the corona device.

From the graph it appears that the parameters should have values of about $N_\phi = 300$ and $N_\beta = 20$ for optimum operation.

The Electrical Charging of Aerosols

A corona charging device fulfilling the theoretical requirements is shown in Figure 3. The aerosol flows through a 1/2" diameter copper tube electrode and a coaxial wire electrode (not shown). Machine screws hold the electrodes in place and permit making electrical connection to the electrodes. A potential of 3500 volts is impressed across the electrodes, the central wire being negative. The field intensity in the corona device is calculated (1) (2) from the ion current by $E_r = \sqrt{2i/K}$. The aerosol stream passes through the corona with a velocity of approximately 50 cm./sec. in laminar flow.

As a test of the theory of charging, the glycerol aerosol was charged by the corona charging device, and the electrical charges on the particles were measured both with the Millikan cell and with the "charge-spectrometer" described in the next section. In addition, a theoretical estimate of the charge was made using the equations derived previously.

The theoretical average charge on the effluent aerosol particles is

$$q_p = \left\{ 3\pi\mu KD_p / 4CN\phi \right\} \exp \left\{ \frac{N_\Lambda - 32/105}{N_\beta} \right\}$$

In Figure 4, the theoretically predicted charges are compared with the charges that were actually measured on the effluent aerosol from the corona charging device. A fair agreement exists. The 25 per cent experimental bias is probably due to charging of particles occurring just outside the entrance and exit of the copper electrode. This additional charging effect was not considered in the theoretical treatment. The lack of uniformity of charges on the particles is shown in Figure 1. The primary cause for the non-uniform charging is a non-uniformity in the diameter of the particles.

Measurement of Electric Charge on the Aerosol

The device developed to measure the electrical charge on aerosol particles is shown in Figure 5 (5). Air is made to travel in laminar motion along a rectangular channel. The aerosol is injected at the centerline of the flowing air stream. By the application of a voltage across the two electrodes, the aerosol beam is deflected an amount dependant on the charge on the particles. The trajectory of the beam can either be photographed (Figure 6) or measured with an optical cathetometer using illumination by a Tyndall beam. On the basis of the equations of motion of a charged particle in an electric field and the velocity profile in a rectangular duct, the average charge on the aerosol particles may be calculated from the trajectory (3).

$$q_p = 6\pi\mu D_p v_{oy} S / CE_x$$

In addition, any non-uniformity in either the charge or the diameter is graphically illustrated by the aerosol beam spreading as it flows along the channel. It is possible to measure the width of the aerosol beam and thereby estimate the lack of uniformity in charge and diameter (3).

A comparison of data taken with the Millikan cell and with the "charge-spectrometer" is shown in Figure 4. The better reproducibility of the latter is apparent.

Conclusions

The results of this work indicate that uniform test aerosols of electrically charged particles can be produced and measured. It is now planned to use the test aerosols in the evaluation of electrostatic air cleaning equipment and for other studies on the properties of electrified particles.

Nomenclature

Any set of dimensionally consistent units may be used.

b - One half the electrode spacing in the "charge-spectrometer"

C - $\{1 + 1.6 \lambda / D_p\}$, Cunningham correction

D_p - Particle diameter

E_r - Radial component of the electric field intensity

ϵ - Dielectric constant of the aerosol particle

G - Parameter characterizing the rate of diffusion of ions, 0.20 $\text{cm}^2/\text{sec.}$

i - Corona current per unit length of electrode

- K - Mobility of air ions, $1.75 \text{ cm}^2/(\text{sec.})(\text{volt})$
- L - Length of the electrodes in the corona charging device
- λ - Mean free path of air molecules, $9 \times 10^{-6} \text{ cm.}$
- $N_\beta - KE_r L / 8Rv_o$
- $N_\phi - 3\pi\mu K / CE_r D_p \left(1 + 2 \frac{\epsilon - 1}{+ 2}\right)$
- $N_\Lambda - GL / 2\pi R v_o D_p \left(1 + 2 \frac{\epsilon - 1}{+ 2}\right)$
- q_p - Electrical charge on the aerosol particle
- R - Inner radius of outer corona electrode
- S - $3.6 \left[1 - (y^2/3b^2) - 0.41(2b/\pi y)\sin(\pi y/2b) + \dots\right]$
- μ - Viscosity of air
- v_o - Average air or aerosol stream velocity
- x - Position downstream in "charge-spectrometer" measured from inlet of aerosol
- y - Lateral distance of aerosol beam from centerline in the "charge-spectrometer"

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Fig. 1—Statistical distribution of sizes and particle charges in a typical aerosol.

Fig. 2—Summary of theoretical equations of aerosol electrification.

SECTION AA

Fig. 3—The corona charging device for electrical charging of aerosols.

Fig. 4—The electrical charge on aerosol particles, a comparison of theoretical and measured values.

Fig. 5—The charge-spectrometer for the measurement of electrical charge on aerosols.

Fig. 6—Photograph of the aerosol in the charge-spectrometer.

PROCESS VARIABLE STUDY OF INCINERATION
USING TANGENTIAL OVERFIRE AIR

Richard C. Corey¹

Introduction

The expanding operations of the Atomic Energy Commission and the growing off-site uses of radioisotopes are making more urgent than ever the need for safe, convenient, and economical means for disposing of contaminated combustible solids that are incidental to these activities.

It is generally agreed that incineration offers the best chance of meeting such criteria as convenience and economy, since the waste can be disposed of at its source, and a very considerable reduction in volume of waste is achieved. However, unlike industrial furnaces for heat and power, incinerators are required to handle materials that are physically heterogeneous and liable to vary widely in composition, depending upon the sources of the wastes. Moreover, incinerators are generally charged batchwise because the charge cannot conveniently be delivered continuously with automatic stoking equipment. These characteristics make incinerator design very difficult, and it might be said in general that little or no sound engineering information is available as a basis for design. The approach in the case of domestic and industrial incinerators is largely of the cut-and-try variety, and it is the rule rather than the exception that these units do not consume the charges completely, with the result that considerable quantities of particulate matter and tarry distillation products are discharged from the stack. This is particularly bad where the cleaning system must be confined to the use of dry filters, as in off-site operations, where wet scrubbing of the gases is not desirable.

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, Anticipating the problems that would arise in connection with incineration of contaminated combustible wastes, particularly in congested off-site areas where the health and safety of the operating personnel and of the community must be considered, the Atomic Energy Commission contracted with the Bureau of Mines to develop an incinerator for low-level wastes composed mainly of cellulosic materials, animals, and miscellaneous solids from laboratories.

Such a unit, or for that matter any incinerator, must achieve complete combustion of its charge with minimum space requirements per unit weight of charge burned per unit time, and with minimum concentration of solids and condensable vapors in the products of combustion. Also to be considered are safe means for removing and disposing of the grate residue, a simple gas-cleaning system, and low cost of the equipment.

These specific requirements for such equipment indicated that no rational design of a prototype incinerator could be made without some knowledge of certain fundamental factors unique to the incineration process. While it is conceivable that a preliminary unit could be constructed from educated guesses concerning the optimum grate area and furnace heat release rates, and later modified on the basis of its performance, this approach is generally expensive, tedious, and unsatisfactory. The widely varying chemical and physical properties of the materials comprising incinerator charges indicate that certain conventional practices used in connection with the design of coal-burning equipment must be modified to achieve efficient burning of such diverse mixtures as rubbish and animal tissue .

Therefore, a small incinerator, approximately 1/5 scale, was constructed and extensive burning tests were made with a uniform fuel under a variety of controlled operating conditions. In this manner it was possible to evaluate certain process parameters in relation to the combustion efficiency and the burning capacity of the unit, and therefore to secure data for the design of the prototype unit.

Owing to certain desirable characteristics of free vortex flow, that is, flow with constant angular momentum, it was decided to introduce all of the combustion air through tangential ports located above the level of the charge. This made it possible to control both the direction and the velocity of the air with respect to the fuel bed, and to correlate the burning characteristics of the fuel in terms of parameters such as the air rate, the dimensions of the air ports, and the height of the ports above the fuel bed. It will be obvious that these are independent variables of primary importance to the designer.

The object of this paper is to describe the experimental methods that were used, and some of the results and conclusions obtained in this phase of the investigation.

Scope of Investigation

As stated previously, the tests were designed to correlate the burning characteristics with independent variables such as the air flow rate through the tangential ports, the discharge area of the ports, and the height of the ports above the fuel bed. For these purposes, tests were made with three different air flow rates, and for each of these rates three different discharge areas and four different heights of the ports were used.

The principal observations were: (a) the time required to burn a given weight of charge completely, (b) the composition and the temperature of the products of combustion, (c) the composition of the gases at various locations within the combustion chamber, (d) the smoke and tar in the products of combustion, and (e) the temperature distribution over the metal shell of the incinerator.

The quantities used to characterize the performance of the unit were: (a) the observed burning rate, that is, the pounds of charge consumed per hour as denoted by the elapsed time between ignition and complete burn out of the charge, (b) the calculated burning rate, derived from the gas analyses and the mass flow rate, and representing only that part of the charge which is burned to carbon dioxide and water, (c) the fuel-air ratio, derived from the calculated burning rate and the air-flow rate.

A series of tests was also made to determine the distribution of tangential velocity in the incinerator for various air flow rates, port areas, and port heights. The object of this study was to establish the relationship between the flow conditions in the incinerator and the flow conditions in the tangential ports. These tests were made with cold air and without combustion.

In order to eliminate the composition of the fuel as a process variable, wood sawdust of relatively uniform composition and size consist was used for all of the burning tests. Its bulk density was about 10 pounds per cubic foot and its proximate analysis on the as-fired basis was nominally 8 percent moisture, 75 percent volatile matter, 17.5 percent fixed carbon, and 0.5 percent ash. The heating value was 8200 Btu per pound, gross.

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Experimental Apparatus

The model incinerator used for these tests is shown in Figure 1. It was constructed from a 55-gallon stainless steel drum. Two tangential air ports, 180 degrees apart, were located at four different levels, each being valved and connected to a manifold so that any pair or combination of pairs could be used at any time. The discharge area of the ports could be changed by means of machined inserts to areas of 0.00166, 0.003 or 0.006 square feet, or approximately in the ratio of 1:2:4.

The observation hole was of sample size to observe about one-half of the fuel bed and to make time-lapse photographs.

Access holes, not shown in the figure, were located at three elevations on one side. Water-cooled probes were inserted through these holes to secure gas samples radially and vertically during the tests.

A thermocouple was inserted through the stack, with the hot junction approximately flush with the inlet to the stack. Owing to its location, this couple provided only a rough indication of the gas temperature and was used primarily for control purposes.

A water-cooled gas-sampling line also was located in the stack to provide a continuous gas sample for a CO₂ recorder, and an average sample for complete orsat analysis.

A Bacharach smoke indicator in the stack drew a measured volume of stack gas through a paper disc, and provided a relative measure of smoke and tars in the gases at any selected time. A continuous tape-type smoke recorder was tried during the investigation, but condensation of water on the tape caused considerable trouble and its use was abandoned.

Several thermocouples were welded to the outside of the shell to provide a continuous record of the shell temperature at selected positions.

Figure 2 shows the general arrangement of the test equipment. A temperature recorder, of the multi-point variety, was used to obtain a continuous record of the gas temperatures and the shell temperatures.

The velocity surveys mentioned previously were made with an airfoil pitometer designed by the Harvard School of Public Health and loaned to the Bureau by Dr. Leslie Silverman.

Experimental Results

Although it is not possible at this time to present the experimental results in detail, some of the more significant observations will be discussed.

First, let us consider the effect of various parameters on the observed burning rate, that is, the time required to consume a given weight of charge. It should be emphasized that this quantity represents the material that disappears in a given time and does not show the amount of combustibles in the products of combustion.

The observed burning rate was found to increase almost linearly with the air flow rate, and for a given air flow rate it increased as the area of the port decreased. Qualitatively, this is shown in Figure 3.

The regions in which tars and other combustibles are discharged are shown at the extremities of the family of curves. Of course, these regions actually are not as sharply delineated as indicated by the curves.

It is obvious that for a fixed port area the linear velocity of the air in the tangential ports increases with air rate. Since the observed

burning rate is a function of both the mass flow rate and linear velocity of the air, the burning rate was plotted as a function of the Reynolds number of the air in the tangential ports. This relationship is shown in Figure 4.

The lower curve is the calculated burning rate, which represents the amount of the charge that burns completely to CO_2 and H_2O . The spread between these curves is approximately the amount of unburned material in the form of CO , H_2 , tars, or carbon. The significance of this lies in the fact that there is an optimum range of Reynolds numbers in which the combustion efficiency is greatest. This is clearly indicated by Figure 5 which shows the ratio of the calculated burning rate to the observed burning rate as a function of the Reynolds number of the air in the tangential ports. Evidently, the optimum Reynolds number is of the order of 15,000.

The effect of air velocity on the oxygen distribution and the burning conditions in the combustion chamber can be characterized by the composition of the hot gases sweeping the surface of the burning charge. Figure 6 shows the composition of the gases inside the incinerator when burning sawdust at constant air rate, but at two different air velocities. The left-hand figures are for a port velocity of 35.8 feet per second and right-hand figures are for a port velocity of 130.8 feet per second. The Reynolds number corresponding to these conditions is 19,000 for the former and 29,000 for the latter. It will be noted that at the low air velocity excess oxygen was always present; however, when the velocity was increased, the oxygen disappeared about four inches from the center of the

fuel bed, and the overall result was the formation of carbon monoxide over a relatively large portion of the fuel bed. While Figure 6 suggests that low air velocities are preferable, it should be indicated that below some optimum value appreciable quantities of tarry products are formed and leave the incinerator unburned. Smoke deposits obtained by filtering a measured volume of the gases leaving at the various operating conditions suggest that at low air velocities the combustible losses are primarily unburned tars, while at high air velocities these losses consist primarily of carbon monoxide and hydrogen. The operating range in which efficient burning can be achieved is roughly that indicated by the unshaded region shown in Figure 3.

This is by no means a complete analysis of the many factors that were investigated in connection with the model studies. For example, the effects of such variables as the geometry of the ports and the height of the ports above the fuel have not been discussed. Nor have the results been given of the velocity traverses made to establish the relationship between the flow conditions in the incinerator to the flow conditions in the tangential ports. These data are now being correlated, and it is too early to discuss the final results. However, in this connection Figure 7 shows the fuel-air-ratio as a function of the tangential velocity of the gases at a radius corresponding to the circle to which the tangential ports are tangent. The maximum in this curve corresponds to the minimum excess air, and suggests that the optimum tangential velocity close to the wall of the incinerator is about 14 feet per second. In addition, the data indicate that below some minimum port area the transfer of linear momentum of the air to angular momentum is zero regardless of

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the linear velocity in the tangential ports. This is suggested by Figure 8, where the ratio of the tangential velocity to the linear velocity is plotted as a function of height of the ports above the fuel bed and the area of the tangential port. Thus, for any given height it is evident that the energy losses involved in the transfer of momentum increase as the port area decreases.

Summary

The following conclusions can be drawn from this work:

1. Efficient combustion of low ash, high volatile wastes can be obtained using only tangential overfire air. Smoke, tars, and other products of incomplete combustion, which might impair the efficiency of the gas-cleaning system, can be maintained at very low concentrations by controlling the Reynolds number of the air in the ports. Undergrate air can be used if it is desired to increase the burning rate per square foot of grate area, but it should be a relatively small fraction of the total combustion air.
2. The incinerator can be operated efficiently with about 40 percent excess air, which is an important factor in designing the gas-cleaning system.
3. Owing to the characteristics of this type of incineration, it appears that the concentration of solids in the effluent gas will be very low -- other things being equal.

Fig. 1—Cross-sectional view of model incinerator.

Fig. 2—Schematic diagram of test equipment.

Fig. 3—Variation of observed burning rate with air rate and port area.

Fig. 4—Variation of burning rate with Reynolds no. of air through ports.
○, observed burning rate, lbs/hr; △, calculated burning rate, lbs/hr.

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Fig. 5—Ratio of calculated to observed burning rate as a function of Reynolds number of air through tangential ports.

Fig. 6—Composition of hot gases in the incinerator at 7, 14, & 21 inches above the ignited fuel.

Fig. 7—Plot of the calculated fuel-air ratio as a function of tangential velocity. +, 0.00166 ft.² port area, O, 0.003 ft.² port area, Δ, 0.006 ft.² port area.

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Fig. 8—Velocity ratio (V_t/V_p) as a function of H_p/H_t at different port areas.

THE ARGONNE INCINERATOR PROGRAM

by

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The problem of incineration at various AEC sites has been under fire for some time. At most sites operational difficulties have prevented the successful operation of production models of incinerators.

Knolls Atomic Power Laboratory constructed a pilot-plant-sized unit and have done considerable experimental work with it. The original design incorporated a system of "dead ending" the combustion gases; that is, running the gases resulting from combustion through a series of absorption chemicals which would remove the products of combustion. This flowsheet would provide the ideal system in that there would be no gases discharged to the atmosphere and therefore no possible radioactive contamination of the surrounding area. Due to the variations in feed material composition, the combustion rate and consequently the off gas volume fluctuated to such an extent that it was impossible to control the process for "dead ending" the gases. This system was abandoned in favor of a system which used conventional wet scrubbing equipment to remove the radioactive particles from the exhaust gas streams. As in the original flowsheet the combustion was supported by oxygen rather than air. Here again the variety in feed material resulted in excessive "puffing" due to accelerated periods of burning. This problem was partially solved by installing an expansion chamber in the gas train between the combustion chamber and the gas scrubbing equipment and by using a mixture of air and oxygen to support the combustion.

Los Alamos, after many design changes, constructed a production sized incinerator. The main problem encountered with their unit was that it would not continually support combustion. After major modifications in the location of the combustion air entry ports and in the method of introducing the combustion air into the combustion chamber, the unit now appears ready to be tested.

The Argonne incinerator has been burning active wastes on a production basis since July 1951. The most serious problem that has been encountered to date has been in buckling that has occurred in the lower walls of the incinerator body. This was apparently caused by local over heating. The insulation has been removed from this part of the incinerator body and was replaced by an air jacket. It is felt that by reducing the temperature of the wall the buckling will stop, however, measurements are being taken to ascertain this fact.

The criteria for the economic feasibility of the incineration process is the cost of storage of active wastes. If some method of storing wastes is available which costs less than \$2.00 per cubic foot, it is cheaper to store the waste than to process it. If the cost of storage is higher, then it is cheaper to reduce the volume of the waste, by incineration or some other process, before storing it.

The nature of work at Argonne dictates the necessity for rigid control of all active wastes. The solid active wastes are segregated into two major subdivisions, combustible and non combustible. All active combustible wastes, with the exception of very active wastes are processed through the incinerator. The cost of collecting, handling, guarding, and transferring the wastes is high. By incinerating the wastes and thereby reducing the volume, a considerable saving is effected.

A great variety of solid materials become contaminated. Included in recent collections were: filters, paper (absorbent, note, news, filter), wood (benches, flooring, tables, desks, chairs), gloves (rubber, canvas), clothing, shoes, laboratory glassware, ring-stands, pipe, fittings, processing equipment of all sizes and shapes, and dead animals (up to goats).

In all areas where activity is present, 7-1/2 gallon cans made of stainless steel and fitting with a foot-operated slide top are provided. Inside each of these dry active waste cans is a cardboard liner.

Two such cans, one for combustible, the other for noncombustible waste, are provided at each location. Any dry active waste may be deposited in these cans if it is small enough and if its activity does not exceed 50 mr/hr. Special containers are provided when requested for bulky or highly active wastes.

A portable stainless steel collection dolly is used to transport the liners when the containers are emptied. Besides scheduled pick-ups, collections are made when requested. Combustible solid waste goes to the effluent control area for incineration. Noncombustible waste is taken directly to the solids storage area.

A storage area is provided for retention of solid, noncombustible radioactive waste. It consists of concrete-lined trenches with removable wooden covers and is regularly monitored to see that active liquids are not building up. The solid wastes are kept in black iron boxes 4 x 5 x 6 ft. in the trenches. These bins are of such a size that eventually they may be covered, loaded on railroad cars, and shipped to a national graveyard if one is eventually set up.

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The storage space is expensive. It costs about \$7.00 a cubic foot. The collection process costs another \$5.00 per cubic foot, making the total cost of solid storage almost \$12.00 a cubic foot. This high cost of storage is the reason combustible wastes are segregated. Nearly 80% by volume of the solid wastes are combustible. They are incinerated in the unit shown in Figure 1 and 2. This unit, designed by A. D. Little, Co., Cambridge, Mass., has a burning chamber capable of handling 100 ft.³ in an 8-hour day.

The charge is introduced through a chute equipped with interlocked doors to prevent the escape of radioactive gases. The charge builds up on the grates of the furnace and is ignited with gas jets. Combustion air is supplied above and below the grates through tuyeres.

During most of the burning period the combustion is self supporting. The gas jets are again used for final ashing. The ash falls through the grates into water and settles down the collection cone through an 8-inch plug valve into a collection drum fitted with an expendable cloth bag filter (Canton canvas). When the drum is full of ash, the valve is closed, a new container is inserted, and the filter bag is used to dewater the ash to sufficient dryness to allow storage in freezing weather.

Combustion gases must, of course, be freed of their radioactivity before discharge. On leaving the furnace, the gases pass first through a Schreier-Bartolucci vane plate washer where the larger pieces of fly ash are scrubbed out with a water stream that also cools the gases. Water for this scrubbing operation is pumped from the bottom of the ash collection drum to the top of the Schreier-Bartolucci tower and returned from the bottom of the tower to the bottom portion of the incinerator body.

The gases are then passed to a Pease-Anthony Venturi. In this apparatus, the high-velocity gas stream is used to disintegrate a water stream admitted at the throat of the Venturi. The resulting intimate mixture of air and water is admitted tangentially to the bottom of a Peabody scrubber. In this disengaging section, the gas and the droplets of water that now contain a large fraction of the smaller dust particles are separated. The gas flows upward through the Peabody tower, passing through fine holes in the scrubbing plates. There the gas is brought into further intimate contact with water or a suitable alkaline scrubbing solution. In the upper portion of the tower, the gas and water are separated by a mechanical baffle system, and the gases then flow to an electric heater located above the scrubbing tower. Sufficient heat is added in this reheater to vaporize any fine mist particles which are still present in the gas and to raise the gas temperature several degrees above the dew point, thus preventing condensation in the remainder of the system.

Both liquid systems must periodically be drained and recharged. The liquid collected is put into the regular effluent-control-building liquid system.

The preceding treatment may be enough in most cases of operation to reduce the radioactivity to a permissible level. However, as a final safeguard, the gases are passed through a filter of the AEC type. Such a filter is capable of removing radioactive particles to well within tolerance levels under operating conditions. When replacement is necessary, the loaded filter is burned in the furnace. From the filter, the gases are drawn through a positive displacement blower and discharged above the roof.

The incinerator is now on routine operation and is processing the daily accumulation of contaminated combustible wastes. It has been demonstrated capable of a beta decontamination factor of 8×10^7 , and this is not the limit. The data from a series of controlled runs made with known quantities of mixed fission product activity are shown in Table 1. The exhaust gas of the unit has always been well below the design specification for the beta air contamination of 2.1×10^5 dpm/m³ and, indeed, has even been lower than the influent combustion air.

This unit is producing about 6 ft.³ of ash per 100 ft.³ of charge. Even though the installed cost (including engineering) is about \$120,000, an operating saving of about \$400 per 100 ft.³ processed is expected, and the unit should pay for itself in a little over a year.

TABLE 1

DECONTAMINATION ACHIEVED IN INCINERATOR

Run	Activity of air in*		Activity of Feed (Total dpm)	Activity of Exhaust Air		Beta Decontamination Factor**
	(dpm/m ³)	(Total dpm)		(dpm/m ³)	(Total dpm)	
1	195	4×10^5	1×10^7	14	2.8×10^4	3.6×10^2
2	116	2.3×10^5	9×10^7	2	4×10^3	2.2×10^4
3	185	3.7×10^5	3.7×10^9	2.5	5×10^5	7.4×10^5
4	166	4.2×10^5	1.6×10^{11}	4	2×10^4	8×10^7

Operating Conditions:

Length of run: $\frac{1}{2}$ hours (2-1/2 hours burning time)
Air flow: 500 m³/hr.

*Naturally occurring radioactivity in air due to radon-thoron daughters.

**Decontamination factor is total activity of air in feed divided by the total activity of the exhaust air.

Since the ANL incinerator was one of the first units to be constructed, it was somewhat oversized. A rather extensive experimental program has been planned to investigate the operating characteristics, and efficiencies of the various pieces of equipment that comprise the unit. The aim of this program is to obtain the maximum efficiency for each type of gas cleaner and for the incinerator itself. Since this is a prototype unit, in essence, for any future incinerators, we are striving to reduce the number of pieces of gas cleaning equipment and thereby reduce both the initial cost and the operational cost of the incinerator.

The major portion of the investigation to date has centered around the Pease-Anthony Venturi-Peabody Scrubber couple. The effect of the scrub water to gas ratio in the Pease-Anthony Venturi can be seen in Figure 3. The water rate was varied between 0 and 13.0 gallons per minute and the gas flow from the incinerator was varied between 285 and 425 standard cubic feet per minute. This resulted in a water gas ratio varying between zero and 45.6 gpm/1000 SCFM. The left side of the curve, the area between 0 and 15 gpm/1000 SCFM shows the result of increased efficiency due to the increased water to gas ratio, and reaches a maximum at about 15 gpm/1000 SCFM. At the higher water to gas ratio it is thought that the water "jets" across the throat of the venturi, rather than forming a spray, which results in a lower efficiency due to the less intimate contact between the scrub water and the flowing gas stream. Visual observations have shown that at a lower water to gas ratio the scrub water sprays into the throat of the Venturi and forms a wall of water through which the gas must pass. The zero point (46% efficiency) is the amount of clean up contributed by the Peabody scrubber since there was no scrub water used in the Venturi during these runs. During all of these runs the efficiency of gas cleaning was measured around the Venturi-Peabody couple and the scrub water rate to the Peabody scrubber was held at 5.5 gallons per minute.

Efficiency appears to be inversely proportional to scrub water temperature in the Venturi over the range investigated (90°F to 125°F) as evidenced in Figure 4. All other variables, except feed composition were held constant during these investigations. A more extensive investigation of the variable of water temperature is in the process of being carried out, particularly in the lower temperature (60°-90°F) range since this range appears to hold forth the promise of more efficient operation.

The Peabody Scrubber was modified so that the scrub water could be introduced on any of the four plates rather than just on the top plate. The results of varying the number of wet plates are shown in Figure 5. As can be seen efficiency is directly proportional to the number of wet plates in the range of zero to three wet plates. It appears that since the same result (93% efficiency) is obtained with both three and four wet plates that the fourth plate is unnecessary.

Water rate to the Peabody seems to have very little effect of the efficiency of the tower as long as the plates were kept wet. Seventy-two per cent efficiency was obtained at 2.5 and 7.0 g/m and 70% at 5.5 g/m. In this experiment the efficiency of the Venturi was purposely kept low so as to accentuate any changes that may have occurred in the Peabody.

The water temperature also appears to have very little effect on the efficiency of the Peabody scrubber. Sixty-eight per cent was obtained at 145°F and 70% was obtained at 100°F.

The effect of primary and secondary air on the particulate concentration of the incinerator exhaust gas can be seen in Table 2. This experiment was done in the nature of a scouting experiment and more extensive investigation will be carried out in the future. The secondary air enters above the grates in a tangential manner and imparts a swirling motion to

the gases. This results in a more complete combustion and as such seems to reduce the particulate loading in the exhaust gas stream.

TABLE 2

Scrub Water Flow Rate

gal/min		
Schreier-Bartolucci	9.0	9.0
Pease-Anthony Venturi	5.0	9.3
Peabody Scrubber	5.5	5.5

Combustion Air Flow, S.C.F.M.

Primary	0	155
Secondary	155	0

Feed Material	Wood	Wood

Particulate Concentration mg/cu.ft.	0.6	1.7

Note: Samples were taken directly after the Schreier-Bartolucci scrub tower.

Sampling of the gas stream to determine the efficiency of each piece of equipment is carried out in two ways. The first method is based on the total amount of activity entering and leaving each unit. The second method is based on the total amount of particulate (based on weight) entering and leaving a unit. Experimental results have shown that these two methods produce nearly equal results.

The gas stream is monitored after it has passed through the final unit of the cleaning train (AEC filter). This monitoring, based on particulate activity insures safe operation of the incinerator with respect to the total amount of radioactivity discharged to the atmosphere.

Sampling of particulate borne in a fluid stream can be accomplished by two means. These methods are isokinetic sampling and instantaneous

sampling. Since the particulate loading of the gas in the ducts varies considerably over short periods of time, the results of instantaneous sampling would not be reliable and, therefore, the isokinetic sampling method was employed.

In order to reduce turbulence and to obtain a true representation of the stream being sampled, it is necessary to have a long straight section (10 pipe diameters minimum) prior to the sample point or to use straightening vanes or some other device so as to produce uniform velocity at the sample point. A device known as a Stairmand disc will produce a uniform velocity and a uniform cross section particulate loading. While this device produces high flow resistance in the duct, it is a convenient means of producing a representative gas flow and was used prior to all sample points. These points are two-inch pipe couplings welded into the gas duct through which the sample probe or head is inserted.

Three types of sampling equipment are used, all employing the principal of filtering the gas stream to remove the particulate.

The monitoring sampling device used to determine the amount of radioactivity being discharged to the atmosphere is a modified Filter Queen vacuum cleaner which draws the gas through a filter paper. For efficiency determinations, the gases which are below 220°F are sampled by means of a conical sample head which contains a Whatman #44 paper. This device is placed inside the gas duct facing downstream. When the gas stream is being sampled the head is faced upstream and by means of vacuum the sample is drawn through the filter paper in the sample head. The sample flow rate is measured by a gas rotameter and then the volume calculated from the length of time that the sample was being pulled.

In cases where the gas temperatures are too high to allow use of filter paper a special fiber glass filter is used. This material has an average pore size of 0.6 microns. The only sample point at which this paper is necessary is prior to the Schreier-Bartolucci scrubber. Here, in addition to high temperatures, a heavy particulate loading is encountered. A sample head large enough not to plug up in the time necessary to obtain a sample would be too large to fit in the gas duct, hence a third type of sampler is needed.

In this sampler the gas containing the particulate is removed from the duct and then passed through the filter media. In order to be on a comparable basis, both influent and effluent gas samples to this scrubber are taken in this sample head.

After the sample has been taken, the filter medium is removed and the radioactive count is determined. For weight determinations, the sample medium is dried and weighed prior to and following the sampling. Both weight efficiencies and activity efficiencies can be determined on each sample. Efficiencies are based on the influent and effluent concentrations of the particulate in the gas at each unit of the scrubbing train.

It is felt that the incinerator program has been on the whole quite successful. The incinerator has operated safely and economically in reducing the volume of dry active combustible wastes produced at the Laboratory. As previously stated this is an experimental model and efforts are being made to simplify the flowsheet.

Fig. 1 — Contaminated combustible waste incinerator.

Fig. 2—Contaminated waste incinerator installation.

Fig. 3—The effect of the water to gas ratio (venturi) vs. efficiency in the Pease Anthony-Peabody couple.

Fig. 4—The effect of scrub water temperature in the venturi on efficiency.

Fig. 5—Effect of number of wet plates in the Peabody on efficiency.

PRELIMINARY REPORT ON THE LOS ALAMOS INCINERATOR EFFLUENT COLLECTOR PERFORMANCE

Industrial Hygiene Group

Los Alamos Scientific Laboratory

Introduction

The general purpose of the Los Alamos incinerator is the reduction of bulk by incineration of combustible laboratory wastes which are contaminated with radioactive materials. The waste may contain all known types of active materials and the effluent from this operation must be controlled in order to protect the surrounding area. The three general functions of the operation are: (1) incineration of waste materials; (2) decontamination of effluent; (3) storage of contaminated ash.

The Los Alamos incinerator is operated by the Engineering Division of the Los Alamos Scientific Laboratory. The responsibility for evaluating the incinerator effluent collectors has been assigned to the Industrial Hygiene Group of the Laboratory.

Incineration of Waste Materials

The contaminated combustible laboratory wastes are received at the incinerator packed in cardboard boxes 13" x 13" x 24½". Each box weighs between 8-20 pounds. The boxes are stacked together into a charge of a given number of boxes and introduced into the incinerator through the charging lock. The outer door is closed, the inner door opened, the charge is mechanically pushed on to the firing grate, the charging carriage is then returned and the inner door closed. In this way it is possible to charge the incinerator with part of the previous charge still burning.

After the combustion of the charge is completed, or at the end of the day, the ashes and residue of the firing grate are dumped in the ash hopper by manually rotating the grates. The unburned material such as laboratory glassware, miscellaneous iron pieces, et cetera, are caught on a small grizzly in the hopper and the free ashes dumped into the receiving and holding tank. The incombustible material is removed and packaged for burial in the contaminated dump.

Decontamination of Gaseous Effluent

The effluent, with the combustion gases, is drawn through the air cleaning equipment by a blower and discharged into a stack fifty feet high. The effluent collecting system consists of the following equipment in order: cyclone dust collector; spray cooler; Pease Anthony Venturi scrubber with its separator and a 2-stage, deep pocket, dry, fiberglas filter (FG #25 followed by FG #50).

Preliminary tests on effluent performance, as of September 1, 1952

Preliminary tests with limited charges have been made on the incinerator. These tests were made with a short-lived, beta-active material introduced into clean laboratory waste. Air sampling locations to determine the efficiency of the various units are located at the following points:

1. incinerator outlet
2. cyclone collector outlet
3. Venturi scrubber outlet
4. dry filter interstage
5. dry filter outlet
6. stack

To date, the air samples have been collected on a Whatman #41 filter paper or on a porous metal disk of equal efficiency. The sampling rate is approximately 1 c.f.m., with proper orifices being installed at the end of the sampling tube pointed upstream to give isokinetic sampling. The filters are then counted for activity.

When the incinerator is operated at full capacity, it is anticipated that the temperature of the combustion gases at the incinerator outlet will be approximately 1500°F. The spray cooler was designed to lower the temperature of the combustion gases from 1500°F. to 300°F. by spraying water into the gas stream. The quantity of water is automatically controlled by a temperature valve with a thermal bulb in the downstream end of the spray cooler. The preliminary operations with small charges give a temperature (in the incinerator outlet) of 800°F. At this temperature, the spray cooler cools the gases to only 400°F. with higher temperatures in the stack than anticipated. The deep bed fiberglas filter and the stack, in effect, are acting as condensers to cool the gas, and water droplets condense out with the effluent discharged through the stack. This complicates the sampling procedure when determining the particulate matter concentration.

Summary of Results

Four runs made with one quarter the rated capacity gave a maximum incinerator outlet temperature of 500°F. The average penetration through all the effluent collections was 0.005% based on activity measurements. When the charge was increased and the incinerator outlet temperature raised to 800°F., the Whatman filter paper used on the stack testing was wetted and was thus useless. The moisture exists as water droplets in the stack air stream. At the time of this preliminary report, the stack sampling method is being modified in order to collect, first, the water droplets and then the particulates. Activity measurements will then be made on both fractions.

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NON-COMBUSTIBLE AND CHEMICAL RESISTANT AIR FILTERS
FOR
HIGH AND LOW TEMPERATURE USE

Walter J. Smith
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Introduction

After the development of the high-efficiency cellulose base filter paper and the task of getting it into commercial production was finished, Arthur D. Little, Inc. was given a contract by AEC to develop a similar high-efficiency filter that would be non-combustible, that would stand high temperatures, that would be resistant to corrosive gases and fumes, and that, if possible, would be reasonable in cost.

At the present time, the AEC working areas make extensive use of the high-efficiency space filters in which the medium is the cellulose-asbestos sheet. So far as we can learn, these filters are serving their purpose adequately, but have the one serious disadvantage of ready flammability. In many installations this can be a hazard. Moreover, cellulose softens when wet and is susceptible to deterioration from the action of some of the common chemical agents. There has always been a question of the permanence and safety of cellulose-base filters when used in and about some of the chemical laboratories and plants of the Commission. Thus, the desirability of producing a high-efficient filter of all mineral fibers has been evident for some time. Other laboratories have been engaged on this same problem or modifications of it for similar requirements of the Chemical Corps and installations of the Navy.

Obviously, a filter medium for high temperature use requires mineral fibers, of which there are only a few types available, with a number of varieties in each type. Thus, we have: glass fiber, asbestos, mineral wools, spun-fused quartz and spun alumina-silica called Fiberfrax. As was demonstrated by early experiments, an all-glass medium is possible if one can afford

the very costly grades of the finest available glass. We found early in our studies that a combination of the less costly glass fibers with certain kinds of asbestos was much more economical and almost as good. Therefore, we have worked mostly with this combination.

There are two ways in which the fibers may be laid down to form a continuous sheet: either dry forming, or wet forming. Over a period of several years extending back into the period when we were developing the cellulose base paper for the Army, we have given careful consideration to both methods, but in the end have placed our emphasis on wet forming processes and the use of paper making equipment.

Glass fibers themselves do not have sufficient binding ability in a sheet to give it necessary ruggedness to withstand the rough handling incident to the manufacture of fabricated filter units. Therefore it has been necessary to use resins for binding the fibers together. The manner of doing this has been worked out and tests have indicated that after the filter unit has been fabricated, exposure to high temperature does not destroy the bond to the point where the filter paper becomes too weak for satisfactory service.

Experimental work has included the preparation and testing of hand-sheets, pilot scale paper mill runs and one full scale run on a large paper machine. Using the media produced in these mill runs, we have been able to make complete model filter units and have tested them in the laboratory for flow resistance, filtering efficiency and have found them to remain satisfactory in operation under elevated temperatures over a period of months.

Although there is still room for improvement, we believe that we have a successful filter that meets the requirements as set forth originally. There is reason to expect that filter units of this type can soon be made and sold on a commercial scale possibly at a price not too different from that of the present cellulose base filter.

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A discussion of some of the details of the work leading up to this situation will give a better understanding of the present status of this filter development. Because there seems to be such wide interest in high temperature filters, a discussion of some of the development details may not be out of place.

Dry-Formed Filters

Since we will discuss this method of forming only briefly, it will be well to do this at the outset, and then leave the subject at this time.

The first experiments with all-mineral fiber filters were made a number of years ago on dry-formed mats of what were then the new super-fine fibers being made in the laboratories of the Fiberglas Corporation. The fibers were coated with an uncured phenolic binding resin for us, then compressed to very thin mats and cured in a heated press. These mats, especially those made with the finest triple A or double A grade of fibers, gave filtering efficiencies equivalent to or better than those of the best cellulose-asbestos papers, and they were very strong. The main objections to them were high cost, unsuitability for pleating into large compact filter unit and lack of production facilities.

After extensive study in cooperation with engineers of the Fiberglas Corporation, it was evident that a machine for producing the dry-formed mats continuously in the quantities required would be an enormously expensive installation. Moreover, it would require a long term of development and construction and the undertaking would be so large that the Fiberglas Corporation could not be expected to bear the cost. At that time, also, the more promising glass fibers for dry forming, that is, those of the very smallest diameter, were very expensive and unobtainable in quantity, and this was a large factor in the decision to switch to wet-forming methods.

Further consideration of this dry-forming problem leads some to believe that it may be possible to produce mats as a secondary operation by blowing air-borne fibers or mixtures of fibers onto a collecting drum with suitable binder material and to pass the sheet thus continuously formed through a curing oven. One of the clients of Arthur D. Little, Inc. is experimenting with a process of this kind and its application to this problem is under consideration. We do not feel, however, that the probability of final success of the operation justifies delaying the work for an indefinite period. Therefore, all of the recent effort has been devoted to wet-forming on a paper machine.

Wet Forming Methods

Paper making equipment already worked out is designed for wet forming of a continuous fibrous web. But paper mills vary widely depending on the kind of paper produced. There is a problem in finding a mill adapted to handling mineral fiber stock and yet flexible enough to meet our needs.

In considering a wet forming process there was a choice of working with all glass fiber or trying to make a sheet containing low cost glass fibers along with asbestos. This sheet would be constructed like A.E.C. or CWS type paper except that cellulose fibers would be replaced with glass.

An all glass sheet requires the finest grades of spun glass fibers and these are expensive. This is still true even though the prices of such fibers have been reduced greatly during the past year. On the other hand, an asbestos containing sheet needs only a relatively coarse glass fiber to form the bulk structure and to act as a support for asbestos fibers. A variation of this idea is to use very fine glass filaments supported on coarse glass fibers which form the sheet structure. However, more glass is needed to do the job than when asbestos is used and the cost again is many times higher.

We have concentrated on the use of glass and asbestos because it offered the best opportunity to provide a highly efficient mineral medium at low cost even though there is one objection that the proper asbestos might be difficult to obtain in time of war.

Asbestos Fiber

Asbestos is a familiar fiber and the one upon which the present ALC type high efficiency filter is dependent. It is a highly effective fiber. It does nearly all of the work in the present ALC and CWS type papers, although it may be present only to the extent of about 15%. This can be demonstrated readily by testing a piece of the paper for smoke or fine dust penetration and burning out the cellulose while the paper is carefully supported on a wire screen. The efficiency of the remaining delicate web of asbestos is no different from that of the original paper.

All types of asbestos are not equally useful for high efficiency air filter media. The more useful variety has not yet been found to occur in our country or even on this continent. Domestic and Canadian asbestoses are of the chrysotile variety which form long soft, silky fibers. This kind breaks down easily but forms a gelatinous dispersion in water and results in a paper that is high in flow resistance. In the recent past a determined effort was made by one of the government agencies to adapt chrysotile asbestos to filter paper manufacture but with very modest success. It is not unlikely that there are deposits of asbestos in this country that could be used but they would have to be sought out and tested as a special project. We are always examining new samples of asbestos in the hope of finding a good domestic source but funds for an active field search have not been available up to the present time.

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The asbestos useful for filter manufacture is an iron and soda containing silicate. It is the blue asbestos found in Bolivia, South Africa and to a lesser extent, in Australia. When beaten in water the fibers break down into cleanly formed microscopic needles.

In one sense it has been most fortunate that blue asbestos works so well as a filter medium ingredient. Until recently it has been the only material capable of providing high filtering efficiency at low flow resistance. It is still by far the cheapest means of doing this. While there are certain recognized disadvantages associated with the use of asbestos we have stayed with it - purely as a matter of economics. AAA glass fiber now may be had at \$3.50 per pound. One pound of cleaned blue African asbestos costs about 40 cents per pound and does the work of two pounds of AAA glass fiber.

Other Mineral Fibers

In addition to glass and asbestos, we have considered bulk mineral wool and the new alumina-silica fiber developed by the Carborundum Company. Mineral wools (other than glass) are coarse, tend to have a high content of slugs and shot and are generally undesirable. Fiberfrax, the Alundum Co. product, is about equivalent to the glass fiber of the same diameter as a high efficiency filter. The material that we examined had a high proportion of shot or sandy particles. It was expensive and unavailable in quantity. The only advantage that this fiber appears to have is that it can be used at very high temperatures. Its softening point is above 1700°C. That leaves us only glass and asbestos to work with.

Glass Fiber

Glass fiber is a manufactured product made of materials which are in good supply. The table following is a list of present glass fiber manufacturers. Glass fiber of a given grade is uniform and dependable in its properties. It can be obtained perfectly clean and requires very little preparation in a wet process. These points make glass very attractive for use in high efficiency

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LEADING COMPANIES IN GLASS FIBER PRODUCTION

	<u>Sales, 1950</u> <u>(Millions of Dollars)</u>	<u>Plants and Products</u>	<u>Notes</u>
1. Owens-Corning Fiberglass Corp.	78.3 (97.4 in 1951)	Newark, O., - wool, mat, marbles Kansas City, Kan. - wool, mat Santa Clara, Calif. - wool, mat Ashton, R.I. - yarn, staple, rovings Huntington, Pa. - yarn, staple, mat Anderson, S.C. - yarn	Anderson plant expected completed by April 1952
2. Glass Fibers, Inc.	3.3 (1.45 to May 1951)	Waterville, O. - yarn, mat Defiance, O. - glass wool	Expansion plans to double capacity of both plants
3. Libbey-Owens-Ford Glass Co.	170.0	Parkersburg, W.Va. - yarn super-fine wool	Plant started operation 11/16/51
4. Tilo Roofing Co., Inc. Glasfloss Div.	10.2	Hicksville, L.I. - rovings, bonded mats	Became division of Tilo on 12/10/49
5. American Air Filter Co., Inc.	12.1	Louisville, Ky. - glass fiber air filters	Mfg. by a subsidiary, Famco, Inc.
6. Gustin-Bacon Mfg. Co.		Kansas City, Kan. - insulating mats	New plant project at Kansas City
7. Perrault Glass Fiber Corp.		Tulsa, Okla. - pipe wrap	

FUTURE PRODUCERS

Pittsburgh Plate Glass Co.	339.4	Shelbyville, Ind. - superfine and strained glass fiber	To start operations in Fall 1952
Ferro Corp.	33.4	Nashville, Tenn. - unknown	To start operations in Fall 1952

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filters. However, we have found that without asbestos the very finest glass fibers must be used in order to do a comparable job. Unfortunately, the cost of glass is an inverse function of fiber diameter. Following are some recent figures.

<u>Fiber Type</u>	<u>Filament diam. microns</u>	<u>Fiber price dollars/lb.</u>
B	3.2	1.20 - 0.80
A	2.3	1.50
AA	1.3	2.50
AAA	0.7	3.50

These fibers are in the class known as "superfine" or the Aerocor product (Fiberglas Corp.). They are made in a two step process in which a coarse filament is first drawn, then this further reduced to a very fine diameter in a high temperature flame. When reduced to a one micron fiber a pound of glass is extended to a filament 145,000 miles in length.

The prices for superfine fiber have been reduced greatly in the past year. We have been told that Fiberglas Corp. now has facilities for large scale production of superfine so that it is now obtainable in tonnage lots.

Moreover, Fiberglas has been developing a new low cost process for making fine fiber in bulk and it was hoped that this would meet the filter needs of A.E.C. Upon examination it was found that the samples as offered contained so much unusable and objectional shot that it gave little price advantage over the higher grade fibers and would be troublesome to prepare for use.

In another spinning process, glass is drawn continuously at a high rate of speed onto a rapidly revolving mandrel. This produces "continuous filament" yarn which is the basis for the many textile applications of filament glass. One grade of continuous filament fiber measures about twice the diameter of "B" fiber. It costs about \$1.00+ per pound and can be obtained as a roving that is readily cut by mechanical means. However, the fibers are coated with a preparation that must be removed before they can be handled readily in a wet process.

Another product, insulation wool, is the least expensive of all the glass fibers although it has a diameter some ten times that which we prefer. Despite the fact that we have made some surprisingly effective filters with this fiber (and asbestos) they were lacking in flexibility and we regard such coarse fibers as unsuitable for high quality air filter media.

Nearly all of our work has been done with "B" fiber in combination with asbestos and suitable binders.

Laboratory Work

Development work in the paper field is guided by the preparation and testing of hand made sheets. We use standard paper laboratory equipment consisting of a small beater, freeness tester, handsheet mold and drum drier. In addition we have a standard Chemical Corps D.O.M. smoke penetration tester.

The following procedure was worked out in the laboratory and found to give consistently good results:

The glass was reduced in a beater at a consistency of about 1/2% until a proper fiber length was attained. Since the fibers cut in this way are of random length, only an approximate figure can be given.

We might say that they range in length up to about 3/16 inch. As a control means, it was found that the freeness tester could be used. In beating or breaking down glass fiber only a light roll pressure is needed.

A cationic urea formaldehyde resin is added to the glass - preferably in the beater. This serves the double purpose of preventing the seizure of adjacent fibers and also conditions the glass surface to receive a binding resin that is added later. At first we made our own dispersing resin but we found a commercial resin that does just as well or better.

Asbestos is beaten in plain water until it is opened up to a freeness found to be suitable for that particular lot of fiber. Again the freeness tester is used to control the amount of beating.

A quantity of the glass fiber slurry is then blended with the proper amount of asbestos slurry, the binding resin added in the form of aqueous emulsion, and the sheet cast in the hand mold.

Upon removal from the mold the sheet is blotted damp dry with just a little pressure - and finally dried on a steam heated drum dryer.

In the DOP penetration tests the handsheets match the performance of A.E.C. or CWS paper.

There is a characteristic of high efficiency air filter media which we have called the "Velocity slope." D.O.P. penetration of the media nearly always changes with air flow rate; usually the penetration decreases with flow rate. The effect varies with the kind of medium and seems to be influenced by the gross fiber. In this respect the glass-asbestos sheet has a better behavior than the present cellulose-asbestos papers.

It is a long step between making successful handsheets and getting off a run of paper in a mill. Making good handsheets only tells us that it might be possible to produce the medium on a commercial paper making machine.

Experimental Runs

Our first attempt to make glass-asbestos medium on a papermaking machine was at New York State University, School of Forestry, in Syracuse, New York.

Because it is necessary to make frequent tests on the sheet as it comes from the machine, it is necessary to have a dioctyl phthalate smoke penetration tester on hand during a paper mill run. Normally, this kind of equipment is cumbersome and therefore almost of necessity stationary. Since we knew that a number of experimental mill trials had to be made, perhaps at different mills, we designed and built a portable DOP tester of such compact dimensions that it could be carried in two suitcases. This unit proved to be invaluable in our later work.

The trial at Syracuse was unsuccessful. We encountered a very serious foam problem in the beater (due to the dispersing agent) and because the centrifugal recirculating pumps whipped air into the stock even when it could be prepared in the beater. Foaming is bad in that the air bubbles attach themselves to the glass fibers causing them to float and to agglomerate. Once this occurs, it is very difficult to get them redispersed.

We were convinced that the mill at Syracuse was unsuited for our purpose. Furthermore a run required about 1000 pounds of fiber and this made the cost of experiments much too high.

After several paper mills had been considered, we visited the Riegel Paper Corporation at Milford, N.J., and learned that they had a small experimental machine that could be made available to us. This company proved to be very cooperative and so helpful on the project that all of our subsequent experimental plant work has been done using their facilities.

Riegel's experimental Fourdrinier machine proved to be ideal for our purpose. It is small (25" wire width) and can be run very slowly so that as little as 60 pounds of stock can be run per hour. This little mill is staffed by personnel accustomed to experimentation. Finally, and this is important, long experience on the part of Riegel made it feasible to foretell the approximate behavior of any furnish on their commercial machines once it had been run in the experimental plant.

Since last October some half dozen runs have been made. For most of them about 200 pounds of fiber were prepared. This gave enough stock to permit a machine run of about 3 hours.

Our experience at Syracuse taught us to keep foam producers out of the beater and since the experimental mill used piston pumps for recirculating stock, there was little trouble with foam.

The only objection to the small machine was that it produced a trimmed sheet but 19" wide. Another five inches would have permitted us to turn out paper wide enough to build full size filters. However, the stock we did produce allowed us to build and test small filter units 8" x 8" x 6" deep.

We learned to make acceptable paper on the experimental machine and felt encouraged to try a commercial scale run.

Commercial Machine Run

On August 8 of this summer, Riegel provided the use of a commercial Fourdrinier machine over which we ran a 4000 pound batch of glass-asbestos furnish.

Some modifications had to be made on the machine to accommodate our run. Our paper forms best from a highly dilute stock. This required running the machine at the slowest possible speed. Means were also provided for adding

additional asbestos to the machine head box for adjustment of asbestos content in the sheet. Changes were made to allow certain unneeded parts for the machine to be bypassed.

In all, about 900 pounds of glass paper were reeled and of this 415 pounds were later slit and re-reeled for shipment to Cambridge, Mass.

In general, we felt that this was a good run. Complete success in a first run is always a hope, but one that is seldom realized. The paper formed surprisingly well on the wire and at a speed that was high for such material. The sheet handled well on all parts of the machine except the wind-up reel which was of the wrong type.

We are encouraged to believe that glass-asbestos air filter medium produced on standard papermaking equipment will provide at the least cost non-combustible, high efficiency, air filters with improved resistance to moisture and corrosive atmospheres.

Very recently there has come to our attention a source of very inexpensive glass fiber that may make the cost of our medium equal to or even less than the present low temperature papers.

September 16, 1952

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APPENDIX

Second Air Cleaning Seminar for AEC Personnel

Institute for Atomic Research
Iowa State College
Ames, Iowa

September 15, 16, 17, 1952

GENERAL DISCUSSION OF AIR SAMPLING FILTER MEDIA PROBLEMS

Reviewed and edited
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APPENDIX

GENERAL DISCUSSION OF AIR SAMPLING FILTER MEDIA PROBLEMS

This appendix is based on a general discussion of air sampling filter media requirements which took place on Wednesday, September 17th in this Seminar and were wire recorded. The resulting transcription has been edited by Dr. Leslie Silverman who acted as panel chairman and have not been reviewed by the respective discussors in order to expedite publication. Any comments are the personal opinions of the discussors and do not reflect the views of the U. S. Atomic Energy Commission or its contractors.

The discussion is divided into two parts. The first, a general discussion of the problem and the second, a panel discussion by representatives of several major AEC activities on the problem of filter media and a consideration of specifications for types of media to be used.

Requirements for Sampling Filters

Leslie Silverman

What are the requirements of a sampling or filter media? (See Table 1)
We have something which might look like Professor Lapple's discussion yesterday in regard to sand and Fiberglas, but we are not dealing with a size of 85' x 85' but a maximum of 85 square inches. In cost we are not dealing with thousands of dollars but with only a few cents. Nevertheless, we do agree that there is a common efficiency basis. Here, however, we are not as vigorously bound by efficiency demands because no hazard to man is involved as at the discharge of a space filter. In other words, the efficiency that we desire is one of convenience and accuracy. When I say convenience, I mean that we should have a paper or medium that will give reproducible efficiencies rather than worrying about absolute values or approaching 100 percent. It is very nice to have a 100 percent value to avoid correction of values for concentration, but we will settle for 99 or even 95 percent because from a health consideration or atmospheric concentration values plus or minus 5 percent in the final results

is not critical.

I do not know, after listening to Mr. Rodgers last night, whether the purists at Argonne are going to stand for plus or minus 5 percent in sampling work but I hope they will. The problem of efficiency then, is more of constancy rather than of extremely high value. In practice, I think anything above 0.9 or 90 percent would be considered satisfactory as long as it remains 0.9 with a known standard deviation.

The problem of resistance to air flow is also not any real handicap. We are not hide-bound to keep our power requirements or consumption at low levels as in air cleaners. We like to have them low simply because the types of pumps or air movers that we can use in the field are limited and we do not want to carry heavy equipment such as high pressure blowers or vacuum pumps. It is desirable to have resistances which are convenient for ordinary types of sampling equipment. We can operate with resistances as high as one-half an atmosphere, but under ordinary circumstances we prefer to keep below 2 inches of mercury even for high volume units (1 to 2 cubic meters per minute). Millipore media, (if you use the HA type in 50 mm circles) may run as high as one-half atmosphere at the cubic foot per minute rate.

The next problem is that of uniformity, this is one of the most important items from the standpoint of both efficiency and resistance. We have found, in the past, that it is easier to get uniformity with regard to efficiency than it is to resistance. If one takes a box of analytical papers, for example, say Whatman No. 42 and tests that box by taking papers at random and checking their air flow resistance, it will be approximately 1 inch of mercury $\pm 10\%$ at a cubic foot of air per minute for a 3 inch diameter disc. You might take another box from another mill run and find that it will be 2 inches. In other words, it depends on the manufacturing, the lot,

and the conditions of manufacture which were followed. Yet, the filter efficiency for this variation may be reasonably reproducible. If we were able to exert control on the production of these papers and do testing such as is done in the case of paper mills that are now making AEC or CC-6 paper, we could perhaps get uniformity in our sampling media. We haven't uniformity in use yet so we cannot hope to get uniformity in production until we have some limitation on the variety of papers in use.

The next problem is that of penetration. Now, by penetration, I don't mean the penetration we usually talk about or the value of 100- efficiency. What I mean is how far do the particulates penetrate below the paper surface. From the standpoint of chemical analysis where one may do a complete destruction of the media; this is not too important but when counting radioactive materials it is important. The so-called absorption factor is involved and if we were able to keep all the particles on the paper surface we would be in a better position. At least, from the standpoint of those people who are concerned with alpha counting.

Now as to discussing filter life. Life and penetration are really tied together. That is, a filter cannot have minimal penetration and still have long life. We would like to keep everything on the surface and yet not provide a barrier at the surface which will have high resistance and not only produces absorption from the media itself but mutual absorption between particles. In order to obtain long life in air sampling filters a deep bed with high void volume is necessary. As a compromise a napped surface is usually possible on a flat media which improves life without seriously affecting efficiency.

For ease in analyses, chemists prefer to have the two requirements I have given in Table 1. Low-ash, because they want minimal entrainment of their dissolved materials and to speed extractions they like to have a media

TABLE 1

Requirements for Air and Gas Sampling Filter Media

A. Desirable Characteristics

1. Efficiency (High and reproducible)
2. Resistance (Low and compatible with ordinary sampling pumps)
3. Uniformity (Reproducibility in manufactured lots)
4. Penetration (absorption) (Minimal surface penetration, compatible with low resistance and high efficiency.
5. Life (Long and compatible with items 1 and 2)
6. Ease in chemical handling
  - a. Low ash
  - b. High solubility
7. Thermal Resistance
8. Moisture Resistance
9. Low cost (Depending upon particular application and type of sampling)

B. Types of Operations for Which Filter Sampling Media are Used

1. Routine environmental monitoring
  - a. In plant or near processes
    - (1) Static or single fixed media - High volume rate
Low volume rate
    - (2) Continuous or moving strip media - High volume rate
Low volume rate
  - b. Outside plant or operations
2. Stack sampling
3. Particle sizing
4. Background monitoring
  - a. Static or single fixed media
  - b. Continuous or moving strip media
5. Air and Gas Cleaner Rating

c. Types of Air Sampling Media Used at AEC and Contractor Sites

1. Cellulose media
  - a. Analytical Filter Papers
    - (1) Whatman No. 1, 41, 42, 44, 50
    - (2) S & S 589 and others
    - (3) Munktells 00 and others
    - (4) Eaton and Dikeman 613 and 623
  - b. Molded forms
    - (1) Paper thimbles
    - (2) Type S pleated filter (MSA)
2. Cellulose - Asbestos
  - a. Hollingsworth & Vose HV-70 9 and 18 mil
  - b. CC-6 or AEC No. 1
3. Glass Fibers
  - (a) Hurlburt glass media
  - (b) Catalog 800 Fiberglas - Corning Glass Company
4. Millipore Filters HA and AA (Lovell Chemical Company)
5. Miscellaneous
  - (a) Cotton plugs
  - (b) Asbestos paper
  - (c) Asbestos fiber pads
  - (d) Synthetic fiber papers and plugs.

readily soluble in convenient reagents. That is, using wet digestion with ordinary acids or solvents rather than having to use fluxing and other elaborate procedures.

Items 7 and 8 in Table 1 are thermal and moisture resistance. These factors are important when sampling stacks where we have high temperature effluents or sampling from such devices as incinerators, especially before the cooling processes. In other words, a sample taken above the incinerator involves gases in the range of 1000°F and higher and without cooling before sampling requires temperature resistant media selection.

Moisture is a factor because media used in saturated streams causes paper to swell or saturate. In conditions encountered in some collector effluents will cause the media to absorb moisture and change its flow characteristics or actually plug.

The last item is the economic factor and is dependent on the amount of sampling to be done. The amount of paper that goes into one large CC-6 space filter (200 square feet) would probably last the ordinary laboratory site a month. Cost is therefore not a critical factor with efficient media but if requirements are high, the cost factor may become important. At the present time millipore media is the most expensive. We have this filter media at the upper end of the bracket which costs dollars per square foot and have other satisfactory media which is on the order of cents per square foot or less. I think these represent the extremes in cost of sampling media. As far as I know, the most widely used media in sampling work has been the HV-70 paper and that is relatively low in cost. I think Mr. Stafford can say more about the cost aspect of this when we have our discussion later.

There are certain factors about the aerosol that are certainly going to effect items 1 through 8. We know that the so-called 5 S's of the

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aerosol namely; size, size distribution, shape, specific gravity, and the surface characteristics will have some effect on resistance and efficiency. The concentration of the aerosol is also a critical factor in sampling because it will determine whether or not a surface of aerosol is formed which will then be doing the filtering. Obviously, the life factor and the loading are also dependent on the volume passed through the media. In other words, we are actually talking about whether high or low volume sampling is the major factor in determining the life rather than any other factor. The amount of a given media which can be presented to the sample air stream is a function of the size of the media holder, its shape and other dimensional factors.

Media in use at the sites and contractors.

I have summarized these in Table 1 although those present may have some additions to this list. Whatman papers number 1, 41, 42, 44 and 50 have all been used for air sampling purposes. We know that other analytical media such as the S & S (Schliecher & Schull), Winktel, Eaton and Dikeman and other papers have been utilized. These have been used as flat sheets or they have been used in the form of thimbles made from pulp. From the standpoint of special papers, we have the Hollingsworth and Vose HV70, used in 9 mil and 18 mil thicknesses. I hope that we can find out why one site (Argonne) is using 9 mil and the other site (Los Alamos) is using 18 mil. We have the so-called millipore media (MF) which has come into use quite recently. The millipore media is available in the so-called hydrosol-assay (HA) type and in the aerosol-assay (AA) type.

I think we all owe a vote of thanks to the Chemical Corp Biological Laboratories at Camp Detrick for getting this media developed and produced through their contracts with California Institute of Technology and the Lovell Chemical Company that investigations were initiated and carried out.

We have some all-glass paper media which is now available. Mr. Decker of Camp Detrick was kind enough to give me some information on a commercial source. I will abstract it for the group so that they will have some idea of its composition and performance. The last materials used for sampling have been miscellaneous types such as cotton synthetic and glass wool fibers in the form of pads or plugs.

You recall we talked yesterday about using 3 stages of glass wool plugs. This idea goes back to the early 1900's and in addition to glass, cotton, steel wool, and various other fibrous media have been used. Another type of sampling that has been done in industrial hygiene work has been the use of gooch crucibles with asbestos fibers in the form of a pad. This is considered as a very efficient filter. I think, from Mr. Smith's discussion, that you can see why. Then we have an all-asbestos media, which the A.D. Little people and others have made which has certain advantages and certain serious structural limitations.

I have probably covered most of the media but the selection and reasoning behind the use of these media are the principal items intended for discussion this morning.

What information is available on the efficiency or performance for the various uses of these media? We have efficiency information from various sources. I hope I do not slight anyone in trying to enumerate these results.

At Harvard for several years we have studies filter media for air sampling of industrial environments. Ten years ago we investigated filter papers for lead fume and dust sampling and there were limited investigations in Europe before that time. We measured the performance of the Whatman series and some other manufacturers' products for lead, iron, fluorides, zinc and cadmium fumes. The principal papers we investigated then were Whatman's 42, 44, and 50.

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After that time, apparently during the war, the Rochester group, in doing certain Manhattan District investigations, selected Whatman No. 41. I was quite interested to find out why Whatman 41 was used so when I visited Rochester a few years ago I inquired, and as far as I could determine there was an analytical chemist at work there that decided that they were going to use filter paper for sampling. He hunted through the drawers and found some Whatman 41. This has been the choice of Rochester ever since. Years later, about 1949, they decided to determine the efficiency of the paper for various aerosols. Sid Laskin did that with uranium aerosols and sodium chloride. The New York Operations Office, Bill Harris' group, have also completed a number of investigations using Whatman 41 on uranium aerosols and have also used it extensively in the field. There are some objections apparent from the critical examination standpoint with regard to Whatman 41 paper in that the papers show obvious pinholes and are low in surface uniformity. I think Mr. Harris can probably tell you the extent of the variation.

The Camp Detrick group have investigated various media. I do not know all their answers because I do not think they have been presented. They were largely responsible for the millipore or molecular media, which we have found has several desirable characteristics. Efficiency with that medium is no problem and neither is penetration since it is really a true sieve. Hence, the paper yields high efficiency but rapid surface buildup of the aerosol. Obviously, this characteristic is going to be detrimental from the resistance and the light absorption or reflection measuring standpoint.

We have seen results of work done at Knolls with regard to Whatman 41 millipore media and HV70. Work was done at Argonne during the days of the Metallurgical Laboratory on HV70, primarily with regard to its use in

radiological physics monitoring work to determine the absorption of the paper for alpha counting. As far as I know, there have been a few investigations at other places for which we do not have much efficiency information. Brookhaven is using a continuous HV-70 strip but I do not believe I know of any performance data that they obtained on efficiency of media, particularly HV-70. Some work is being done at Oak Ridge with regard to efficiency of various media. In the Handbook on Air Cleaning you will note that there are some data on radioactive aerosols removal which were taken from work done at Oak Ridge by John Goss and others. I believe it is really Ed Struxness' group. If I am correct on that I think Ed or Bill Baumann can verify it.

As far as I know, most of the work at the other sites has been of a field or empirical nature and I think they will report on them during the panel discussion.

I do not have much more to say about media so I hope when we have our panel group here each man in the group will discuss his own requirements and the reasons for selection of media.

I have this letter from Hurlbut to Mr. Decker which I would like to abstract because it gives up-to-date information on all-glass media. We have not been primarily concerned with all-glass medium sampling except we know that it will satisfy requirements seven and eight (Table 1) very well. This is a description of one type of paper made solely with ultra-fine glass fibers. The company which makes this paper happens to be the Hurlbut Paper Company located at South Lee, Massachusetts. I understand there are three other paper companies making this type of paper primarily for electrical insulation, not filtration. As Mr. Smith pointed out yesterday, glass media may be high in cost but I think that this is a situation which will depend upon demand. The source of these

filter fibers that Hurlbut used is Glass Fibers, Incorporated of Toledo. The paper is described as X935B. The paper is manufactured of glass fibers with a diameter ranging between 0.2 and 1.5 microns. The fibers are made of E glass, which has a melting point somewhere around 450°F. The X935B paper contains a binder of rubber-like nature. This gives good physical properties and high chemical resistance and strength. These are all factors which might also affect its use as a space filter as well as in air sampling. The internal bond strength, the tensile strength, the impact and shock resistance of this paper formulation is better in comparison with 50 other binders tested at Hurlbut's laboratory. The chemical resistance of the paper is excellent and the paper can be immersed in water or 10% solutions of hydrochloric acid for a long time without appreciable loss in strength. The same result was found for sulfuric, acetic and nitric acids.

It was determined by two independent laboratories that crushing, rolling, bending and quite rough handling of the paper does not impair the air filtering properties. It was rolled, for instance, between the palms of the hands for one minute and the efficiency of the paper checked afterwards. The DOP efficiency was the same. For the X935B paper, tests show that DOP penetration was less than 0.005 percent. Exposure of the paper to 400°F does not impair the air filter properties at all. It was found that the pressure drop was approximately 1 inch of water at 5 feet per minute. The pressure drop improves slightly (drops 5 percent) after exposure to heat. Exposure of the filter at about 1500°F would melt the fibers and destroy the filter. Other fibers, in experimental production, may in the future allow the manufacture of filter paper which would be able to stand temperatures up to 3000°F. The results obtained so far at Hurlbut and checked by other laboratories, indicate clearly that the manufactured glass fiber paper has a bacteria arresting efficiency of 99.999 percent.

This development makes glass fiber paper usable therefore, for several sampling applications. We now have available a wide variety of papers and several are used^{at}/the different sites. We would like to get some approach to limiting the number of papers used and try to standardize and get consistency among the AEC organizations doing air sampling. If this is done, the results can be readily interpreted in the same light. We are not trying to close the door to new media. I would feel that today we have the answers to almost all of the air sampling filter media problems.

A year ago, when we had our first Seminar, the same problem came up and it was proposed that we would have some kind of a meeting to decide what should be requirements for the papers needed. Mr. Stafford told us then, and I am sure he was correct, that he can produce any kind of paper in terms of cellulose or cellulose-asbestos combinations to meet the requirements we have stated here (Table 1) at least through item 6. The question of temperature and moisture problems arise in certain special instances. The problem of using paper for particle sizing and background counting of low orders brings up questions of selecting millipore or special high surface efficiency papers. That, in general, is all I intended to say about sampling media.

General Discussion on Sampling Media

The best way, I believe, to have our discussion is to call those on our panel and have each member discuss types of paper they use in their operations and reasons for their choice. I will be glad to answer any questions now pertaining to what I have said this morning.

Question: (Anonymous) Does glass paper have any advantage over cellulose containing paper in measuring changes in weight in gravimetric sampling:

Leslie Silverman: (Harvard) Glass papers show little or no absorption but I think there is always some adsorption. I might point out that this glass paper

was largely done at the initiation of the Naval Research Laboratory and through their efforts the fiber manufacturer has been able to produce these superfine fibers. My opinion is that absorption is practically nil on the glass but adsorption still remains as with other sampling media. If you can get equilibrium before weighing, then it will be a big advantage to use all-glass paper.

I have neglected here, one paper which I should have mentioned, that is the so-called type S paper which is used in high volume sampling which is a cellulose-bagasse mixture. It contains no asbestos and uses the bagasse for high wet strength in formulation. We have some efficiency data on these and I believe NYOO may have some to report.

Question: (Anonymous) Who makes that medium?

Leslie Silverman: (Harvard) It is made by Mine Safety Appliances Company. It is actually an application of the Hawley process for making paper maché forms but the cellulose fibers are mixed with the bagasse fibers and sucked onto a screen making the pleated filter as shown in the Handbook on Air Cleaning, passed out to you this morning.

One thing I would like an answer to is "Why Los Alamos uses 18 mil HV-70 and why Argonne uses 9 mil HV-70?" I understand from the manufacturer that both are made to the same resistance and penetration specifications. In other words, some changes may be made primarily in what I think would be the penetration characteristics. Both media have the same so-called Navy or Army Chemical Corps efficiency-pressure drop ratio.

In addition to those data I mentioned earlier we have some data which was obtained on chromic acid mists and lead fume with layers of different papers. We also have a project on lead fume removal for various papers which is sponsored by a smelting company in our laboratory. That investigation is going on at the present time because some of the papers on which we now

have adequate efficiency data are too high in resistance for field use and more air flow for the given size filter and holder is necessary.

Panel Discussion

Panel: Leslie Silverman, Harvard - W. B. Harris, New York Operations Office - Frank Adley, Hanford - Edwin P. Hyatt, Los Alamos - Walter J. Smith, A. D. Little, Co. - G. O. Payne, Argonne - Willard Baumann, Oak Ridge.

Leslie Silverman: I think perhaps the group that have used Whatman 41 the most has been NYOO. I would like William Harris to discuss what and why they have selected for sampling filter media.

Mr. W. B. Harris: (NYOO) In the first place, I believe that the matter of efficiency is primarily one of selected rather than overall efficiency. I do not think it makes a great difference whether our filter papers are 90 percent or 80 percent or 50 percent efficient, as long as they are reproducible for all types of material. We are willing to accept, for example, radiometric counting where we know that we do not get more than 70 percent of the actual material counted so that at best we are looking for 70 percent efficiency. Now the variability in that is great. I believe that the studies we have done indicate that 70 percent efficiency is ± 10 percent on individual samples. It also depends on the type of material, its air concentration and particle size and several other factors. I would limit our efficiency requirement to a requirement of consistent efficiency for all types of material. One of the items which I feel is very important, which Les did not mention here is the mechanical strength and the ease of handling the paper. Our people on a survey of installations take several dozen samples and unless the sampler holder and the operation of putting the sample in and out of the holder is simple and the medium is strong you ruin the sample. I believe, therefore that strength is a very important consideration in development of paper media.

Another thing is the simplicity of the paper holder that we use for the

paper. Where we know samples have to be taken and paper has to be placed in and out of the holder rapidly it is important that this be a relatively simple matter. New York has been using the Whatman 41 paper for what I believe is a very good reason. About 5 years ago we were under the influence of Rochester (University of Rochester) because this institution, at that time, was the only real high-class industrial hygiene laboratory made available to the Commission. When we set up our health unit there were three people in it, an M.D., an instrument man and an industrial hygienist. The instrument man right away decided that he would make sure that we have enough equipment to do our sampling so he asked Rochester what to use for sampling. They said they used Whatman 41 filter paper so we contracted for this Whatman grade and got what I believe, I have never obtained the exact number, but it must have been about 50 million pieces of 1 1/8 diameter of Whatman filter paper. I say it must have been 50 million because it is now 5 years later, our program has increased and the little boxes of 100 papers each are still there. You can imagine why we have a vested interest in Whatman 41 filter paper. I suspect that by now we must be getting somewhere near the end of this but I am not sure. Now as for the measuring of efficiency, we have been very anxious to get a good measure. However, I must admit that despite Les' recitation, that all^{of}/the places that have done efficiency measurement, I do not believe there has ever been an effective measurement of the efficiency of any of these media, and by effective, I mean one which in a concrete manner takes everyone of the variables and eliminates them. I do not believe we have any good idea of the efficiency of any of the papers by particle size. What is the difference in efficiency between a particle size of 0.05, 0.1, 0.5, 1 micron and 5 microns. We should have a performance curve of that. We should know the variability of size so that when we are in an atmosphere which is primarily particles less than 1 micron, we can interpret the sample

in definite distinction to a sample which is taken in an atmosphere where particles are primarily over 5 microns. We do not know accurately what is the efficiency of the paper with changes in velocity through the paper. That has never been accurately defined. There have been a number of various types of a given media and they vary. They are not the same. Some work which LaMer did, indicates that the curves go up and some work which Tracerlab did indicates that the curves go down with increased velocity. I believe that work which was done at Rochester indicated a peak in the curve. There is certainly some variation in velocity, superficial velocity through the paper with which I am not satisfied at all.

There is the matter of measurement of counting efficiency of the paper, in other words absorption, either self-absorption or internal absorption. We have done tests and have some results. Just as we have performed efficiency studies and have other results. We have done them with a practical approach in mind. We know that it is not a scientific approach. We hope to be able to do it in a manner which is scientific but we have not had the time.

For example, we did a pretty good study on the efficiency of Whatman 41 against the materials that we normally run into in our plants such as the uranium salts and oxides. We set up atmospheres that had substantially the same particle distribution that we find in the plants, according to the Cascade Impactor, something like 2 or 3 microns mass median. We measured high efficiencies and they were consistent with all our runs. The efficiencies were better than 98 or 99 percent. We felt the samples taken must be reliable. I am sure that there are many types of materials that we find in the plant for which this paper (41) is not good). Also, we did the same kind of thing for the degree of absorption in the paper. We went through our files and picked out about 500 samples and we picked them deliberately in low, medium and high range of activity on samples with I believe 0 - 10 micrograms, 10 - 100

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micrograms and 100 - 1000 micrograms on a sample. We picked them from areas that had primarily a hydrolized fume, UO_2F , which is supposed to be of very small diameter; with a uranium oxide fume which is on the order of 0.01 micron and with uranium dioxide and uranium tetrafluoride. Those samples were all counted again, the original counts were checked and they were then analyzed chemically. From this we got an analysis of the amount of penetration into the paper. We used a 70 percent figure because it looks like the best fit. We are reasonably confident that most of our samples would fall in that area. On a basis of that, we have put some confidence in our results. However, we have tried to evaluate by the elimination of variables that absolute efficiency of Whatman 41 and of other papers. We have found that against the molecular filter, the Whatman 41 does not do very well where the material that we are collecting is extremely fine. One of the pieces of work that we did was in conjunction with another study on the sampling of daughter products of radon and thoron. We set up atmospheres of radon and thoron and have attempted to measure their concentration by means of the collection of their daughters and measurements. We at first cleaned the area of dust and took samples and it took us a long time to find that we had not quite cleaned it out because when we finally got the area clean of other dust it was very difficult to find the radon and thoron. I think we have pretty well established that radon and thoron are picked up on other dust particles, so that the results that we got in that study are not of much value inasmuch as we cannot define our starting material. We did use the millipore filter, and the all-glass filter, both the extra fine glass about 0.7 micron a more rigid paper (averaged about 1 1/2 microns) I believe. We used some paper which was made up by A. D. Little, which contained all asbestos. It was a very thin membrane of asbestos on a grid support. We found that all of these media gave us a considerably better retention. We measured alot more

on these samples than we would with Whatman 41. I am convinced from these studies that although Whatman 41 is a less efficient filter (by the way, that also holds true of HV-70) we got much poorer results with HV-70 than we did with these other presumably finer filters. The HV-70 was somewhat better than Whatman 41 but not a great deal. I am sorry I cannot give you any numbers on these. It was just work that was never really very extensive.

Leslie Silverman; (Harvard) We are glad to know the Whatman 41 story. I hope it might be convenient to utilize surplus to eliminate the poor efficiency paper.

William Harris; (NYOO) I would like to say it is not a poor efficiency paper. On industrial dust it was a good efficiency paper it showed better than 98 percent and consistently so and the material is extremely economical. I am sure, however, that there is a big variation in particle size efficiency.

Leslie Silverman; (Harvard) I would like to make one comment on what you said. It would be very nice to have all this particle size versus efficiency studies but we do know that most of these media are going to give high efficiency down to 0.3 micron when using the present DOP test. Now, I for one, am not convinced that the DOP test is the answer to this problem because it is a liquid aerosol and I think you get a completely erroneous impression of the performance of a media if you depend on a liquid aerosol alone. I think the answer, which might be an adjunct to what Bill Harris said is that we should have these efficiencies over a range. The solid aerosols of the type encountered in practice are the ones that he has gone a long way towards getting answers for their particular problem are the ones to use for tests. Many similar type dusts are encountered in other AEC sites and therefore, the information that they have will be very useful.

Considerable amount of work on high efficiency sampling filter media has been done at Oak Ridge.

William Harris; (NYOO) I would like to say something in addition to what you said, if I may.

Leslie Silverman: (Harvard) Surely.

William Harris: (NYO) I agree with Les 100% in that any stock that we place in DOP

testing of these papers is not well advised. Testing with the liquid aerosol is not the answer to our problems. On the basis of this, the NYO has just concluded a contract with Victor LaMer at Columbia to produce a piece of test equipment which will do exactly what the DOP tester will do except with a solid aerosol. In other words, an aerosol which can be measured with the optical analyzer and is easily generated in a generator and sized optically the same way the DOP is handled. I believe that he can do it as he has indicated and when it is finished it will be a very useful tool for everyone.

Leslie Silverman: (Harvard) I think there is one thing that Mr. Stafford and Mr. Smith are going to point out that I think they will go along with some of our needs here but will also point out that the DOP test is a very useful aid in manufacture to control uniformity and from that standpoint it has a considerable merit. What I was going to say before was that Oak Ridge has done a fair amount of work in this field and they are continuing the work and Willard Baumann has agreed to say a little bit about the work that they are doing.

Willard Baumann: (Oak Ridge) Well, the history of filter papers at Oak Ridge is based upon the DOP test and was started off using Whatman 42 and 44 because they showed low penetration with DOP. The reason they used the DOP was because there was another program going on down there, "the protective equipment evaluation program" and anyone that has used the DOP knows that it is pretty easy to use and you get rapid results. How good the results are, what they mean, may create some objection. We started to use the 42 and 44 papers and the reasons we did not like them was because after we had used them for some time they gave high resistance. We were limited because we were using 1 inch discs of paper and we wanted to get more airflow through the paper so we decided to investigate other types of paper. Using the DOP rig, we

investigated Whatman 41, 42, 44, 50 and HV-70. We also investigated, I think, a polyethylene filter that the Chemical Corps. loaned us. All these results were written and summarized in one of our progress reports. Based upon the work that we did, we decided for Alpha uranium materials, to go over to HV-70 paper using a single thickness and a 9 mil paper. This was based mostly on our DOP work. We found that with DOP we got high efficiency and good air flow characteristics through HV-70 paper. We also confirmed the work that Laskin has done, namely when we increased our velocity through 41 paper we found that our penetration decreased. At the present time we are using HV-70 paper for all our Alpha emitting contaminants and we are using Whatman 44 for beryllium, (Beryllium is really our only non-radioactive material with which we have to contend). One of the reasons we decided to do this testing was because we could not find anything available in the literature. We were like Bill and the others, when we tried to find anything in the literature it just was not there. Whatman 41 was being used but we did not like it because it gave high penetration. We decided to build a dust box and we hope to evaluate our filter papers again. What we are using in the dust box is a heterogeneous uranium. I think it is U_3O_8 and at the present time some of the early cascade impactor samples indicate that it has a mass median diameter about $7/10$ micron.

John Gallimore has done some of this work and we have not done enough to report on. What he did find out was pretty interesting and he has some counter efficiency data. We have been using for HV-70 based on field experience, a count efficiency of about 70 percent. We found similar results for his test work using HV-70; using Whatman 41 paper he got about 50 percent. (As I understand, Bill Harris gets about 70 percent). With the millipore filter we got 88 percent and with No. 44 64 percent and with CC-6 paper we found 82.5 percent.

Our program will consist of checking all these papers for efficiency.

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We are going to use an aerosol that we encounter in our particular installation namely uranium salt and see how well we can control concentration and particle size in this dust box. I guess we will find that out in time. Probably, after we get some figures we will continue to use the HV-70. I might say that we are using every type of paper in our work. We are using high volume samples with 41 and pleated paper. The only thing that runs consistent is for beryllium and there we continue to use No. 44.

Leslie Silverman; (Harvard) Do you feel there is enough advantage in the millipore paper for counting to stick to that for Alpha?

Willard Baumann; (Oak Ridge) The only trouble with millipore media is cost. It is very expensive since we are processing roughly between 100 to 200 samples per day. If we restrict it for beryllium we might be able to use it but there would be no advantage because we use a spectrographic method and Whatmann 44 has fairly low ash which fits our requirements for beryllium.

Leslie Silverman; (Harvard) Was the millipore used AA or the HA?

Willard Baumann; (Oak Ridge) This was HA. We have AA now and we will probably check it soon. I do not know whether there will be any difference.

Leslie Silverman; (Harvard) Bill, do you know which one you had?

William Harris; (NYOO) We have had both. We only used a few papers. I have two objections to their use, one of them is that in using a couple hundred per day the cost is tremendous and the other is the mechanical handling. It is brittle and hard to get in and out of the holder. It is just a difficult thing to handle. On a productive basis, where you are turning out hundreds of samples a day, it does not work well.

Leslie Silverman; (Harvard) Our primary application of it in our work is for particle sizing and direct microscopic examination. Its unique value is that you can flood it with immersion oil and get transparency and thus see agglomerates as they were collected. No other technique has enabled us to detect

agglomerates in aerosols after collection. This, as far as we are concerned, is one of its outstanding advantages because we feel that we can get high efficiency at far less cost. For particle sizing work I think it is unique. It also is soluble in acetone which is an advantage in chemical work.

Walter J. Smith: (A. D. Little) I would like to talk a little first about the DOP tester.

I agree it has certain drawbacks but if it was not for the DOP tests we probably would never have gotten anywhere. An extremely rapid way of testing samples from the time we start to prepare a paper formulation in the laboratory until we have an answer to its penetration can be as little as 10 minutes. In that way, you can go through experiments pretty rapidly. I do not think it is any exaggeration that in the course of our paper work we have made many thousands of hand sheets. At one time we feared also that the DOP tester was probably giving us something that would not be comparable with the results you might get in practice so we worked with cascade impactors and finally got a model to our satisfaction and compared it with the DOP results. In general, for submicron sized particles of atmospheric dust, there was always a different correlation. If DOP penetration was in the order of a few hundredths of a percent so was the atmospheric dust penetration of submicron size as determined by particle counts on an impactor slide. By comparison for a result of that kind we might have to run our pack on such clean air for many hours. The counting is tedious. You can never depend on one count and without exaggerating the situation one bit I would say that there have been times when we have spent two days getting a single answer of efficiency per paper compared with the matter of just minutes on the DOP. For that reason, for routine work, the impactor did not fill a very big place. On the other hand, we all know that there are particular media which show after the DOP tests had been operating a while, that penetration increases. In the case of the millipore filter the surface appears to fill so rapidly that you do well to get a reading at all. The effectiveness of the DOP tester, I think, is brought out

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by the fact that the manufacturers of the space filters all have a DOP tester, a large one. They have a huge smoke generator and pass DOP through the complete unit, 1000 cfm and take a sample before and after. It is a rapid way of telling whether a particular filter is acceptable. I have watched them with an inspector from one of the areas testing filters for acceptance and almost as fast as they can handle them they can tell whether they are over or under the specification.

Two years ago, Mr. Stafford and I made a tour of the areas and among other things we asked about the test and monitoring filter practices. We came away with a distinct feeling that there is plenty of room for improvement, especially on simplification. It seemed that everybody had his own ideas of what should be used and in some cases we felt that they were not using the best thing. A choice in some cases was dictated by the matter of availability, if a man could open a drawer and take out a piece of filter paper, well, that is what he used. In other cases, there was a reason for particular choice and we found one case, as Les did, where some authority in the forgotten past had decided on what should be used for a paper and it was carried on. In a few cases, we had the suspicion that the person felt his work was so important he just needed something different. There is opportunity for simplifying and giving everybody what he wants. For the past few years there have been so many new developments in fibers I think you can probably give every person with a separate project a different filter.

Sometimes I think there is probably a real need for a special paper and just the past 6 months I have been impressed with the determination of one laboratory to get a certain filter. I think it would be well to take the time to tell you about it. About 6 months ago I think the first request was for a set of characteristics of some samples. Mr. Stafford made out a few sample sheets and sent them out. This was to Los Alamos. About 3 months later we got a request for a quotation on 100 sheets each of those from the Purchasing

Office of the University of California and we wrote back that we were not in the business of making the paper and we did not have them in stock. They insisted, however, that we provide a quotation. Well, we could not do that working under AEC Contract so we said perhaps we could make them up on our contract. I tried to find out who the man was that wanted them. I thought I knew him from the previous correspondence but I could not locate it so I took a chance and we made up 50 sheets. I thought that would take care of it but very recently we received a request to please complete the order.

On the matter of fine filters, I think we all know what the absolute type filters can do and the only thing that I would like to add to that is this - that we get the impression from all this that we are working with nothing but mineral fibers. That is not necessarily so. There are some cases where it is necessary to digest or incinerate a filter in order to get a gravimetric result or to recover something that is caught. It is true that most of the present work has been directed toward fine glass fiber or asbestos fibers because they are cheap and easily available. There is a distinct possibility that the organic fibers, which are also being made in finer and finer dimensions, could be used for this purpose and we have done enough to convince ourselves that you can make an all-organic medium consisting of coarse fibers supporting finer fibers or also organic fibers and get efficiency similar to the absolute papers. I just point that out because some of these fibers have to be disposable after they are used.

Leslie Silverman: (Harvard) We have had sent to us, not too long ago, some papers made out of Dynel fibers, which apparently will pass the DOP test with high results. We also have Polystyrene, Polyamide, and Nylon fibers all in the range of a hundredth of a micron to half a micron and it is quite possible now to make chemically soluble filters from these micro-fibers. These will dissolve in acetone, carbon tetrachloride or a suitable solvent. Again now it is a

matter of these fibers being only an experimental production item and our demand for air sampling uses would never satisfy the requirements manufacturers would like to have. It is possible to get papers made on a hand sheet basis of any of these superfine synthetic fibers. I do not know what particular advantage one plastic has over another but they have thermal and other physical differences. Most of them are not too high in air flow resistance, but the ones that are completely chemically soluble provide a means of getting your sample in solution and elutriating your sample from the solution or the solvent if you want to make a particle size separation. They do have some other attractive features. We still do not have a good sampling media as a filter which can be placed into the electron microscope for micrography work. We hope that in the near future we can get millipore media in a thickness that will permit it to be put right into the electron microscope and not offer any background shadow. It looks as though it might have some promise. One field where these organic fibers will appeal to the chemist is in ashing where there is no significant ash to bother their analyses.

Los Alamos has been doing a large amount of air sampling both on the site and off the site and Mr. Edwin Hyatt of their industrial hygiene group is here in place of Mr. Harry Schulte, who unfortunately is ill. He will make a few comments on their problems at Los Alamos.

Mr. E. C. Hyatt: (Los Alamos) The most pressing question that you had Les, was why does Los Alamos use 18 mil HV-70 and Argonne 9 mil. You asked this some time ago and I have been asking around Los Alamos. The industrial hygiene group has only been there about 4 1/2 years but it goes back before them and we are trying to lay it in the lap of the army. The routine sampling has been used since the day of the Manhattan Project at Los Alamos. There are pretty good reasons for using the HV-70. First, as to the 18 mil, the double thickness makes it more rugged and the health physicists and monitors claim that this is the most important requirement. They actually have tried the 9 mil and it

is not as rugged as the 18 mil. The HV-70 paper we have found is more efficient than the Whatman 41. For routine sampling we have also found that there is an absorption of approximately 30 percent for the alpha material, and 70 percent counting efficiency. This is comparable to the Whatman 41. Another thing, when you have expensive sampling instruments that have been made up for a certain sampling paper it is convenient to continue using them. There are over 300 samples per day taken at Los Alamos with the HV-70 paper 18 mil. This varies up and down for 300 ± 50 . We do use it routinely in Filter Queen units. We use a piece 9 x 4 inches or 36 square inches.

Recently there has been an investigation to get better sampling paper for certain types of sampling operations. Since this is an unclassified session we can not disclose the type of alpha material but we have about 5 different types that are sampled. In any case, first I should say the habits of the health physicists are to run off samples as long as 7 1/2 to 8 hours per day. In some cases you might have this paper loaded in other places the particle population is so light that at the end of the 8 hours you might have 2 or 3 particles which would be actual tolerance and under a wide variety of conditions. Most of these are done with HV-70 paper. A very important factor is Los Alamos' research and development projects where there are a lot of new materials being used constantly. When you sample for these new materials you like to check your counting against chemical analysis. This is the greatest weakness of HV-70. We think ash and insoluble asbestos are troublesome. When you have unusual materials collected on your filter it is literally impossible to dissolve it without getting a great mass of ash. Also, for this reason we are using a lot of Whatman 41. HV-70 is used in Filter Queen units placed in a room and in designated positions. Whatman 41 is often used. We probably never take more than a 30 minute sample with Whatman 41. We use the same

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holder and paper as NYOO, the 1 1/8 inch. In fact, I think we got our first stock from Bill Harris.

In addition we do a lot of Cascade Impactor work for routine sampling. We have been finding absorption of 30 percent on the Cascade which is approximately equivalent to HV-70.

There is one question that we would like to raise. We are not completely satisfied with No. 41 on certain types of operations because of its non-uniformity. Harris, I believe, stressed the fact that you had a uniform efficiency. On some of them you can see pinholes and others you cannot. I raise the question that efficiency may not be so uniform as we have been led to believe. Along with the Whatman 41 we have used a lot of molecular filters (MF). We have 8 or 10 Cascade Impactors with molecular filter adapters so it is beginning to be used routinely. At this point I will deviate from the routine operations at Los Alamos to collection of fallout from various Nevada tests. I believe that there is little I can say about the nature of the material from fallouts. You have read about it in the papers and I am sure at least that much is unclassified. Isn't it Les?

Leslie Silverman; (Harvard) Yes, I read about it in the paper. That is the truth. It has been necessary to know they test in the U. S. and collect large numbers of samples.

Mr. E. C. Hyatt; (Los Alamos) They want to know two things, the concentration and the particle size. For the particle size studies we have used about three dozen Cascade Impactors and a lot of molecular or millipore filters. We have obtained some of our most significant results, we think, with the molecular filter as the fifth stage instead of the Whatman 41, for the simple reason that we have obtained material that is not collected with Whatman 41. We have tried both HA and AA, the only difference we can see so far is in pressure drop.

The type S as Silverman has mentioned has been used extensively in the Hi-Vol sampling and also for atmospheric sampling around Los Alamos

up until this year. Again the type S cannot be counted because it is a thick paper. Being about 1 inch thick we cannot count it very decently and you have to ash it.

MSA 2133 which happens to be a flat paper with more efficiency than the type S paper has been substituted and it can be counted readily. This paper can also be ashed. For the work at Los Alamos we are now using thousands of 2133 papers and I think that Harris is also using an equal number all over the United States in their sampling work. We would like to ask this right back at Les. We understood that the efficiency was tested for the 2133 and our tests last spring and our results also indicated that it was very efficient. As a result, there are others now using it on the same type of work and everybody is satisfied with it but we know absolutely nothing about it. The only thing I know is that the BM 2133 is used in respirator pads and carries a Bureau of Mines approval.

Leslie Silverman: (Harvard) I am afraid I cannot answer that because 2133 is a number that does not ring a bell with me. We never tested it. All I remember about respirator pads is that we had used type S in our unit and the next thing I knew was that in our so-called Hi-vol Sampler, the group at M.I.T. has been following NYO in using the flat respirator pads from the Comfo-respirator in place of the pleated paper. We can disclaim honestly responsibility for 2133 except for saying that NYO used it. We never ran any efficiency tests and the only efficiency tests on Hi-vol Samplers have been with regard to the Type S or Whatman papers.

Mr. E. C. Hyatt: (Los Alamos) We ran some interesting tests in various places using two Hi-vols side by side which is always subject to error, of course, out in the open where you do not have comparable conditions with the pleated Type S paper and the Comfo flat paper which is the 2133 approval number. We got approximately 3 times as much on the 2133 paper. We heard that for

certain types of industrial dust, 2 to 3 microns, I believe Type S was 80 percent efficient. We think that we were losing the material in ashing. One of the reasons 2133 is very good is it is rugged and you can not break it. It is literally impossible to break it and it is one of the best papers we have ever run across. It is very nice to count but we do not know the penetration.

Leslie Silverman: (Harvard) How much air can you get through on the Hi-Vol?

Mr. E. C. Hyatt: (Los Alamos) We were getting around 57 cfm at an elevation of around 6,000 feet. Of course, elevation is a volume factor here.

Leslie Silverman: (Harvard) The only thing I know about the efficiency of 2133 is that it passed the Bureau of Mines approval test with Type A dust, which means that it should be between 89 and 97 percent efficient. They use a dust loading of 5 milligrams per cubic meter + 1. If you sit down and figure out the efficiencies based on Bureau of Mines requirements, based on the amount passing at the end of the period test, you will find that 0.4 of a milligram after 1 1/2 hours test is permitted with the above loading on a silica dust of 0.6 μ mean/^{size}with a given standard deviation. Harvard has never tested No. 2133 filters.

Mr. E. C. Hyatt: (Los Alamos) I would like to point something out about 2133 in some of these investigations. We have found that 2133 increases very little in resistance over quite a long sampling period. In other words, collecting even a fairly heavy mat of particles on the surface makes relatively little change in the resistance across the paper. My explanation for this, it may be wrong, is that the paper tends to stretch with this large volume of air going through it and the pores open up some. It may be that the efficiency is variable and that at the end of the sampling period it tends to go down. That may not be true but I would like to point it out.

Leslie Silverman: (Harvard) Does 2133 have a heavy nap on the surface?

Mr. E. C. Hyatt: (Los Alamos) It has some nap on the surface but you can see a definite low in the paper. It may be stretching and the efficiency may be lower.

Leslie Silverman: (Harvard) We did measure the effect of stretching on sampling papers and Hi-Vol samplers and we checked the area when stretched. We found that there was some stretch but off-hand I would say that the nap was a greater aid to getting a thicker mat on the surface and still keeping resistance down.

Mr. E. C. Hyatt: (Los Alamos) There is one thing we might add, Les, that the Health Physics group and the Industrial Hygiene group at Los Alamos have been meeting in the last month to reconsider and to reevaluate all of the paper and sampling instruments used and we are very interested in this subject because the health physicists frankly admit that they do not think they have the ideal sampling paper or instruments and are ready to listen to anyone who has ideas on anything that is better. The whole field is really open. I understand that there are some projects that have adopted papers and they will not talk about any other. We will. We will talk about other types of papers and if anyone has a better one we are very interested in hearing about it and using it.

Leslie Silverman: (Harvard) We have a representative here from Hanford who has done a considerable amount of work on filter media and also on respirator pads. Maybe he can tell us something about 2133.

Mr. Frank Adley: (Hanford) We use by far CC-6 in greater quantity than we do 41 or any of the other papers due to the fact that it was one of the first high efficiency papers that came out for site use and in addition to being high in efficiency there was more known about it, hence it was adopted for wide use at Hanford. It is used at the present time in large quantities. We use it for off-site monitoring, we have several stations surrounding the plant in the communities. We use CC-6 for that purpose. We use it for in-plant monitoring of buildings and personnel on a fairly routine basis. Over a period of time it was possible

to develop pretty good data on counting efficiency of such paper so we feel that the results are fairly reliable when we count them. On occasions, however, we have come across instances where we wanted a different type of paper, primarily because we wanted to do a chemical analysis on a sample. I think everyone that used CC-6 is aware of the fact that there are constituents such as asbestos which foul up your analysis and for that reason primarily, we went into different papers.

The one we started using was Whatman 41. At the time we adopted that we were involved in studying a uranium contaminated atmosphere contaminated with U_3O_8 . Then we sampled with Cascade Impactors, regular special filter heads with just sampling medium and we also used the Hi-Vol samplers. There was a question all the way through as to what we were getting for collection efficiency so when we were well along in the study we thought we had better check back to get performance. We knew the experience with lead fume and dust and other fumes. They had done some work at Harvard a number of years ago. So we were interested in seeing what we were getting for uranium. The atmosphere that we were involved with in the plant was U_3O_8 medium. The particle size was about 0.6 to 0.7 micron and the standard deviation was about 4 to 5. We set up a test procedure in a laboratory and could generate U_3O_8 similar to the conditions in the plant only on a smaller scale. We ran that through the various filter media and from that point into an electric precipitator. Frankly, I have not had much reliance on electric precipitation. When it is working it is a dandy unit, but you can never go away for 5 minutes in the next room and feel that it is doing well. We developed an electric precipitator unit which was made rather precisely as for the circuit and voltage pack, central electrode and the collecting tube. We ran efficiency tests when we got it completed and found out that if we held the central electrode at about 10,000 Kv we could be assured of about 99.7 percent efficiency. We

usually run it up about 14 or 15,000 Kv just to make sure. So we backed the filter media with the precipitator and got a few values. The Whatman 41 filters we set the atmosphere in the laboratory to see just what its characteristics were as to particle size and we ended up with the particle size of 0.5 micron and a standard geometric deviation of 4.9.

In the series of tests which we made on Whatman 41 we found a mean efficiency of 92.2 and 98.8 was the highest value. I think the loading and probably the particle size variation had more to do with the variation in filtration efficiency than anything. It might be that there are pores in the Whatman 41 which pass the fume.

We also checked the MSA pleated filter, that is, the Type S that we get from MSA, and it was found that they were fairly high in efficiency but not dependable by any means. Not as dependable as Whatman 41 which in itself was not too good. The pleated filter tests varied from 87.3 to 99.4 which was the highest value for unimpregnated pleated units.

Leslie Silverman: (Harvard) Did you count these?

Frank Adley: (Hanford) No. They are chemical analyses. Radiochemical analysis all the way through. We are not through with this study yet by any means although I do not mean it is going to be an extensive study. We still have^a/few more things to investigate. Just before I came away we had some AAA Hurlbut's glass-fiber medium around, X935, and we got that from Al Blasewitz. I do not know whether Al is here this morning or if he has gone home, but I am not sure just where he got it. It is identified as Hurlbut's No. X935. The tests that we have run on that, so far, are well over 99 percent in efficiency with the exception of just two samples which for some reason were low (I call low 98.7 and 96 percent). The others were well over 99 percent.

Anonymous: May I ask at what rate you ran the Type S?

Frank Adley: (Hanford) We varied from 12 to 180 cfm.

One interesting feature about the AAA medium that we found in the test arrangement I told you for testing with U_3O_8 , was that when we placed the AAA fiber medium in the holder and started using it as we had with the Whatman and the pleated filter medias, we found that a disc ruptured. This got us interested in whether filters had any decrease in strength under various loadings. With clean media we ran a series of tests for various pressures and found the following results. We had a 2 inch opening and placed the filter between 2 plates. We increased the flow of air through the test media until the pressure drop read up to 0.75 inches of mercury at which point it burst. We decreased the size from 2 inches to 1 1/8 inches and the inches of mercury bursting pressure on 2 tests was 1.9 and 2.4. Getting still smaller openings down to 1/2 inch resulted in values of 4.5, 4.5, and 7.5. It turned out that the pressure to burst through a 1/4 inch open suspension was 16.6 inches of mercury.

In another series of runs we made we placed the filter in between the plates and introduced uranium fumes from the chamber through 1/2 inch openings. We found that when the load was 0.2 milligrams per square inch, bursting occurred and that pressure was 2.3 inches of mercury. Correspondingly, through the same 1/2 inch openings with a 1.34 milligram per square inch the bursting pressure was 5, with a load of 2.5 the bursting pressure was 6, with a load of 3.2 the bursting pressure was 7.5, etc. That just about covers the tests we have run up to date.

There is one thing I thought of this morning which I want to mention here in connection with filter tests and the efficiency of collection of various sampling devices. It goes back to Dr. Lapple's statement yesterday that we have an air cleaning device which was supposed to be 99.999 but how many 9's do we finally add on to 99 when we get through? Assuming we have

an aerosol of say 100 units entering a filter medium and that filter is 98 percent efficient, you will have two units going through. Although your device is actually 98 percent efficient you might be sampling the upstream influent with a sampling entering device which is 99 percent efficient. Downstream where the material is usually either a lower particle size you probably get a lower efficiency, say 85 percent, or you end up with an assumed efficiency of the air cleaning device if you want to carry it out far enough. If you are concerned with stating efficiencies of air cleaning devices you should not lose sight of the efficiency of your appraising device. Sometimes it makes an appreciable difference, especially when you are up around 99 percent efficiency. When you are down around the lower efficiencies (60, 70 and 80 percent) it does not make a great deal of difference but you might be interested in more accurate results in high efficiencies.

Leslie Silverman: (Harvard) Frank brought a good point up with regard to the testing of air cleaning devices. We have run into the same problem and for that reason tried to get as efficient a sample for that purpose as possible.

George Payne: (Argonne) Argonne's problems may provide some answer to 9 mil versus 18 mil HV paper. I recall some of the things that were studied in the early days, and one of the papers tested is one, I think, that you probably made Dr. Stafford. This was an asbestos suspension on a very fine tissue. At that time we were using one of the NDRC papers and I remember that the harder paper would result in less absorption.

I think that one other point I should make clear at this time is the fact that our laboratory has not had an industrial hygiene section for a very long period of time. If enough people can be trained by Silverman, we can hire them. Meanwhile we hope to build up an organization to do some particle size work. At this time we have done practically nothing

in this field.

I think that many of you people here realize that much of this work was done during Metallurgical Laboratory days and the HV-70 paper was essentially the NDRC paper made at the requests of them to Dr. Stafford. We are continuing now and had used these papers during this whole period of time. We have done beryllium sampling and have used Whatman 50 for this purpose. I cannot give you the reasoning behind the choice of that particular paper. I do know that it satisfies the chemists who do this analysis and we are able to collect sufficient quantities of sample in the standard filter holder in order to get reliable data.

Within the last two or three years we have added a background analytical group to the Radiological Physics Division and Andrew Staney is the chemist in charge of this particular group. He is now making studies of outside air and he has been using the HV-70, 9 mil paper. As mentioned here the chemical handling is a very major problem and we propose to use millipore filters after we have done some work with them and feel that they satisfy the chemical handling aspects.

One of the problems, I think that I do not feel particularly clear on, is the fact that with the proposed reduction in permissible levels for the alpha emitting materials which we are primarily interested in, I should say, for good statistical reliability the volumes of air that can be handled and collected in a short period of time are going to play an important role. The resistance or pressure drop and the paper filtering velocity I think are going to play a role in the absorption efficiency. I think that if going to higher increased velocities in order to collect reasonable quantities of air in a reasonably short space of time is going to play a role in the absorption phenomena in the paper. This is something that ought to be investigated thoroughly. With the proposed reduction it is going to make the air problem much more difficult to evaluate. As I said, our investigations

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have been practically nil and I do not believe I can add anything more to the description.

Leslie Silverman: (Harvard) One thing that comes to mind after this discussion today is do we need standard methods of air sampling and, if so, what are we going to standardize on? If we are not in that position what areas or investigations are needed to solve some of these problems that have been brought up in the discussion this morning? I would appreciate some comment from the group as to whether or not we are in a position to standardize on 18 mil or 9 mil HV-70 or standardize on Whatman 41 until Harris' supply is gone, or if we should standardize at all. The floor is open to discussion on the point. Is there any discussion from the floor on the question of whether we should standardize or try to get one thickness of HV-70 adopted. Aside from the handling or strength standpoint I have not heard a great deal of reasoning behind 18 versus 9 mil paper. I suppose it will be troublesome to close the Filter Queen that has a double thickness of paper in it, but I believe any of the sampling heads for this instrument will take 9 or 18 mil paper.

Mr. Stafford: (A. D. Little) I have a few comments on these papers. As long as you are buying a known filter which is of good quality you will get good results but if the company or source should change they do not know what they are getting. AEC people are buying these papers just by name but they do not know what they are getting and there is nobody in the Commission whose duty it is to test these papers and find out if they are constant in quality. Now you talk about tests made on Whatman 41 a few years ago. Well, Whatman 41 today or next month may be quite different and nobody knows it and you use the data that we made for the paper that Whatman was making at that time. The Whatman's papers are made, of course, for chemical filtration and they are tested primarily for that. There could be considerable change from one

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year to another. If they can get the proper kind of rag their paper has certain characteristics of interest to AEC but perhaps a year from now they may be using a different material and their paper is different and except for the filter paper for the space filter there are no specifications or no definitions of these things except by number and they come from certain manufacturers. I have been interested in the S&S paper and that is made in this country. Somebody concerned can go to the mill and have them understand what the requirements are and make sure that they are fairly uniform from year to year. Whatman is made in England and they make a great many grades. While they are wonderful paper makers, they make primarily for the chemical laboratory which is wet filtering and I do know there is a big variation in certain sheets of Whatman 41.

Leslie Silverman: (Harvard) I would like to suggest that in order to make sure we get consistency in HV-70 or its equivalent, that some specifications be made up that can be duplicated by paper manufacturers and that we come to some agreement about an all-cellulose paper which is comparable in resistance and filtering characteristics to anyone of the Whatman or other series. The group should accept this media for their purpose to avoid the problem of item No. 3, (Table 1) uniformity, because as Mr. Stafford indicates, you may have Whatman 41 of one type today and something completely different tomorrow. Most of us cannot buy a 10 year supply such as Harris has and even in that supply there may be a good deal of variability.

Mr. J. A. Lieberman: (AEC) Is there any information available on the roughly comparable efficiencies, for a given aerosol, between the AEC paper or the CC-6 paper and HV-70?

Mr. Stafford: (A. D. Little) Well, HV-70 is practically the same formula as CWS-6 except that it is beaten a little more and made a little stronger. It has about the same efficiency for DOP but its resistance is 50 percent or

maybe double what the other is. Its surface is harder and that is why you like it and can handle it. I do not know how Hollingsworth and Vose makes it but they probably have not made more than three or four runs because they make the paper by tons and you use it by little discs. This is one trouble in any new paper such as the one Les mentioned, that is paper of Dynel fiber. They can make up some hand sheets but it is a tremendous step to get that in production. No paper mill is interested in doing it unless they are sure of carload lots and it costs a lot of money to do it.

As for this glass paper I think that you may be able to use this Hurlbut paper. They are excellent paper makers and they are using a very uniform finish.

About the asbestos sheet that has been mentioned here, if sheets of plain asbestos such as we have made by hand prove to be valuable, I am quite sure you could never get it made in a paper mill. It would always have to be a laboratory operation. There is one exception to that and in the contacts I have had just recently that there might be some hope. Johns-Manville is now making, in a small mill in New Hampshire, all asbestos sheet made of Canadian asbestos which is purified and is used for bable wire. If asbestos sheets could be used, there is a commercial source. It is not very strong, I would say it is only about 5 mils thick, but Canadian asbestos makes a stronger sheet than any other kind and that could be used for sampling. Has anyone ever heard of it and tried it? If not, I would be glad to get a sample and send it to anyone who is working with asbestos.

Mr. J. A. Lieberman: (AEC) What I was leading to was this. Since the AEC has a specification for the production of space filters we have, almost ipso facto the specifications the mill must meet to make the media that go into these filters. If the paper itself is suitable why can we not kill two birds with one stone, i.e. use it for a sampling paper?

Mr. E. Stafford: (A. D. Little) Well, I wondered why you did not use the space filter paper.

Leslie Silverman: (Harvard) Penetration is the most important problem. If you use the same composition but calender it thinner then it might be suitable. In other words, I gathered from what Mr. Stafford said that the composition of HV-70 may be variable.

Mr. E. Stafford: (A.D. Little) Yes, on Whatman but not on HV-70. I am quite certain that they use the same composition as they use on AEC but they treat it different to give it more strength and therefore its resistance is high but they make it so that the penetration is about the same or maybe a little better.

Leslie Silverman: (Harvard) I do not think the supply problem should be too bad. I do not know whether I am saying things out of turn but I think if everyone got together a large enough supply could be purchased to take care of the sampling needs for a long time.

Mr. E. Stafford: (A. D. Little) I think that would be an ideal way to do it then all samples would be alike.

Leslie Silverman: (Harvard) Well, maybe Joe (Mr. J. A. Lieberman) and Art (Arthur Gorman) would look into that phase.

Mr. Arthur Gorman: (AEC) This is the second year now in which this thing has been discussed. I think if the group here who use these papers would indicate what they want and we could get a good consensus on the criteria they want these papers to measure up to, we can get AEC to follow through and get the papers you want and identify it with an AEC number for AEC work that everybody understands. We do need your judgement as to what you need and if you are going to have one, two or three types of paper. I am hoping that out of this discussion we can get something that will give us some facts to use.

Leslie Silverman: (Harvard) I gather that from our discussion this morning and our discussion last year that there are about three kinds of paper that would satisfy all of the

needs. One which is the HV-70 or its equivalent, the other which is Whatman 41, 44 or its equivalent and the last one some high volume media such as used in the 2213 or the Type S filter. I do not presume to say that we ought to boil it all down to one and get rid of the three. Mr. Harris indicates he thinks it can be reduced as two types.

Mr. William Harris: (NYOO) I do not see why the characteristics of the HV-70 and the Whatman paper cannot be combined into a single sheet.

Leslie Silverman: (Harvard) That obviously means eliminating asbestos if that is correct. In other words, would everybody here be happy if we had an asbestos free paper? I do not think everyone agreed but that is exactly what I believe Mr. Harris is proposing, that we get an all-cellulose paper or low ash paper with efficiencies that are high and consistent.

Mr. E. Stafford: (A. D. Little) The trouble with most organic fibers is that they are hard to produce uniformly.

Leslie Silverman: (Harvard) Let me ask this question, Walter and Earl. What can we expect in an all-cellulose paper?

Mr. Walter J. Smith: (A. D. Little) There is one possibility there to give some consideration to but we have not had the fiber to try as yet. As you know, when you beat a cellulose fiber, just let me point out one thing further. Some people think that a paper filter has a binder to hold it together. That is not so and if you watch these fibers as they are worked in water they begin to soften and fragment. Under some circumstances you can keep their shape and press them into a sheet.

Leslie Silverman: (Harvard) Well, it would appear if we do any standardization that it should be on a low ash paper. Now, obviously, in making low ash paper they treat the pulp by acid extraction. That will be one of the requirements because the Whatman 40 series are relatively ash free. If we are going to standardize or get a uniform paper used it must be ash free. I think we can agree to that.

Mr. William Harris: (NYOO) The second filter type is the high volume filter.

Leslie Silverman: (Harvard) Now that one is an ash problem too, isn't it?

Mr. William Harris: (NYOO) No, that is not much of an ash problem because when a sample is taken 24 to 48 or even 72 hours, you get so much material on the filter that the ash content of the sample itself is not significant.

Leslie Silverman: (Harvard) How about yours, Ed. Is ash a problem there?

Mr. E. C. Hyatt: (Los Alamos) I think it is.

Leslie Silverman: (Harvard) We have a difference of opinion, Frank?

Mr. Frank Adley: (Hanford) I do not want to argue but there are many cases where you run a high volume sampler because the concentration is very low.

Leslie Silverman: (Harvard) Well, I do not want to get involved in a long discussion on this. Apparently Art, there is some need of an ash-free all-cellulose filter which I think our friends at A. D. Little are in the best position to make. The question of specifications for an asbestos paper media apparently exists in AEC No. 1 or CC-6 paper. It is a question of that paper being too difficult to handle, although Hanford uses it in their sampling program. I think what we should do is have a conference of those people that are directly interested as we had proposed last year as to what exact specifications must be drawn up and I would like to leave it that way if it is agreeable to the group.

Walter J. Smith: (A. D. Little) I believe a questionnaire would be desirable to circulate to get response of interested people.

Leslie Silverman: (Harvard) Well, I think that would be a good idea if you would assume the burden of making up a questionnaire for the poll and see what sort of response you get. I think all of those here would fall in line with that. You might get such a variety of answers that you would be right back where we started this morning but I think we now have a pretty good idea as to what we need. We could boil down at least seven different sampling media into possibly two.

Mr. George Payne: (Argonne) In discussion this morning several of the installations are rather large and apparently are limited to various test facilities but there are a number of installations which have essentially no testing facilities for efficiencies of various other items like this. It would be very nice to have available some booklet which might describe quite adequately some of these papers for outside uses.

Leslie Silverman: (Harvard) I think that can be done after we agree on what can be expected of these papers. I think that would be part of the program.

Arthur Gorman: (AEC) We will initiate an action towards getting some results if everybody here would talk with the people back home as to what they want and when we write out to you for the information give all the data you have. I think a year from now we will be pretty well along.

Dr. Melvin First: (Harvard) I think Les, there are two problems involved here. One is to decide which papers are now available that you want to use and secondly, the development of a new paper if it is desirable, if the ones that are now available do not meet the requirements. In any standardization, I think we should start with what is now available.

Leslie Silverman: (Harvard) What is available now is not very standardized as I gathered.

Dr. Melvin First: (Harvard) No, that is exactly it. If a step was to be made in standardization, one problem would be to consider what is now available and standardize on a few types temporarily and simultaneously do a development program for developing new types which would be more satisfactory than what is now available.

Leslie Silverman: (Harvard) I gather that the questionnaire should accomplish the first part of that program and the second part should result from what sort of dispersion we get in answers in the questionnaires.

Dr. Melvin First: (Harvard) That possibility might also be raised in the questionnaire as a special item.

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Dr. Leslie Silverman: (Harvard) I think that is part of Walter's job and we can give him some help on that. One thing I would like to know is whether or not this type of meeting is worth repeating again within a year or two. As you know from our discussion, a good portion of it is for training of people unfamiliar with air and gas cleaning problems. We have had a representation here of about 60 percent with regard to previous attendance and contributions and we still want to keep on training if there is any real need for it. It is quite evident, at least from my standpoint, that it is worthwhile to get together at yearly or intervals close to that range and discuss progress on these problems. I would like to get some ideas as to the sentiments of the group in that regard. Is this worth repeating in a year or two? Do you have people at your site or location that would be interested in the review part of the work and do you have people who would like to contribute to the air cleaning aspects or gas cleaning aspects of their program? Any discussion on that?

General discussion resulted in a unanimous opinion in favor of repeating the seminar within a year at a different site with emphasis on new developments.

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