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DEEP-BED FILTER PERFORMANCE TESTS

G. A. SCHURR

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Savannah River Laboratory

Aiken, South Carolina

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DEEP-BED FILTER PERFORMANCE TESTS

by

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Wilmington, Delaware

JULY 1972

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ABSTRACT

Comparative tests of filtration efficiency and particle holding capacity of sand and "Fiberglas" filters have been performed. Filters tested were modeled after designs currently in use at the Savannah River Plant and Hanford Works. The test program included: 1) efficiency determinations of sand and "Fiberglas" filters using accepted DOP aerosol testing techniques routinely used for the efficiency determinations of HEPA filters, 2) efficiency evaluation of specific sand deposits, and 3) simulated smoke loading of both the sand and "Fiberglas" units. The tests have provided engineering data on filter performances, specific sand efficiencies, filter safety, and costs.

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INTRODUCTION

The usable life of the deep-bed sand filter in service at the Savannah River Plant is unknown. These filters have been in service for 16 years. Recent mechanical failures may hasten their replacement. Quantitative filtration efficiency data collected during their use have been restricted to analysis of radioactive components. Activity measurements before and after the filter have indicated efficiencies of >99%. The study reported herein was conducted at the request of Du Pont's Design Division to provide additional engineering criteria for specifying new filter units optimizing on cost and safety. The sand and "Fiberglas"* filter media were singled out for study due to their satisfactory service at Savannah River and Hanford Works, respectively. The data developed in this program provide useful guidance for expected performance standards of either media, and identify design limitations and advantages for each case.

* Registered tradename of Owens Corning Corp.

DETERMINING FILTER EFFICIENCY

A filter's efficiency is a measure of the unit's ability to collect particulates from the air stream. A high efficiency air filtration system is one which has a particle collection efficiency approaching 100% for 0.3-μm particles. It is desirable that a sand or "Fiberglas" deep-bed filter be designed to provide high efficiency filtration. The use of dioctylphthalate (DOP) to produce submicron particles for determining filtration efficiency is a standard procedure. For the tests reported here, efficiency was determined using in-place HEPA** filter testing equipment at the Savannah River Plant.

The DOP aerosol generator used produced a polydispersed aerosol having an average particle size of 0.7 μm. A light-scattering particulate-detection instrument manufactured by Air Techniques, Inc., Baltimore, Maryland, was used to measure the relative DOP aerosol concentration upstream and downstream of the filter units.

SAND FILTER TESTS

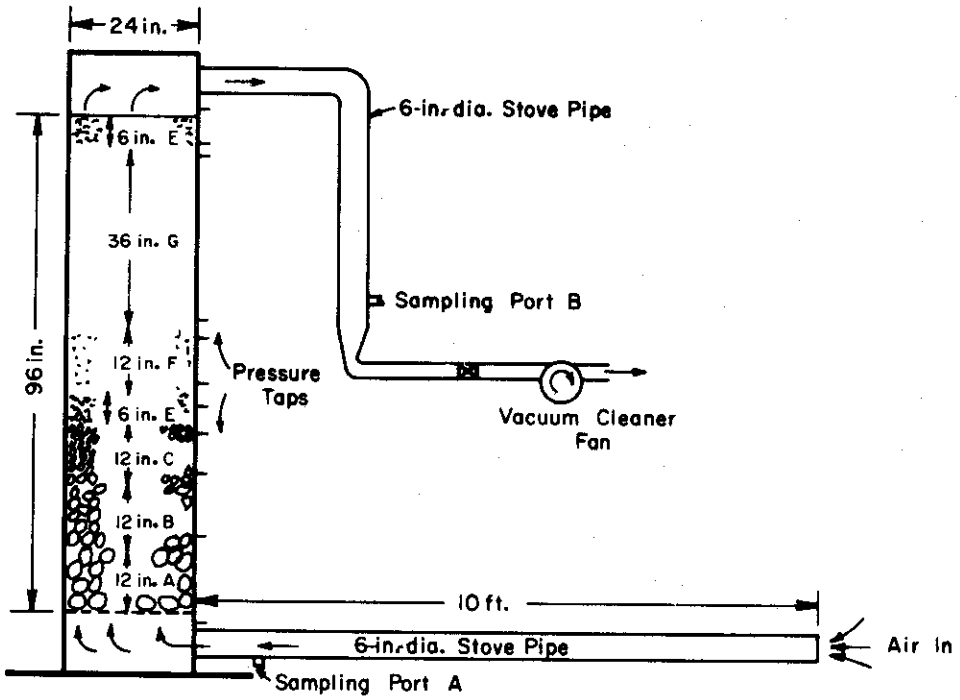
The sand filter test program was directed to determining:

- The efficiency of the Savannah River sand filter design for submicron particles
- The effect of compaction of the bed on filter performance
- What variation in aggregate specifications can be made to maintain or improve efficiency without unreasonably increasing operating pressure

A 2- by 2-ft plywood box, 8 ft high, with one side transparent, was constructed to hold the deep-bed filter media under test. A fan was operated at expected pressure drops and at superficial flow velocities up to 15 ft/min in the bed. Figure 1 shows the aggregate grades of sand and gravel specified for the operating Savannah River filters.

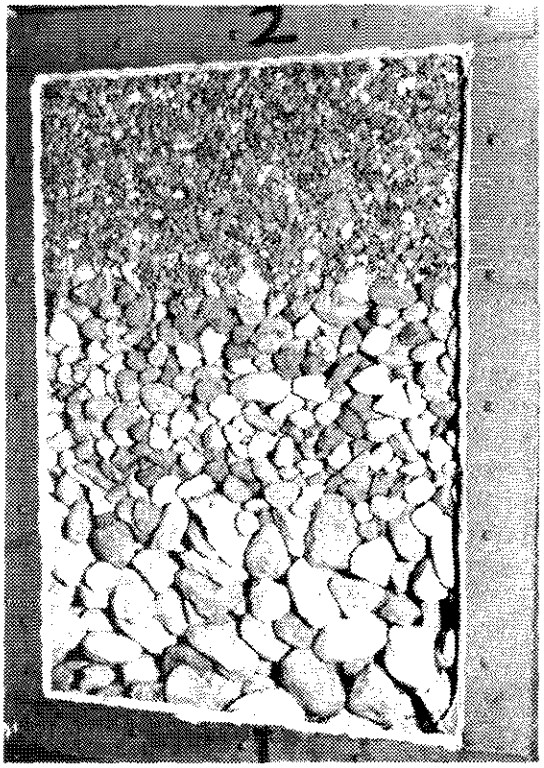
To duplicate the existing sand filters as closely as possible, sand and gravel was obtained from the original source and vendor (Northern Sand and Gravel Co. of Muscatine, Iowa). The required layers of gravel and sand were placed in the test filter by hand per specification. Figure 2 shows the graded sand levels as viewed through a transparent side of the model. Fittings for 0.25-inch copper tubing were placed in the filter wall so that

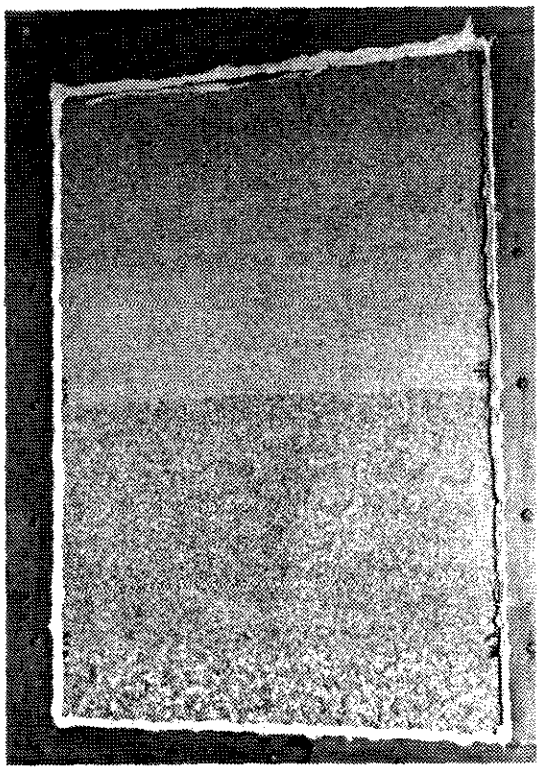
* High Efficiency Particulate Activity.



Gravel	Particle Size
A	0% retained on 3-in. screen; less than 2% passing 1-1/4 in. screen
B	0% retained on 1-1/2 in. screen; less than 2% passing 5/8-in. screen
C	0% retained on 5/8-in. screen; less than 5% passing 1/4-in. screen
Sand	
E	Less than 1% retained on 1/4-in. screen; less than 25% retained on 4 mesh screen; less than 5% passing 8 mesh screen
F	Less than 5% retained on 8 mesh screen; less than 5% passing 20 mesh screen
G	Less than 2% retained on 20 mesh screen; 20-40% retained on 30 mesh screen; less than 1% fines and dirt passing 50 mesh screen

FIGURE 1. Sand Filter Test Apparatus





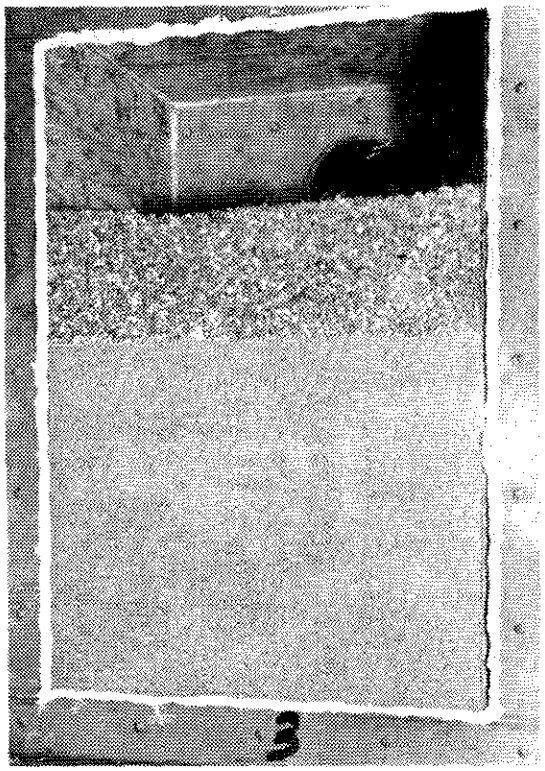


FIGURE 2.
Types of Sand in Sand Filter

static pressure could be measured one inch on either side of each interface between sand grades. A vane anemometer measured the flow velocity in the duct and the average or superficial flow through the filter itself. Sampling ports were located as indicated in the filter for air sampling for efficiency determination.

Three test series were conducted on the sand filter. Each test measured filter efficiency as a function of air velocity through the filter. Pressure through the bed was simultaneously monitored.

In addition to the sand loading described later, tests were conducted with the same loading but following compaction of the sand layers achieved by bed agitation. This closer packing produced a total bed contraction of 1-3/4 inch overall. A final test condition was created by removing the top 18 inches of the sand of the compacted bed, thus leaving 24 inches of "G" sand. The filtration efficiency and pressure dependence measured in these tests are shown in Figures 3 and 4. Efficiency for a "new" sand filter with a 5 ft/min velocity would be about 99.95% as determined by DOP.

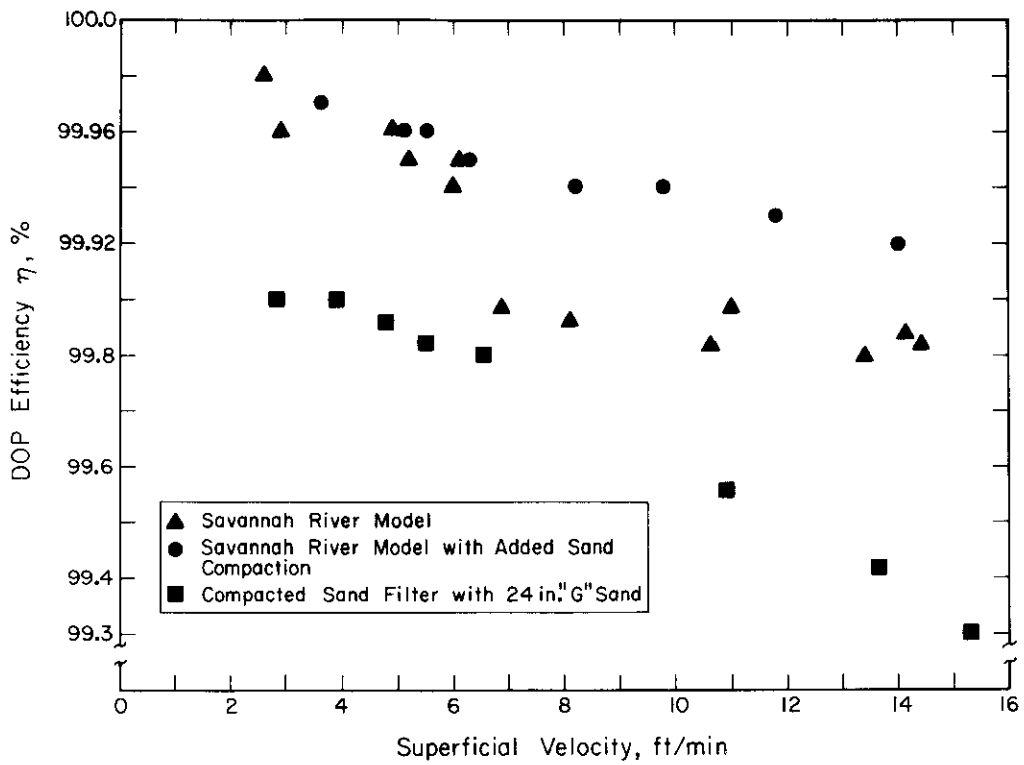


FIGURE 3. DOP Efficiency of Sand Filter as a Function of Superficial Velocity

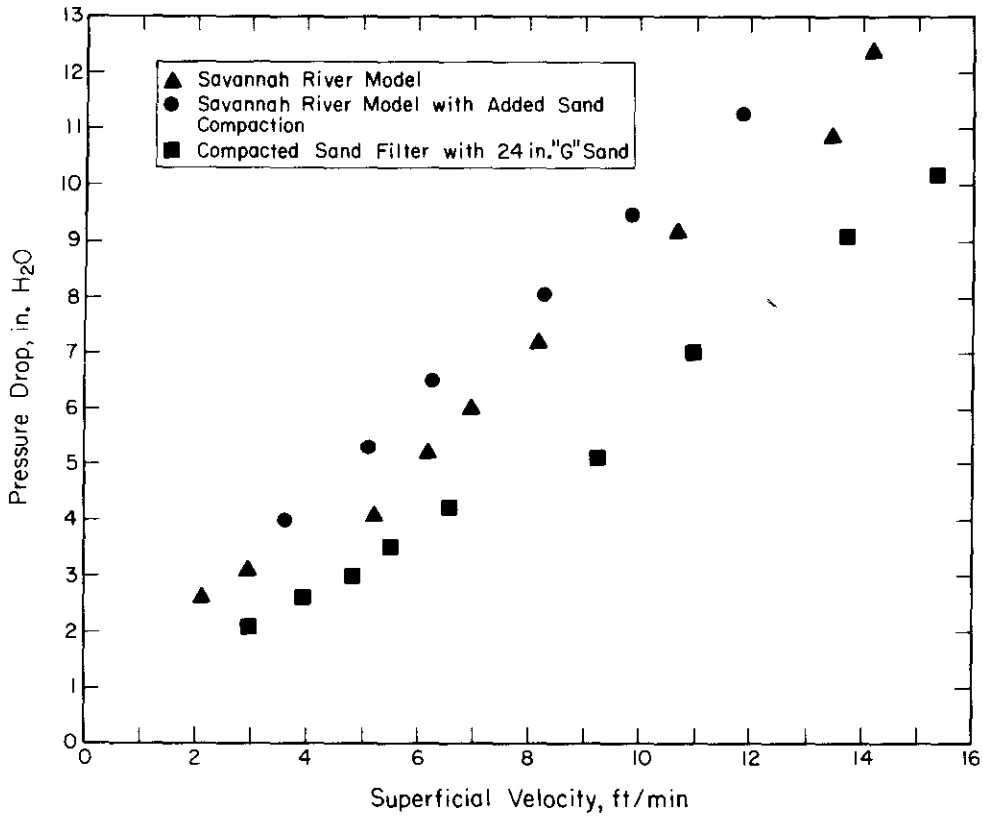


FIGURE 4. Sand Filter Pressure Drop as a Function of Superficial Velocity

The pressure drop reported is as measured for the specific loading conditions. The pressure drop varied considerably from one bed loading to another, but efficiency was not materially affected. However, closer packing through agitation consistently produced a 15% pressure rise at 5 ft/min velocity with a marginal improvement in efficiency. The importance of the "G" layer to ultimate efficiency is evident in the significant decrease in collection efficiency of the 24 inches of "G" sand as compared to 36 inches of "G" sand.

PERFORMANCE OF "G" SANDS FROM DIFFERENT LOCATIONS

Although sands for the operating filters were from Northern Sand and Gravel Co. of Iowa, transportation costs make it economically attractive to exploit local sands. Vendors with sufficient deposits for supplying a filter were asked to submit samples fulfilling the size criteria for a "G" grade sand. The samples received were individually tested for DOP efficiency and compared to the Iowa sand. To conserve on handling problems and sample

requirements, a 6-inch column shown schematically in Figure 5 was constructed. The test procedure was the same as that described for the full filter bed. Table I summarizes the test data. The sands of particular interest were tested under relative humidities of 30% and 65%. In addition, these sands were dried by heating so that electrostatic forces are present. Variations in collection efficiency were noted, but the sand supplied by Northern Sand and Gravel Co. was superior in every case.

To determine the effect of moisture in the filter, 1500 ml of H_2O was seeped into a 36-inch deep bed of Iowa "G" sand. With 500 ml at the top and 1000 ml about 3 inches from the bottom, pressure and efficiency both increased (Table I).

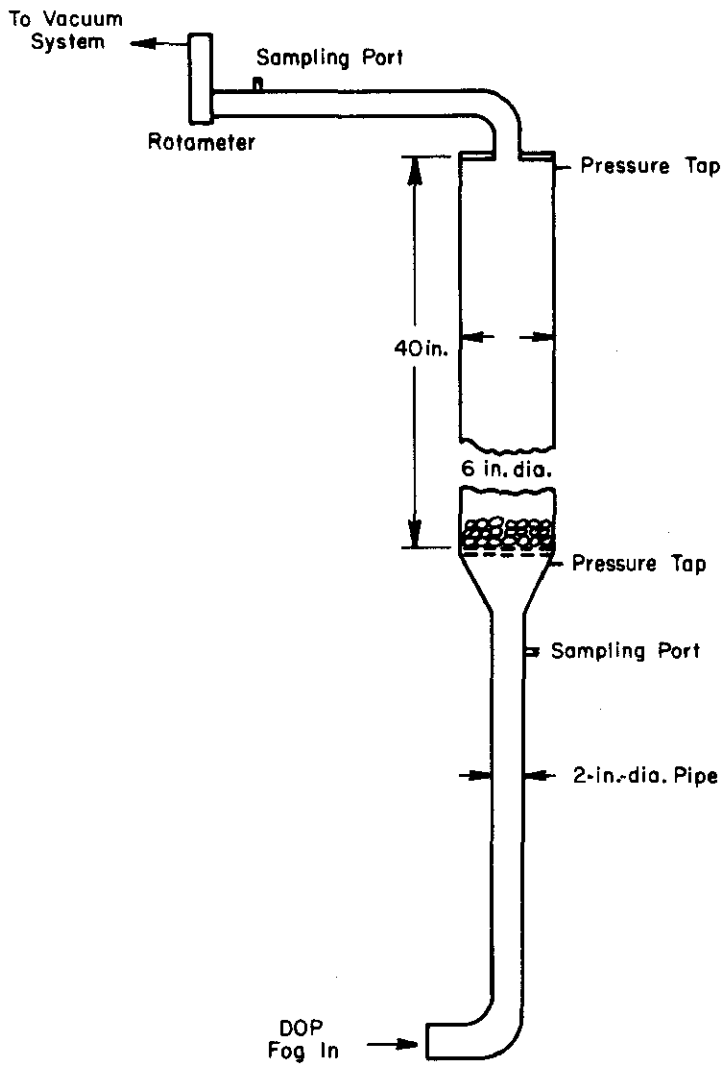


FIGURE 5. Efficiency Test Apparatus for "G" Sands

TABLE I

DOP Efficiency Tests for "G" Specification Sands

5 ft/min Superficial Velocity

Vendor	Sand Depth, in.	Relative Humidity, %	ΔP, in. H_2O	Efficiency η, %	Moisture Content
Northern Sand and Gravel (Iowa)	12	65	1.3	99.0	Sand moisture equilibrated with atmosphere
	24	65	1.6-1.9	99.95	
	36	65	2.4-2.6	99.97	
	33-7/8 (close packed)	65	2.8-3.0	99.98	
	12	30	1.3	93.0	
	18	30	1.9	98.3	
	24	30	2.1	99.76	
	36	30	2.6	99.92	
	36	65	4.0	99.986	1500 ml H_2O seeped to sand in place
	18	30	1.75	>99.998	Sand dried by heating prior to placement in filter
	18	30	1.75	98.2	Saturated steam blown through sand in place to make it 0.8% H_2O
Columbia Silica (S.C.)	24	65	1.2	97.5	Sand moisture equilibrated with atmosphere
	36	65	3.0	99.25	
	18	30	.94	92.0	
	24	30	1.2	97.1	
	18	30	0.8	99.6	Sand dried by heating
Dawes Silica (Ga.)	24	65	1.5	99.8	Sand moisture equilibrated with atmosphere
	36	65	2.1	99.92	
	33.5 (close packed)	65	2.5	99.95	
	18	30	1.5	98.0	
	24	30	1.7	99.7	
	18	30	1.5	>99.85	Sand dried by heating

"FIBERGLAS" FILTER TESTS

Operating experience with a deep-bed "Fiberglas" filter unit at the Hanford Works indicated satisfactory performance. To more directly compare the "Fiberglas" filter with the sand filter, a "Fiberglas" unit was fabricated in accordance with Hanford's specifications and tested under similar conditions. The filter media was purchased from American Air Filter Co. Figure 6 shows the arrangement and packing details. The prefilter consisted of 84 inches of "Fiberglas" hand packed to achieve average loading densities indicated in Figure 6. The final filter cartridge was

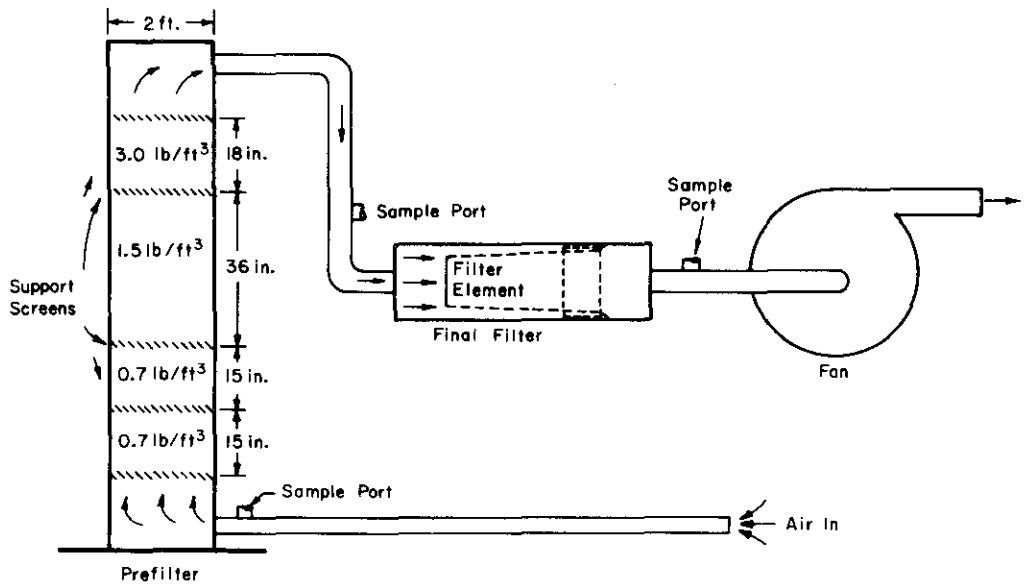
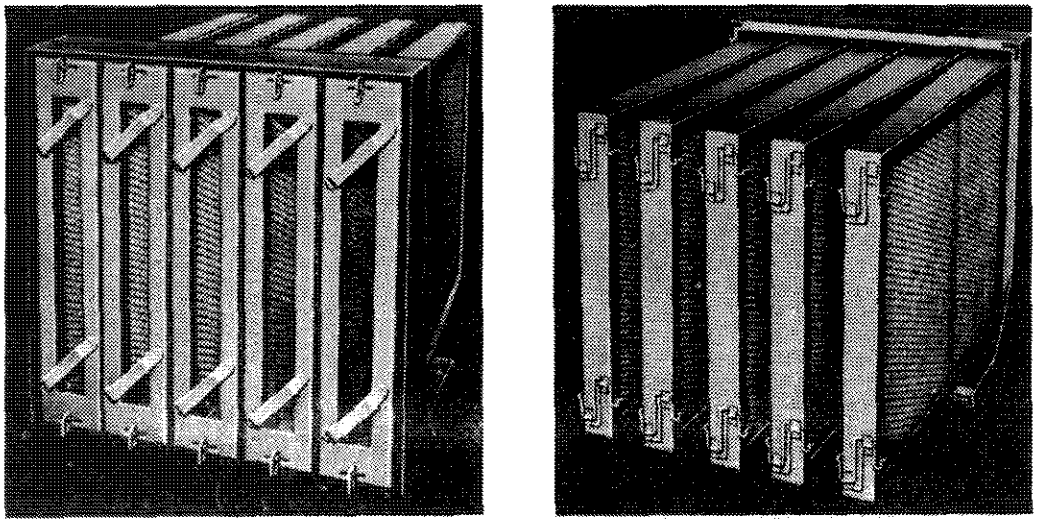


FIGURE 6. "Fiberglas" Filter Test Apparatus

assembled by American Air Filter using No. 25 and No. 50 "Fiberglas" batts arranged as shown in Figure 7. The prefilter was 4 ft^2, and the afterfilter had 10 ft^2 of filter media exposed. The nominal operating velocities were 50 ft/min in the prefilter and 20 ft/min in the final filter at 200 scfm in the model. The final filter assembly was mounted in a rectangular box and sealed by caulking. Suction through the filter was provided by a fan, which was throttled to control the flow rate. Table II shows DOP efficiency, pressure, and velocity data.

At a nominal velocity of 50 ft/min through the prefilter, an overall efficiency of 99.94% was measured. This is lower than the theoretical efficiency calculated by considering the prefilter and final filter separately. A problem is encountered in achieving uniform packing density in the prefilter and in eliminating

bypassing in both filter beds. In this case baling techniques developed for larger filters would prove advantageous. Sealing of the final filter package is also critical and can only be adequately inspected by efficiency measurement across the bed. Reported efficiencies are probably lower than those for carefully packed filters.



Front Rear

FIGURE 7. American Air Pocket Filter

TABLE II

Results of "Fiberglas" Efficiency Tests

Velocity, ft/min (Prefilter)	Total ΔP, in. H_2O	Efficiency, %		
		Prefilter	Final Filter	Total
27	1.35	-	-	99.95
50	3.0	65-70	99.88	99.94
130	5.0	-	-	99.92

SIMULATED SMOKE LOADING

The filter units in service for fine filtration of large gas volumes are designed for relatively low particulate concentrations. This condition is expected to prevail for all normal operations. However, in the unlikely event of an accidental fire, the particulate load to the filter from the products of combustion could reach a high level for a short period of time. Predicting such a smoke load is almost impossible because it depends on the fuel, available oxygen, and burning rate to define the fly ash, aerosols, or carbonaceous dust that might be emitted. The likelihood of any product reaching the filter is in turn dependent on its tendency to agglomerate, on settling velocity, and on affinity for the conveying ducts or tunnels.

Because of many variables controlling the nature of an accidental fire, some model material must be chosen that could be used for relative holding capacity tests. A carbon black powder, "Raven 15", manufactured by Columbian Carbon Co., was selected for its particle size distribution and surface properties. This material is expected to represent a reasonably adverse smoke condition. Carbon black, artificial smoke, and smoke produced by burning selected fuels were compared in a series of controlled burning tests of single fuels. Figures 8 and 9 compare particle size distributions for the fuels burned under controlled smoldering and rapid burning conditions. A modified cascade impactor was used to determine the particle size by weight of the smoke and dispersed model material. The model material spans the range of expected particulates from a fire.

The relative holding capacities of the sand and "Fiberglas" filters and determination of critical-bed regimes were principal objectives in these tests. The respective sand and glass units shown in Figures 1 and 6 were used for comparative tests. Because the amount of smoke that might collect in the canyon and ducts leading to the filter is not known, entrance effects were eliminated by inducting the carbon black directly into the plenum under the filter beds. Thus, the amount of carbon black metered to the filter minus that amount which collected in the plenum represents that quantity of powder collected in the filter.

Because the density of smoke might vary in the event of a fire, rate of injection of the carbon black was also varied. Smoke density was estimated visually. The injection rate (smoke density) was steadily increased during the early part of the test until some maximum continuous rate was reached. Because for the same filter area, the sand filter handles only 1/10 the air volume of the "Fiberglas" filter at nominal operating conditions, the rate of carbon black injection was also controlled at about that ratio. For both tests, a bed pressure drop of 15 inches H_2O was considered to indicate a plugged filter.

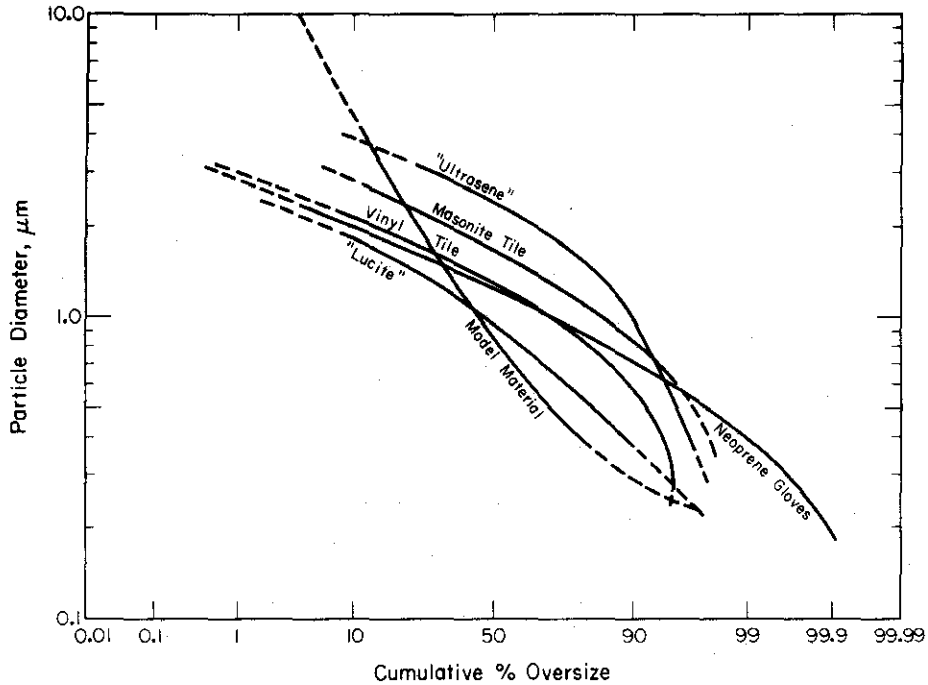


FIGURE 8. Particle Size Analysis for Smoldering Conditions

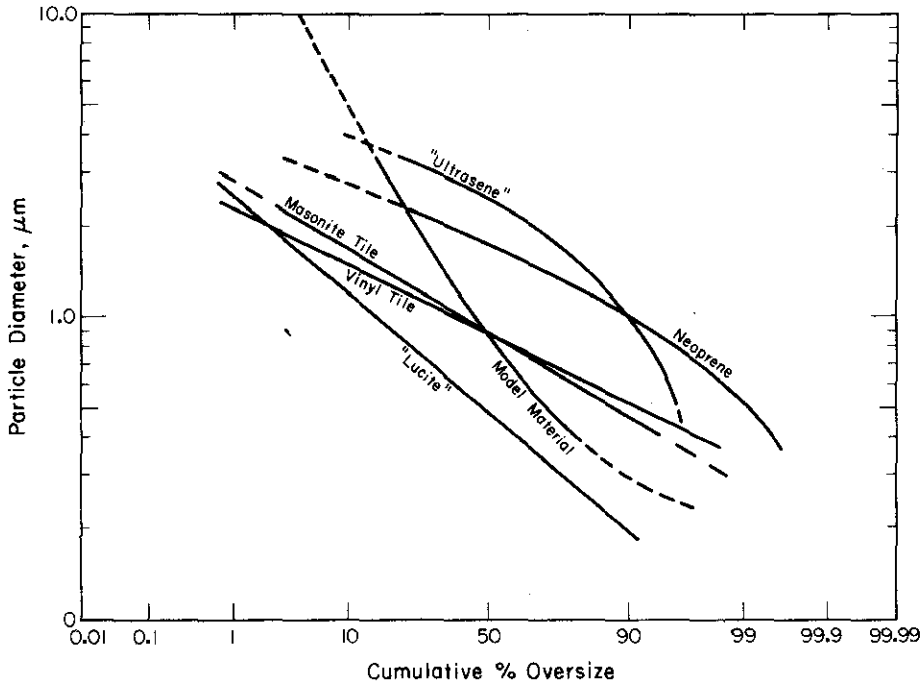


FIGURE 9. Particle Size Analysis for Complete Burning

SAND FILTER

Figure 10 shows the pressure rise in the bed as a function of weight of injected carbon black smoke. Pressure across the filter bed, pressure one inch above the E-F interface, and pressure one inch above the C-E interface are shown. Pressure drop in the "G" layer remained constant through the test series. The E-F interface appears to be the limiting bed region in terms of particle collection. Figure 11 shows the E-F sand interface taken early in the test and at its conclusion. It is visually evident that the carbon black was penetrating into this bed layer. When the sand was removed, the black penetrated approximately 3 inches further into the bed at the center than at the walls of the bed. The plenum under the filter media was loaded with dust, but this was only approximately 6 oz by weight compared to the 4.6 lb injected into the bed.

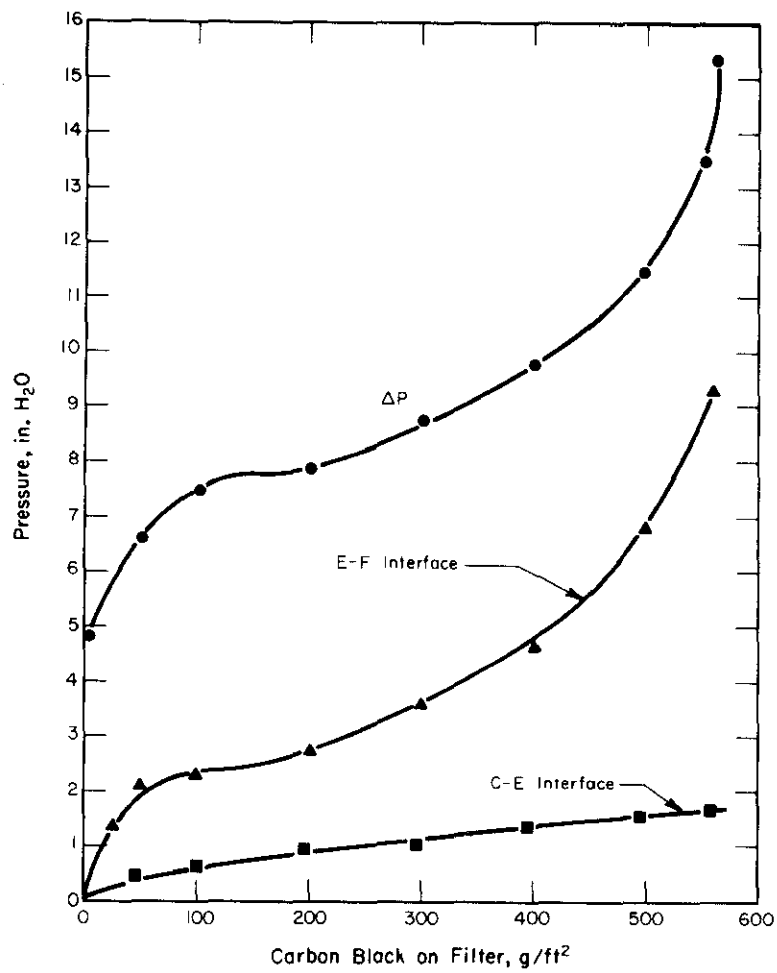


FIGURE 10. Pressure as a Function of Carbon in Sand Filter

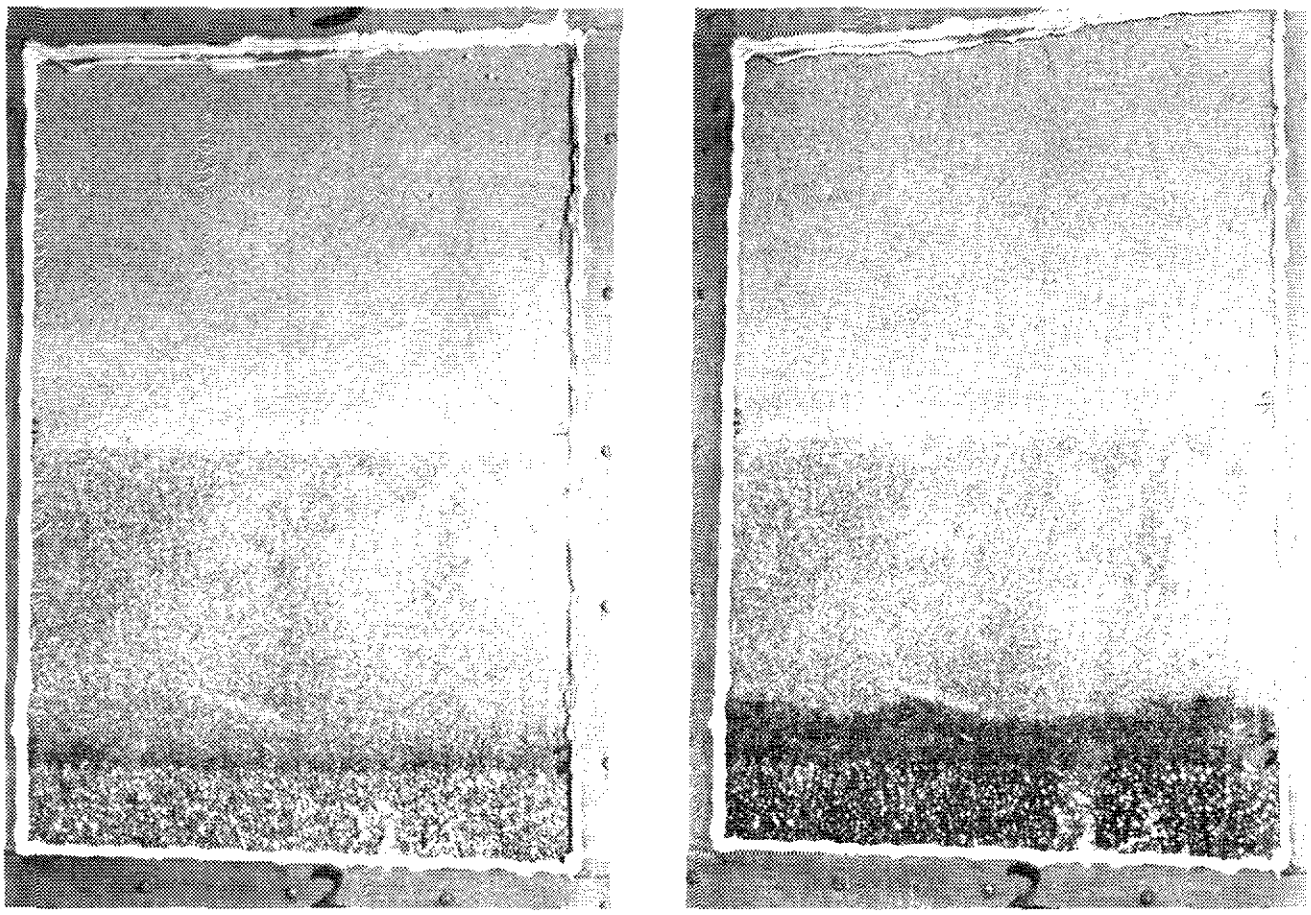


FIGURE 11. E-F Interface of Sand Filter Before and After Smoke Tests

"FIBERGLAS" FILTER

Figure 12 shows the pressure effect in the "Fiberglas" filter as a function of bed loading. The pressure drop across the entire filter, across the prefilter, and at the interface between the 0.7 lb/ft^3 and 1.5 lb/ft^3 packing densities is shown. The data represent a classical performance for such a filter. Each successive bed sustains the increased pressure rise until it "fills." At this point the effectiveness of that particular layer's filter efficiency may be sharply decreased, and the pressure remains

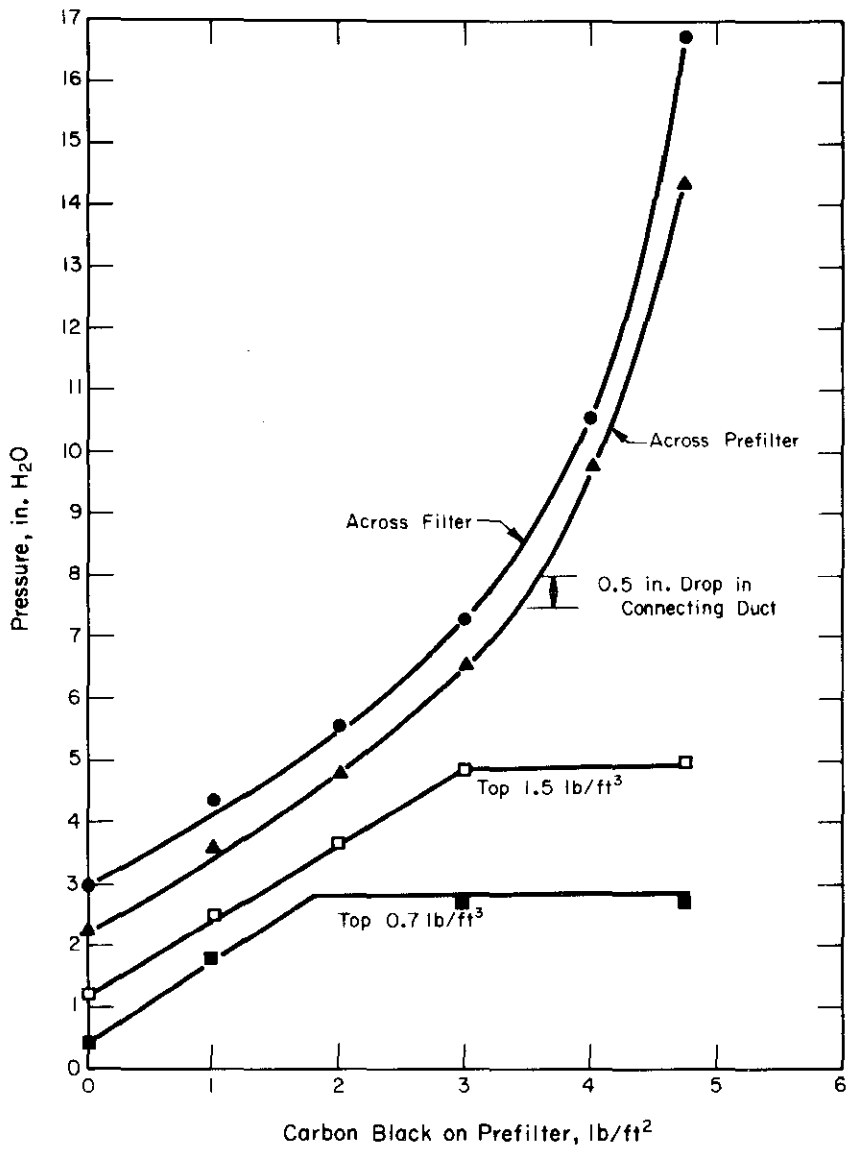


FIGURE 12. Pressure as a Function of Carbon in the "Fiberglas" Filter

constant. This action continues through successive beds and some shifts could occur if a sudden shift in carbon black should occur. Such a sudden shift was not observed. For this test, only about 4 oz of carbon black remained in the plenum out of 19 lb injected into the filter. The carbon black collection on the walls increased more rapidly than in the middle. This may indicate a stronger tendency for bypassing on the walls unless suitable flow diverters are provided. Figure 13 shows the veins of black penetrating the 18-inch layer packed at 3 lb/ft^3.

FIGURE 13. Channeling of Carbon in "Fiberglas" Filter

COMPARISON OF SAND AND "FIBERGLAS" FILTERS

PROPERTIES

Properties of sand and "Fiberglas" are compared in Table III.

To compare the smoke capacities of sand and "Fiberglas", the bed pressure rise as a function of injected carbon black per scfm of gas through 1 ft^2 of filter area was measured (Figure 14). Relative holding capacity depends on when the fire occurs in the pressure drop life of the filter and the total quantity of smoke reaching the filter. In these tests, carbon black was injected into the sand filter for a total of 6 hours and into the "Fiberglas" filter for a total of 3 hours. Overall rate of injection was 10 times heavier in the "Fiberglas" filter than the sand, consistent with the relative magnitudes of superficial velocity (Table III). These tests provide a basis for comparing life expectancy for the filters.

Advantages and disadvantages of sand and "Fiberglas" filters are listed in Table IV. Sand filters compare favorably to glass fiber construction in demonstrated reliability, inherent freedom

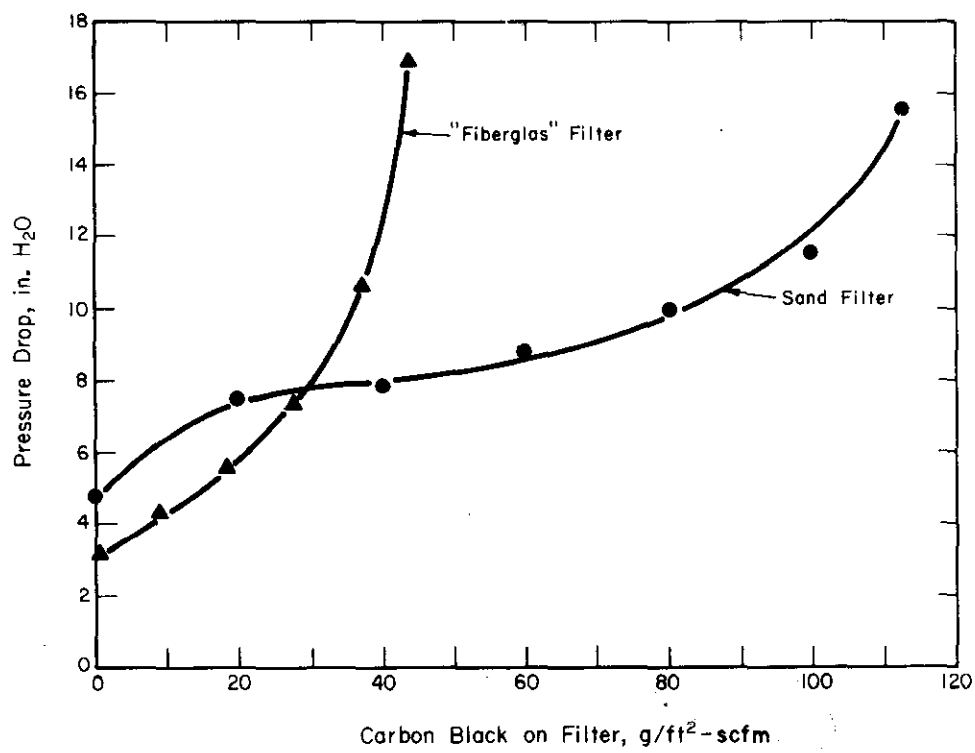


FIGURE 14. Comparison of Sand and "Fiberglas" Filters during Smoke Tests

TABLE III

Properties of Sand and "Fiberglas" Filters

	Sand	"Fiberglas"
Superficial Velocity, ft/min	5	50
Pressure across Filter Media, in. H_2O	4.8	2.7
Air Flow, scfm/ft^2 filter area	5	50
Lbs filter media ~~weight~~, lb/scfm	160	.23
DOP efficiency, %	99.95 ±0.02	99.94 ±0.03
Smoke capacity, lb/ft^2 (to 15 in. H_2O)	0.74	4.5
Smoke capacity, lb/cfm	0.15	0.09

TABLE IV

Advantages and Disadvantages of Sand and "Fiberglas"

Sand	"Fiberglas"
Advantages	**Advantages**
Relatively self-sealing	Operates at relatively low pressure and high velocity
Efficiency improves with life (to point of breakthrough)	Considerable design flexibility depending on collection efficiency
Proven design	Life status of filter more easily predicted from pressure monitoring
Limitations	**Limitations**
Little design flexibility within cost and efficiency limits	Can bypass or leak
Higher operating pressure	Efficiency performance can be variable
Larger filter area	Greater design challenge in effective sealing
More difficult to predict life via pressure monitoring	Dependent upon quality control in manufacturing filter media

from channeling, thermal resistance, and demonstrated long life. The "Fiberglas" filter requires more care in fabrication than sand filters to protect against edge leakage and channeling. The effect of moisture on a glass fiber filter's performance is dependent upon design - usually having a deleterious effect on high efficiency elements. The "Fiberglas" model filter is only 1/30th as effective as the sand filter for a heat sink.

The "Fiberglas" system does offer a significant reduction in space requirements and a small reduction in initial operating cost due to lower pressure drop when the filters are clean.

A number of design and construction considerations will have to be resolved to produce a "Fiberglas" filter acceptable for service where high reliability under all operating conditions is the prime requirement.

A review of the data led to the conclusion that under normal design operation the sand and glass fiber filters were comparable in performance. However, in consideration of the unusual or accident situation, the inherent stability and self-sealing features of the sand filter are superior to the glass fiber construction. Therefore, for applications where credible incident criteria must be met, selection is weighted in favor of a sand filter construction for anticipated Savannah River Plant requirements.

COST

Evaluations (Table V) were prepared for a Savannah River Plant sand filter to be located in the Technical Division area (Cases I and II) and for a Hanford "Fiberglas" filter (Case III) to establish the relative investment. Results indicated no difference within the accuracy of this type estimate, although a slightly lower cost was obtained for the Hanford "Fiberglas" filter. The potential savings do not appear to justify developing a definitive design and more meaningful cost estimate.

TABLE V

Filter Characteristics and Capital Investment

Case	Description	Media Pressure Drop, in. H_2O	DOP Media Efficiency, %	Media Velocity, ft/min	Relative Investment (Filter Only) % Diff
I	Improved Upflow Sand Filter	5	99.94	5	0
II	Reverse Flow Sand Filter	5	99.94	5	+5.5%
III	"Fiberglas" Prefilter	2	90.00	50	
	Pocket-Type Afterfilter	1	99.88	20	
	Combined:	3	99.94		-13.0%
IV	"Fiberglas" Prefilter	2	90.0	50	
	HEPA Afterfilter	1	99.97	5	
	Combined:	3	99.99		-28.0%

To improve the efficiency of both filters, afterfilters were considered (Table VI). Series combinations are listed with calculated potential efficiency. HEPA filters are characterized by very high collection efficiencies, limited collection capacities, and low operating temperature limits. These filters cannot be used alone for service, but their very high collection efficiency could be used advantageously in series with a deep-bed prefilter. To meet the requirements of high reliability and resistance to thermal damage in fire incidents, a sand filter is required as a prefilter (possibly deleting some of the fine "G" type sand). While estimates for this combination were not made, it would appear that no economic advantage could be realized.

TABLE VI

Efficiencies of Filter Combinations

	Prefilter	Velocity, ft/min	ΔP, in. H_2O	η, %
A.	Sand, 36 in. C, 12 in. E,F,G	5	1.9	97.8
B.	"Fiberglas" (Hanford)	50	2.0	90.0
	Afterfilter			
C.	HEPA	5	1.0	99.97
D.	American Air Filter	20	0.8-1.0	99.88

Series Combinations

	ΔP, in. H_2O	η_{th} %
A + D	2.7-2.9	99.997
A + C	2.9	99.999
B + D + D	3.5-3.8	99.9999
B + D + C	4.0	99.99999