RESPIRATOR FILTER PENETRATION USING SODIUM CHLORIDE AEROSOL

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CONTENTS

ILLUSTRATIONS

TABLES

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by

B. I. Ferber,[1] F. J. Brenenborg,[2] and A. Rhode[2]

ABSTRACT

Sodium chloride aerosol was employed to determine respirator filter penetration in a manner suitable for use in Bureau of Mines approval and certification procedures. The aerosol was produced by an ultrasonic generator and treated to yield the proper conditions of relative humidity, particle size, and concentration. Respirator filters were exposed to the aerosol; filter penetration (down to 0.02 percent) was determined with a flame photometer. Results are comparable with those obtained in another laboratory using different equipment.

INTRODUCTION

The testing of respirator filter penetration is one of the requirements in the Bureau of Mines system of approval and certification of respiratory protective equipment. Sodium chloride (NaCl) aerosol, when it is generated under controlled concentrations and particle-size distributions, may be used to fulfill this requirement. There is general agreement among industrial hygienists that an NaCl aerosol has many advantages over other materials used in filter testing. It is a solid particulate and therefore a more representative aerosol than a liquid droplet such as dioctyl phthalate (DOP). Analysis is rapid with high sensitivity based on flame photometry. Particle size of the aerosol can be changed readily by varying the concentration of NaCl that is used to generate the aerosol. NaCl could serve as the standard aerosol for all particulate filter penetration testing, since it is fairly representative of solid, polydisperse particulate contaminants in the particle size range that may be encountered in mining and industrial practice. Its detection

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speed and sensitivity[3] make it more practical than the gravimetric method for silica and wet-chemical methods for lead that are currently used. Further, the system has potential for making rapid changes in the ambient concentration and providing a chart recording of penetration.

In our experiments, NaCl particulate is fed into a test chamber. This aerosol is drawn through the filter at several flow rates, and a sample of the filter effluent is analyzed with a flame photometer to determine the filter efficiency. The method has been described previously.[4] Modifications were made as required for our purposes.

The results of our work are compared with those submitted by E. C. Hyatt of the Los Alamos Scientific Laboratory. Differences between the two sets of results on varying batches of commercial respirator filters may be primarily due to variation in the filter media itself from batch to batch. The use of different instruments for generating the aerosol and for detecting the effluent, ambient concentration, and particle-size distribution may have contributed to these differences.

EXPERIMENTAL WORK

The test setup is shown photographically in figure 1 and schematically in figure 2. A supply of filtered compressed air at 40 psi is used. A flow of 11 lpm serves as the carrier stream for the NaCl aerosol. The latter is produced by a DeVilbiss[5] Ultrasonic Nebulizer, Model 800, using a 1-percent aqueous solution of NaCl. This aerosol flows to a surge jar where the heavier water droplets fall out. Another stream of air is passed through two drying towers (in series) that contain indicating silica gel for drying the compressed air. This dry air is metered through a rotameter at 4 cfm and is then fed into a chamber where it dries the NaCl aerosol from the surge jar to less than 60-percent relative humidity, the degree needed for optimum filter penetration. It also keeps the filter under test from being wetted. The relatively dry NaCl aerosol enters at the top of the test chamber through a distribution plenum. Unused aerosol is exhausted through two ports at the foot of the chamber, so that the chamber is under slight negative pressure.

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[3]Hounam, R. F. A Method for Evaluating the Protection Afforded When Wearing a Respirator. Health Physics Division, Atomic Energy Research Establishment, Harwell, United Kingdom, UKAEA Research Group Report AERE-R-4125, 1962, 8 pp.

White, J. M., and R. J. Beal. The Measurement of Leakage of Respirators. Am. Ind. Hyg. Assoc. J., v. 27, No. 3, May-June 1966, pp. 239-242.

[4]Burgess, William A., and Parker C. Reist. Supply Rates for Powered Air-Purifying Respirators. Am. Ind. Hyg. Assoc. J., v. 30, No. 1, January-February 1969, pp. 1-6.

[5]References to specific brands, manufacturer's names, trade names, and model numbers are for identification only and do not imply endorsement by the Bureau of Mines.

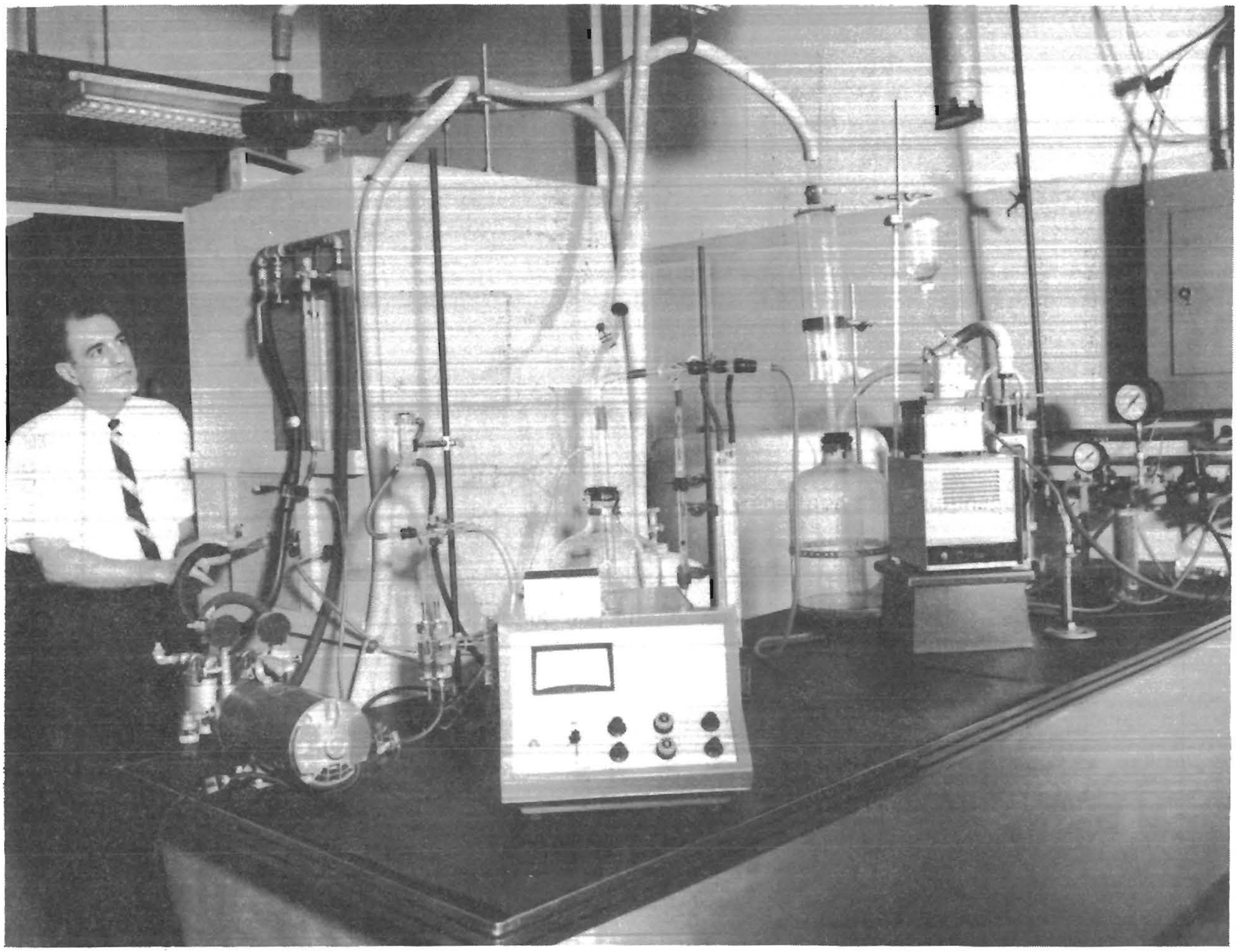

FIGURE 1. - Sodium Chloride Aerosol Generation, Filter Testing, and Detection Unit.

The chamber atmosphere is sampled with a membrane filter (0.8μ pore size) for 10 minutes at 10 lpm. The concentration is determined from the increase in weight of the filter and the volume of air sampled. Penetration is determined as the percentage of the ambient concentration leaking through a respirator filter; hence there is no need to measure the concentration more frequently than at the start and the end of a series of tests. A thermal precipitator is used to collect samples on electron microscope grids for particle-size determination. Representative fields from the electron microscope grids are photographed on 2- by 2-inch photographic glass negatives. The counting and sizing are done directly from these negatives and tabulated as shown in table 1. A plot of particle size versus the cumulative percentage of particles is made on logarithmic probability paper, as illustrated in figure 3. This plots out as essentially a straight line.[6]

[6] Drinker, Philip, and Theodore Hatch. Industrial Dust. McGraw-Hill Book Company, Inc., New York, 2d ed., 1954, p. 193.

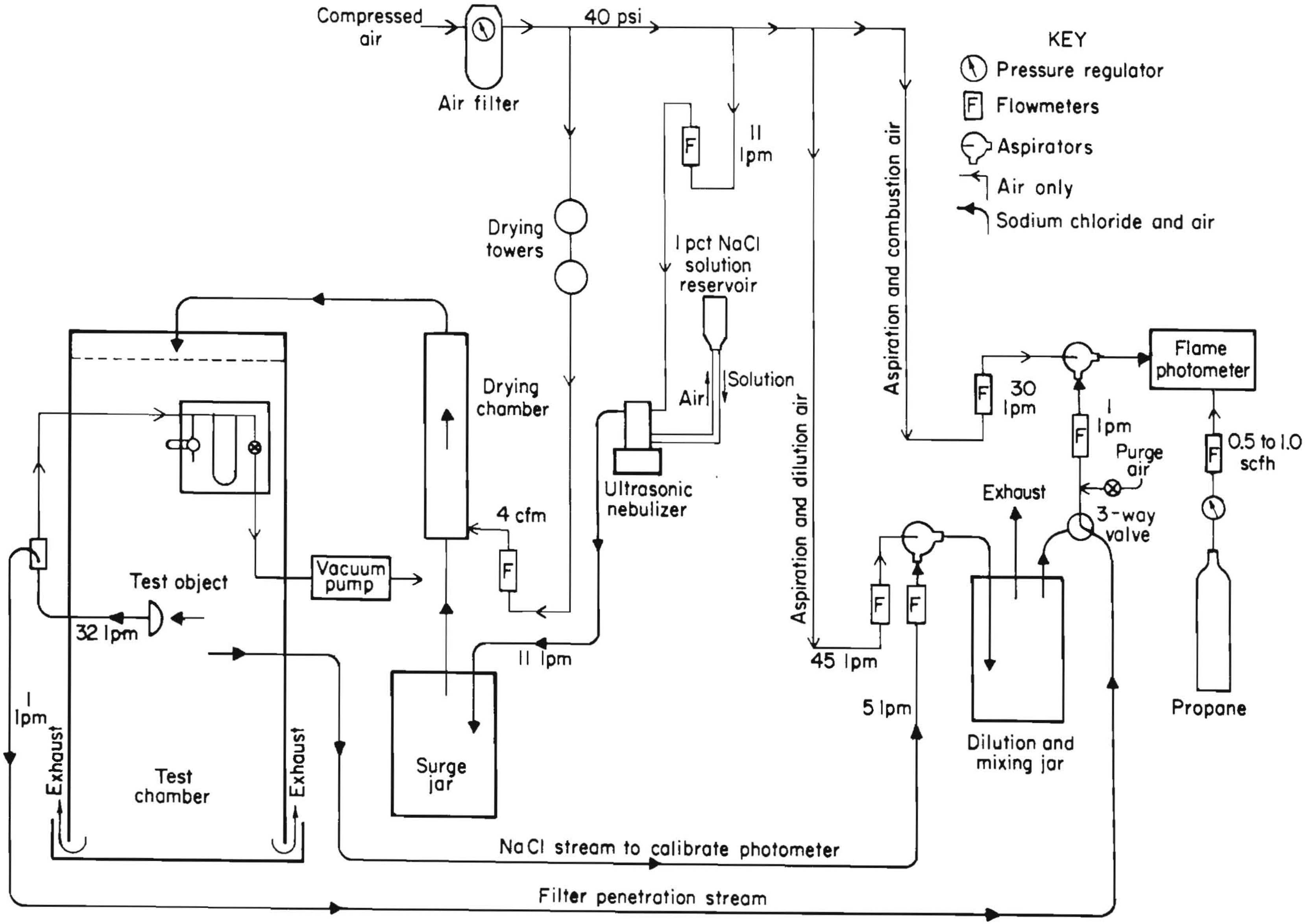

FIGURE 2. - Apparatus for Generating Sodium Chloride Aerosol and Evaluating Respirators and Filters.

TABLE 1. - Particle size distribution

Group	Upper size limit of group, μ	Group frequency (number of particles in group)	Number ≤ upper size limit of group (cumulative number of particles)	Percentage < upper size limit of group (cumulative percentage)
1	0.052	34	34	5.24
2	.104	69	103	15.87
3	.156	99	202	31.12
4	.208	84	286	44.07
5	.260	76	362	55.78
6	.312	49	411	63.33
7	.364	36	447	68.88
8	.416	28	475	73.19
9	.468	30	505	77.81
10	.520	48	553	85.21
11	.572	24	577	88.91
12	.624	18	595	91.68
13	.676	13	608	93.68
14	.728	12	620	95.53
15	.780	16	636	98.00
16	.832	6	642	98.92
17	.884	3	645	99.38
18	.988	4	649	100.00

Particle size distribution is confirmed by enlarging the 2- by 2-inch photographic glass negatives to 8- by 8-inch paper positives and doing the counting and sizing with a Zeiss Comparator.

A specially modified Baird-Atomic KY-3 Flame Photometer is calibrated after the aerosol concentration in the chamber is determined gravimetrically. A 5-lpm aliquot from the chamber is mixed with a 45-lpm flow of clean air. A 30-lpm stream of clean flame-supporting air aspirates a 1-lpm aliquot of this calibration mix into the flame photometer. This accurately prepared calibration mix is used to set the flame photometer at 100 percent of full scale, as follows:

Commercial propane is used as a fuel for the burner. The flame, supported by a 30-lpm airflow, is adjusted to provide a quilted display of cones on the grid of the burner. Steadiness of the flame is important. Optimum burning is attained when the flow of propane is 0.25 to 0.50 lpm. The photomultiplier tube high-voltage control, on the left-hand side of the cabinet, is turned off (fully clockwise). The three-position knife switch is placed in the upper or "Na" position, the Na range control is moved back three turns from fully clockwise, and the Na balance control is set near zero. While the accurately prepared calibration mix is flowing to the flame, the photomultiplier high-voltage control is adjusted to give a reading of approximately 90 on the meter. Then, the meter is adjusted to 100, using the Na balance control. The sample aspirator is purged and, if necessary, reset to zero using the center control. The Na balance control is again set to 100 (with

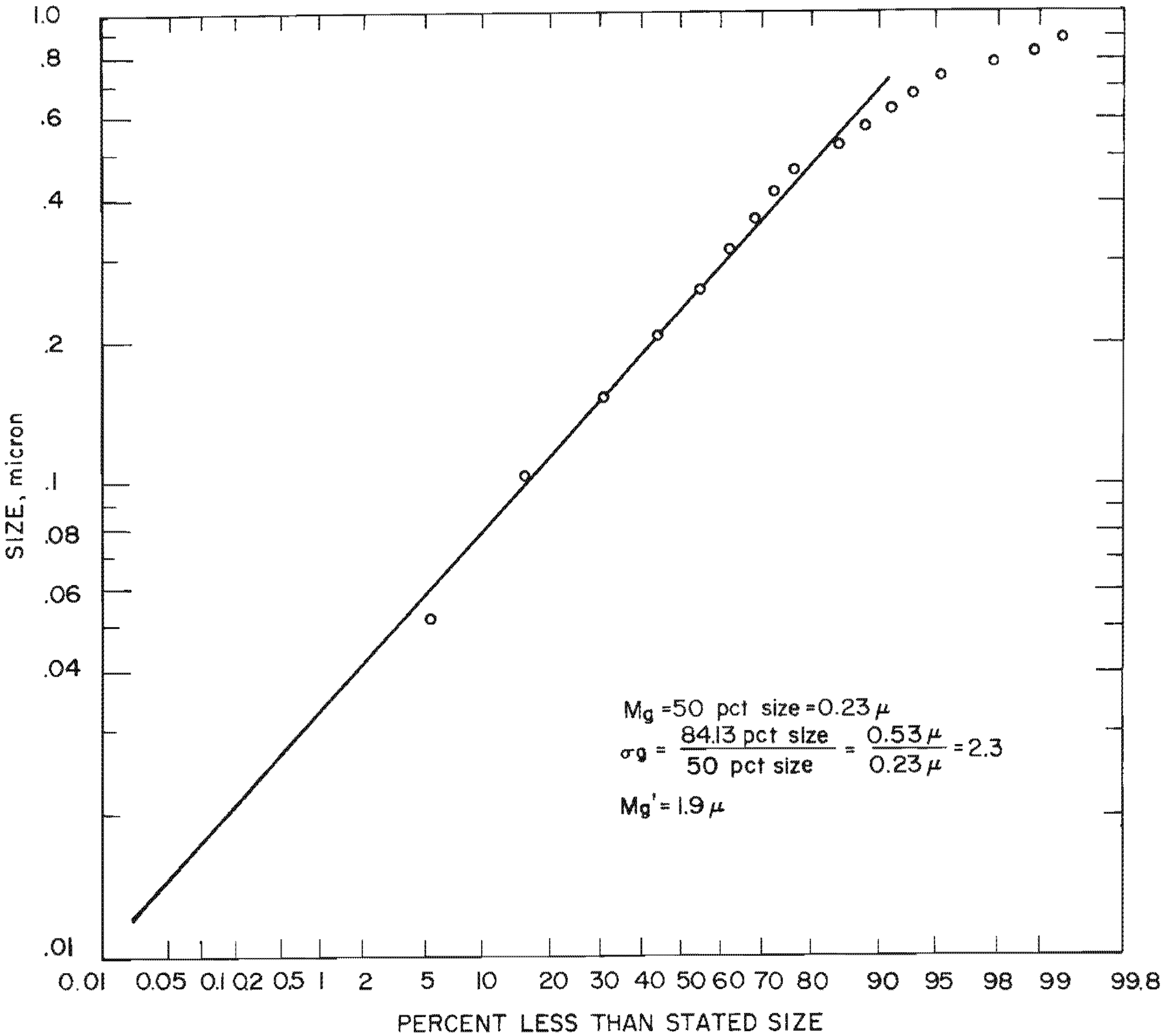

FIGURE 3. - Logarithmic-Probability Plot of Data in Table 1.

calibration mix) and the center control to zero (after purging) until these two settings are stable.[7] The flame photometer is now ready to measure the filter penetration as a percentage of filter input. The instrument reading is linear with the penetration over the range measured.

The filter to be evaluated is placed on a fixture and inserted into the test chamber. A pump draws the air (containing NaCl) through the filter and flowmeter at either 16, 32, or 42.5 lpm. Figure 2 shows the flow distribution, using 32 lpm as an example. The pump has a self-contained mechanical filter on its inlet to minimize the corrosive effects of the NaCl on the pump, if any

[7] Excess adjustment of the balance control indicates that NaCl concentration in the chamber is varying considerably.

should leak through the filter under test. An outlet filter on the pump keeps the room and the flame photometer from NaCl contamination in case of leakage during the test. As in the calibration, 30 lpm of flame-supporting air aspirates a 1-lpm aliquot of the filter effluent to the flame photometer. The filter is exposed to the NaCl aerosol until a maximum steady readout is obtained on the instrument. This occurs in the first few seconds of testing. The readout indicates the percentage filter penetration.

TEST RESULTS AND DISCUSSION

Chamber concentrations, as determined gravimetrically, ranged from 49 to 52μg NaCl per liter of air (or mg/m^3). Moisture could not be observed nor measured on the membrane filters used for collecting concentration samples. An attempt was made to measure the NaCl concentration in the chamber with the flame photometer. However, the instrument was flooded by the large amount of NaCl present, even after repeated dilutions. Concentration determinations were also tried with a sodium ion electrode. Results were erratic because the NaCl in the chamber was below the detection limits of the sodium ion electrode.

The particle size distribution as determined directly from the 2- by 2-inch glass plates showed a count median diameter (Mg) of 0.23μ with $\sigma g = 2.3$. This is comparable to an Mg of 0.2μ and $\sigma g \sim 2$ reported by another investigator.[8] Our Mg is equivalent to a mass median diameter (Mg') of 1.9μ. Enlarging the photographs and sizing the particles with a Zeiss Comparator showed the Mg to be 0.3μ with $\sigma g = 1.98$ (Mg' = 1.23μ). The particle size obtained with the Zeiss Comparator compares favorably with the sizing that was done directly.

Respirator filter penetration results are tabulated in table 2. These results reflect separate runs on different filters. Ultimate sensitivity attained with the flame photometer was a penetration of 0.02 percent. Table 2 also gives some information on penetration of these filters by dioctyl phthalate (DOP). No conclusions can be drawn from the DOP data because the filters were not the same ones that were tested against NaCl. Variance between filters will not allow valid correlations.

[8]Work cited in footnote 4.

TABLE 2. - Bureau of Mines respirator filter penetration tests

Filter	Percentage penetration at--					
	16 lpm		32 lpm		42.5 lpm	
	NaCl	DOP[1]	NaCl	DOP[1]	NaCl	DOP[1]
HIGH-EFFICIENCY FILTER						
1...............................	[2]<0.02	-	<0.02	0.000	<0.02	-
	<.02	-	<.02	.005	<.02	-
	<.02	-	<.02	.002	<.02	-
	<.02	-	<.02	.001	<.02	-
FUME FILTER						
Fiber glass 2....................	4.3	18	5.0	-	4.2	20
	2.4	13	5.4	-	2.4	18
Treated paper 3..................	[3]>10	14	>10	-	>10	16
	>10	15.5	>10	-	>10	15.5
	>10	16	>10	-	>10	15.5
Treated paper 4a.................	>10	13	>10	-	>10	25
	>10	20	>10	-	>10	25
	>10	16.5	>10	-	>10	20
	>10	18	>10	-	>10	23
	>10	20	>10	-	>10	23
	>10	18	>10	-	>10	18
Treated paper 4b.................	1.3	4	1.4	-	1.7	4
	1.2	2	1.1	-	1.5	3
	1.2	3	1.1	-	1.7	3
	1.6	4	1.4	-	2.0	5.5
	.9	3	.9	-	1.5	4
	1.9	4	1.7	-	2.3	5.5
Organic and asbestos fibers 5.....	-	-	1.4	-	-	-
	.8	4	1.8	-	1.2	10
	.8	4.5	1.7	-	1.3	11
	1.2	5.5	2.6	-	1.6	10
	1.3	6.5	3.0	-	1.5	10
	1.0	5.5	1.9	-	1.2	8
	1.2	5.5	1.7	-	1.2	7
DUST AND MIST FILTER						
Organic and asbestos fibers 6.....	>10	40	>10	-	>10	43
	>10	40	>10	-	>10	42
	>10	44	>10	-	>10	47
Organic and asbestos fibers 7.....	>10	42	>10	-	>10	45
	>10	45	>10	-	>10	45
Resin impregnated wool 8..........	>10	85	>10	-	>10	80
	>10	86	>10	-	>10	77
	>10	87	>10	-	>10	74
Resin impregnated wool 9..........	.5	74	1.1	-	2.4	56
	1.9	72	3.2	-	6.7	58
	2.1	71	2.7	-	7.7	52
	.6	38	.3	-	2.4	24
RESIN WOOL BATT FILTER						
45 oz/sq yd 10....................	0.1	0.58	0.4	-	0.1	1
	.02	.34	.3	-	.02	.50
	.02	.40	.3	-	.02	.68

[1] Data on DOP penetration were furnished by the Respirator Group, Approval and Testing, Safety Research Center.
[2] Lower limit of detection with Bureau equipment.
[3] Upper limit of detection with Bureau equipment.

This tabulation brings out the following:

1. "High-efficiency" filters are more than 99.98-percent efficient, as claimed by the manufacturer. The rate of airflow through the filter does not affect its performance down to 0.02-percent penetration.

2. A new type of filtering material, resin wool batt, shows a penetration of less than 1 percent. It is slightly less efficient than the "high-efficiency" material. Also, DOP penetration increases here with increased airflow.

3. Fume filters (intermediate efficiency) show very little consistency, even when made of similar materials by the same manufacturer. This is pointed out by treated paper filters 4a and 4b which are made by the same manufacturer. One shows very high penetrations with both NaCl and DOP, while the other shows much lower penetrations with both aerosols. Fiber-glass filters have an efficiency between these two types of treated paper filters. The fume filters that are most efficient against NaCl aerosol are those made of organic and asbestos fibers; however, some treated paper filters are slightly more efficient against DOP than organic and asbestos fiber filters. Penetration increased, in almost all instances, as the air velocity through the filters increased.

4. The least efficient filters (dust and mist) showed high penetrations with both DOP and NaCl (except for the Code 9 filters). The resin-impregnated wool filters showed much higher penetrations with DOP than did the organic and asbestos fiber filters. There is no apparent explanation for the relatively low penetrations obtained with the Code 9 filters.

Results of comparable tests performed by the Los Alamos Scientific Laboratory[9] (LASL) are tabulated in table 3. Only general comparisons can be made, since LASL did not use manufacturers' names in identifying filters tested. Workers at LASL generated their aerosol with a mechanical aspirator, rather than the ultrasonic nebulizer we used. They determined penetration with the British-manufactured EEL "Respirator Tester;" we used a factory-modified Baird-Atomic Flame Photometer. The maximum concentration of their test aerosol was 10μg NaCl per liter of air, while ours was 52μg per liter. Their particle-size distribution showed an Mg of 0.05μ, $\sigma g = 2.35$, and an Mg' of 0.45μ; our Mg' was 1.23μ. A comparison of table 2 with table 3 shows that, despite these differences in test conditions, LASL results are comparable to Bureau of Mines results for the high-efficiency and resin wool batt types of filters. Fiber glass and treated paper fume filters also show comparable results by the two laboratories. Fume filters of the organic and asbestos fiber type tested by LASL showed higher penetration than when tested by the Bureau. Also, LASL

[9] Mitchell, R. N., D. A. Bevis, and E. C. Hyatt (Los Alamos Scientific Laboratory, University of California, Los Alamos, N. Mex.) A Comparison of Respirator Filter Efficiency Measurements by NaCl and DOP. Pres. at American Industrial Hygiene Conf., Denver, Colo., May 12-16, 1969, paper 143, 30 pp.; available from Bureau of Mines Safety Research Center, Pittsburgh, Pa.

showed lower DOP penetration with dust and mist filters of the resin-impregnated wool type.

TABLE 3. - Respirator filter penetration tests performed by the Los Alamos Scientific Laboratory[1]

Filter	Percentage penetration at--			
	16 lpm		42.5 lpm	
	NaCl	DOP	NaCl	DOP
HIGH-EFFICIENCY FILTER				
A	[1]0.002	[1]0.001	0.002	0.002
B	.002	.001	.007	.004
C	.002	.001	.003	.003
D	.002	.002	.015	.009
E	.002	.001	.014	.003
FUME FILTER				
Fiber glass	3.1	4.0	6.5	7.5
Treated paper	7.5	8.3	12.5	14.8
Organic and asbestos fibers	17.0	19.7	24.5	25.0
DUST AND MIST (RESIN-IMPREGNATED WOOL) FILTER				
A	0.8	2.5	3.8	21.3
B	29.0	30.0	40.0	40.0
C	24.5	46.0	44.0	68.0
RESIN WOOL BATT[2] FILTER				
Media weight, oz/sq yd:				
62	0.005	0.001	0.015	0.006
52	.006	.25	.22	.46
48	.05	.31	.32	.65
36	.12	.54	.75	1.50
24	.33	1.10	1.40	3.30
18	.47	1.25	1.70	3.50

[1] Lower limit of detection.
[2] Impregnated with approximately 15 percent resin.

CONCLUSIONS

An NaCl aerosol can be readily generated to test the penetration of respirator filters. Filter penetrations between 0.02 and 10 percent are accurately detected with a flame photometer and are readily reproducible. Changes in the test concentration can be rapidly made and detected. The system provides a more sensitive and rapidly recording mechanism for particulates than is presently being used for the Bureau of Mines approval testing of respirator filters. Results obtained by this laboratory verify those obtained by another laboratory using different equipment. The method may also be used for routine quality control in the manufacture of filters.

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