American Industrial Hygiene Association Journal

ISSN: 0002-8894 (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/aiha20

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To cite this article: B. I. FERBER , F. J. BRENENBORG & A. RHODE (1972) Penetration of Sodium Chloride Aerosol through Respirator Filters, American Industrial Hygiene Association Journal, 33:12, 791-796, DOI: 10.1080/0002889728506747

To link to this article: https://doi.org/10.1080/0002889728506747

Penetration of Sodium Chloride Aerosol through Respirator Filters

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A method has been previously described for using a sodium chloride (NaCl) aerosol to measure penetration through respirator filters. The detector used at that time was not sensitive enough to determine the penetration of high-efficiency filters designed for protection against highly toxic particulates and radionuclides. In the present method, an ultrasonic nebulizer is still used to produce a NaCl mist. The NaCl concentration has been reduced to 10 μg/liter, and the particle size has been decreased to 0.53 μm, mass median diameter. Respirator filters were exposed to this aerosol at airflows of 16 and 42.5 liters/min. The flame photometric detector in this study could determine filter penetration in the range of 0.0005 to 51.6%. This is suitable for measuring the penetration of high-efficiency filters.

Introduction

A NUMBER OF METHODS may be used to measure respirator filter efficiency. One of the more accurate and sensitive methods involves sodium chloride (NaCl) as the test aerosol. This aerosol, in controlled concentration and particle size ranges, is passed through a respirator filter. The concentration of NaCl aerosol penetrating the filter is measured with a sensitive flame photometer. The respirator filter efficiency is expressed as percentage of penetration or the ratio of the amount detected in the filter effluent to the filter's input concentration. This procedure has been described previously.[1]

In filter testing, methods having increased sensitivity are desirable. In our earlier work we could detect filter penetration down to 0.02%. This is inadequate for measuring the efficiency of filters designed for respiratory protection against extremely high-toxicity particulates and radionuclides. A more sensitive flame photometric detector, the EEL respirator tester, can detect filter penetrations down to 0.0005%. The use of the latter instrument necessitated changes in the test system, which are described herein. Results of

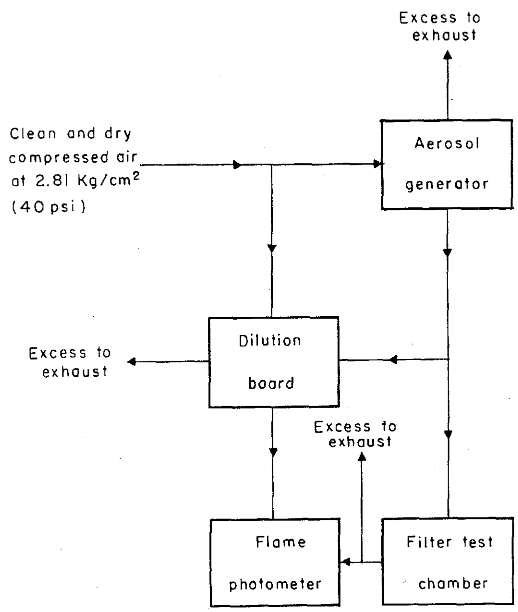

Figure 1. Flow diagram of test apparatus.

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.

respirator filter penetration tests are given and comparisons are made with results obtained on similar filters by the Los Alamos Scientific Laboratory.

Experimental Procedure

The test apparatus is shown schematically in Figure 1. Clean air is supplied at 2.81 kg/cm^2 (40 psi). Excess moisture is removed by a refrigerated air dryer, and the stream is split between the aerosol generator and the dilution board. The sodium chloride aerosol output from the generator is split between the dilution board and the filter under test in the test chamber. Various sodium chloride concentrations are set up on the dilution board to calibrate the flame photometer. The penetration of commercial filters is then measured.

Aerosol Generator

The air going to the aerosol generator is distributed as shown in the diagram in Figure 2. The NaCl aerosol is produced from

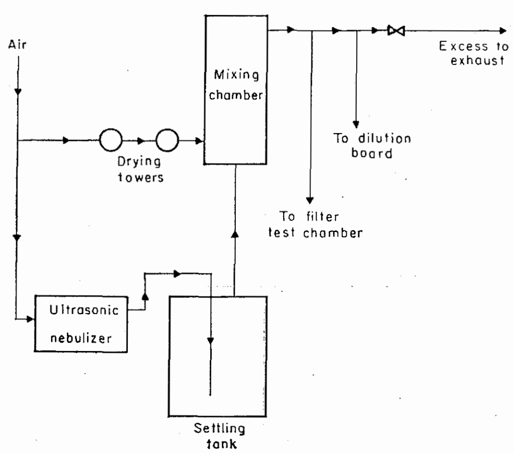

Figure 2. Schematic diagram of aerosol generator.

a 0.1% aqueous solution of NaCl by a Devilbiss ultrasonic nebulizer, Model 800. The carrier air flows at 13.2 liters/min. The nebulizer output passes to a settling tank, allowing the heavier droplets to fall out. Another stream of air, further dried by passing it through silica gel and flowing at 113 liters per minute (4 cfm), is mixed with the moist aerosol from the settling tank. This aerosol is then piped, as required, to either the dilution board, the filter test chamber, or the exhaust. The line to the filter test chamber has a port to sample the aerosol for both concentration and particle size distribution.

Concentration and Particle Size Distribution

Sodium chloride concentration is determined by sampling on a membrane filter (0.8μm pore size) for 10 minutes at 10 liters/min, at the entry to the filter test chamber. The NaCl collected on the membrane filter is then weighed. This value, together with the volume of air drawn through the membrane, determines the input concentration to the filter test chamber. A second membrane filter was used as a backup to trap NaCl not caught by the first one. The accuracy of this method was cross-checked with a Perkin-Elmer Model 403 atomic absorption spectrophotometer.

Particle size determinations of the NaCl aerosol are made from thermal precipitator

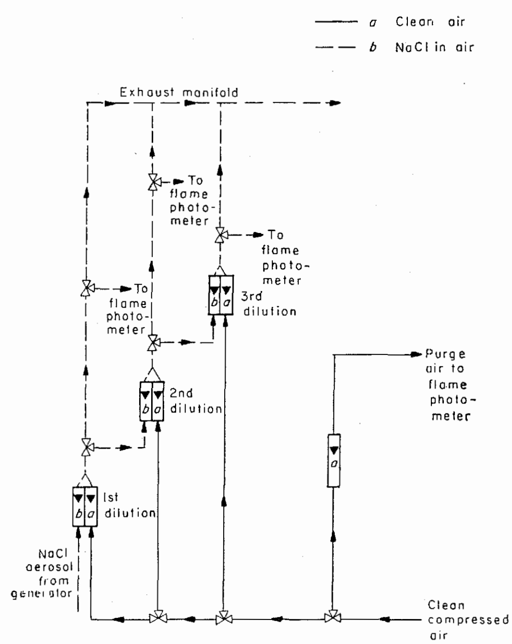

Figure 3. Schematic diagram of dilution board.

samples that are collected on electron microscope grids.

Dilution Board

One of the aerosol streams is fed to the dilution board (Figure 3), where three known concentrations of aerosol for calibrating the flame photometer can be provided. A 1-liter/min flow of NaCl aerosol from the generator is mixed with 9 liters/min of clean air to provide the equivalent of 10% penetration to the flame photometer. Additional dilutions to calibrate the flame photometer for penetrations representing 1% and 0.1% are made by taking a 1-liter/min aliquot from the preceding dilution and mixing it with 9 liters/min of clean air. Unused aerosol in the airstream is vented to an exhaust. The dilution board can also provide a measured stream of clean air for purging the flame photometer at its optimum flow rate of 10 liters/min.

Flame Photometer

The flame photometer used in these tests is the EEL respirator tester made by Evans Electroselenium Ltd., Halstead, Essex, England. Propane, used as a fuel, is supplied at 0.70 kg/cm^2 (10 psi) and a flow of 0.16 liter/min. The propane is mixed with the sample stream which is supplied at 10 liters/min.

Filter penetrations are read out on the EEL through switch-controlled meters. Linear readouts are in full-scale ranges of 0.1%, 1%, and 10% penetration. An auxiliary meter was installed for higher range readings. This provides a nonlinear (parabolic) readout in the 10 to 51.6% penetration range.

The EEL is calibrated by supplying it with purge air and adjusting the zero with the preset "zero" potentiometer for each of the penetration range scales. A NaCl calibration concentration from the dilution board is then introduced into the EEL at a rate of 10 liters/min. The concentration introduced represents 0.1%, 1%, or 10% filter penetration and is used to set full scale on the meter for each range by means of the "100" preset potentiometers. The flame photometer is now ready to measure penetration through a respirator filter.

Filter Penetration Testing

The path of the NaCl aerosol through the test filter is shown schematically in Figure 4. The filter under test is positioned within the airtight test chamber. The pressurized test stream from the aerosol generator is adjusted for flow rates through the respirator filter of either 16 or 42.5 liters/min, as measured by a flowmeter on the effluent side. A 10-liter/min aliquot of this filter effluent is fed to the flame photometer. Penetration through the test filter is then read out on the meter. The maximum steady readout, which occurs in the first few seconds of testing, is the penetration. Filters tested were all commercially

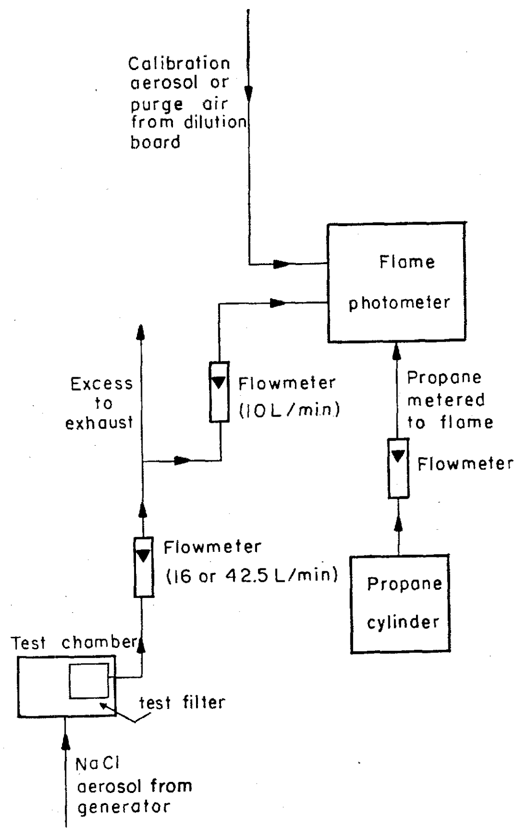

Figure 4. Schematic representation of respirator filter penetration testing.

available, Bureau-approved respirator filters. They are classified as one of three types—high-efficiency, fume, or dust and mist.

Results

Concentration and Particle Size Distribution

Filter input concentrations, gravimetrically determined, were 10 ± 1 μg of NaCl per liter of air. Backup membrane filters did not show any NaCl leaking through the first membrane. Sodium chloride samples collected from the input concentration for gravimetric determination were also analyzed by atomic absorption spectrophotometry. A number of comparative measurements were made and representative analyses are shown in Table I. There is close correlation between the two methods.

A plot of particle size versus cumulative percentage of particles, made on logarithmic probability paper, was linear, indicating a log-normal distribution. From this plot, the count median diameter (CMD) was determined as 0.15 μm and the standard geometric deviation (σ_g) as 1.9. This data yields a mass median diameter (MMD) of 0.53 μm.

Respirator Filter Penetration

Results of respirator filter penetration tests are tabulated in Table II. The penetrations shown for each are averages of at least six filters and were measured at flows of both 16 and 42.5 liters/min.

Penetration through some of the filters, as determined by the flame photometer, was checked both gravimetrically and by atomic absorption spectrophotometry. Close agreement between the flame photometer and the atomic absorption method is shown in Table III.

Discussion

Differences between the present work and the prior work[1] are discussed. An attempt is also made to compare our results with those obtained on similar filters by the Los Alamos Scientific Laboratory.

TABLE I

Comparative Analysis of NaCl by Weight and by Atomic Absorption Spectrophotometry

	Concentrations Found (μg NaCl/liter air)	
Sample Number	By Weight	By Atomic Absorption
1	9.2	9.1
2	9.6	9.7
3	9.4	9.2
4	9.8	10.2
Average	9.5	9.6

TABLE II

Filter Penetration Tests

		Percentage Penetration at:	
Filter Type	Filter	16 liters/min	45.2 liters/min
High-efficiency filter	A	0.003	0.004
	B	0.005	0.002
	C	0.001	0.004
Fume filter	D	2.17	3.93
	E	5.60	9.63
	F	8.41	13.2
	G	4.62	7.93
	H	7.78	11.6
	I	4.47	7.18
Dust and mist filter	J	15.5	31.2
	K	10.9	27.2
	L	0.14	0.81
	M	7.50	13.0
	N	0.85	4.90
	O	0.67	3.62
	P	0.17	1.21
	Q	11.4	18.5
	R	7.58	11.4
	S	7.53	12.2
	T	2.96	7.61
	U	2.42	7.79
	V	10.5	23.7

TABLE III

Respirator Filter Penetration by Comparative Methods

	Percentage NaCl Penetration		
Filter	Flame Photometer	Atomic Absorption	Gravimetric
1	32.0	31.8	30.0
2	25.9	27.4	26.4
3	22.7	21.0	24.0

Aerosol Generator

The concentration of the NaCl solution in the nebulizer was decreased from 1% to 0.1%. This provided a desirable decrease in the aerosol concentration and in the particle size distribution. The carrier airflow was increased from 11 to 13.2 liters/min to overcome the effects of the additional pressure encountered in this system. This carrier air had a relative humidity of 60%, the same as in the prior study.

Concentration and Particle Size Distribution

The aerosol output concentration from the generator holds sufficiently constant so that a determination at the start and end of a series of tests is adequate. A filter test concentration of 10 ± 1 μg of NaCl per liter of air was chosen. It is felt that this is more representative of concentrations of extremely high-toxicity particulates than the 50 ± 2 μg of NaCl per liter of air that was used previously. The MMD was decreased from 1.9 to 0.53 μm to impose a more severe condition on the filters under test.

Dilution Board

The presently used detector is a multi-range instrument, replacing the single-range device used previously. Consequently, a dilution board was built to provide the necessary dilutions for calibrating the detector.

Flame Photometer

Filter penetration is the percentage of input, ambient, or challenge concentration leaking through the respirator filter. The lowest detectable penetration with the EEL is 0.0005%. This is a considerable improvement in sensitivity over that of the Baird Atomic instrument used previously. The latter's minimum detectable penetration is 0.02%.

We found that penetrations greater than 10% flooded the photomultipliers of the EEL flame photometer. The wiring was modified so that a resistor in series with one of the photomultipliers could be shorted by using an added toggle switch, when necessary, to reduce its supply voltage from 800 to 600 volts direct current. This decreased the EEL sensitivity to permit determination of NaCl filter penetrations up to 51.6%.

Respirator Filter Penetration

Measuring penetration at a flow of 32 liters/min, as was done previously, was considered unnecessary. Most investigators report penetrations only at 16 and 42.5 liters/min.

As is generally found, fume filters, as well as dust and mist filters, show considerably higher penetrations at higher flowrates.

Results reported by Los Alamos Scientific Laboratory[2] (LASL) are given in Table IV,

TABLE IV

Filter Penetration—Bureau of Mines (USBM) versus Los Alamos Scientific Laboratory (LASL) Results

	Percentage NaCl Penetration at:			
	16 liters/min		42.5 liters/min	
Filter Type	USBM	LASL	USBM	LASL
High-efficiency filter	0.003	0.002	0.004	0.062
Fume filter	5.60	7.5	9.63	12.5
	4.62	3.1	7.93	6.5
Dust and mist filter	15.5	27.0	31.2	42.0
	0.14	0.8	0.81	3.8

along with our comparable results. Strict comparisons cannot be made because LASL did not identify filters by name; also, they used a smaller particle size and a lower challenge concentration when penetration fell below 1%. Our results are almost all consistently lower.

In the comparative check of respirator filter penetration by flame photometry, atomic absorption, and gravimetry, close agreement was shown between the flame photometer and atomic absorption results. The gravimetric results are the least trustworthy because of the limited sensitivity of balances when weighing a trace amount of NaCl collected on a membrane filter.

Different methods of preparing filters,

their materials of construction, their filtering areas, and various other factors affect filter performance and preclude comparisons between different models of filters. There are too many variances among them to allow for valid statistical correlations of penetration.

Conclusions

An improved flame photometer can be used to detect NaCl aerosol penetration rapidly and accurately in the range of 0.0005 to 51.6% through respirator filters. The lower limits are important for checking the performance of high-efficiency filters for respiratory protection against extremely high-toxicity aerosols and radionuclides.

The variation in filter efficiency found in measurement of filters of the same type is probably due to filter variance, since the testing system itself seems to be fairly precise. Perhaps the system described can be used by filter manufacturers as a quality control measure to produce filters with more uniform performance.

References

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2. Mitchell, R. N., D. A. Bevis, and E. C. Hyatt: Comparison of Respirator Filter Penetration by Dioctyl Phthalate and Sodium Chloride. *Amer. Ind. Hyg. Ass. J. 32:* 357 (June 1971), and personal communications with the authors.

Received May 29, 1972

Notable Physicians

The following communication received by the Editor is brought to your attention:

"I am editing a book on renown and notable physicians and their faith.

I am interested in obtaining contributors who have a special knowledge of the faith and/or religion of one or more notable and outstanding physicians. I am considering such physicians as Sir William Osler, Sir William Fleming, however the notable physicians could still be alive.

Anyone interested in this project or who would suggest renown physicians to write about may contact me at the following address: Claude A. Frazier, M.D., 4-C Doctor's Park, Asheville, NC 28801."

Correction

On page 304 of our May, 1972 issue there is an error in the title of the article by J. D. Shreve, Jr., and J. E. Cleveland. The word "Ratio" was mistakenly printed as "Ration". The correct title is "Effects of Depressing Attachment Ratio of Radon Daughters in Uranium Mine Atmosphere".