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AND NaCl AEROSOLS

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HEPA-FILTER TESTING: COMPARISON OF DOP
AND NaCl AEROSOLS*

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Abstract

We measured the penetration of high-efficiency-particulate-air (HEPA) filters by test aerosols of sodium chloride (NaCl) and dioctyl phthalate (DOP). Our purpose was to study the NaCl method for testing the efficiency of these filters and to compare the NaCl method with the DOP method. The NaCl-aerosol generator was built using the standard British system as a guide, but it included some modifications to the sampling and photometric-readout systems. This generator produces polydisperse particles with a diameter of $0.68 \mu\text{m}$ in a range of 0.02 to $2 \mu\text{m}$. The thermal DOP-aerosol generator ($0.3 \mu\text{m}$) was located at the Hanford Environmental Health Foundation.

Thirty-two filters were tested using both aerosols. In general, the penetration of the DOP through the filter was about two times greater than NaCl at both 200- and 1000-cfm (rated flow). The NaCl, although not as penetrating as the DOP aerosol, could be used effectively to test the efficiency of HEPA filters in the 0.001-to-5% penetration range.

Introduction

The penetration of high-efficiency-particulate-air (HEPA) filters has been measured by a number of methods⁽¹⁾. The two most common standard test aerosols are sodium chloride (NaCl) used in the United Kingdom^(2,3) and dioctyl phthalate (DOP) used in the United States⁽⁴⁾. DOP, however, has several disadvantages. First of all, because of its solvent properties, it can adversely affect the filter media being tested⁽⁵⁾. Secondly, a liquid monodisperse ($0.3\text{-}\mu\text{m}$) aerosol is not normally encountered in field conditions. Hence a solid, polydisperse test aerosol would be more appropriate and yield more meaningful efficiency data. Other advantages of a NaCl system include its shorter test period, easier operation during in-place testing, and generally lower cost.

The purpose of our study was to compare the NaCl and DOP methods of testing HEPA filter efficiency and to determine the relationship between the two types of penetration measurements.

Description

NaCl Test Apparatus

The NaCl aerosol system (shown in Fig. 1) was assembled using the British system^(3,6,7) as a guide and reflected the changes outlined by Dorman⁽⁸⁾. The apparatus basically consists of an air-flow control system, an atomizer, and a NaCl analyzer.

* Work performed under the auspices of the U.S. Atomic Energy Commission.

Filtered air is moved through the ductwork using a blower. The flow is controlled using two adjustable dampers and is measured by noting the pressure drop across a calibrated orifice plate.

The test aerosol is produced by aspirating a 2.0 wt% NaCl solution into four atomizers (only two shown) using compressed air. The resultant droplets dry as they move down the duct and produce the solid, polydispersed aerosol. A circulation pump provides a continuous flow of solution into the spray box. Baffles are placed in the duct to ensure homogeneity of the aerosol when it reaches the filter.

The NaCl in the air entering and leaving the filter was determined by flame photometry. Continuous samples were passed close to a hydrogen flame. The resultant emission in the 5890Å region was measured with a photomultiplier (PM) tube, and the total integrated count was shown on a scaler-timer⁽⁹⁾. In this way, large variations in light output could be averaged electronically, and reproducible readings were easily obtained.

Performance of the NaCl Generator

Figure 2 shows the particle-size distribution of the NaCl obtained using a Model 202 Royco Particle Counter.* The count mean diameter was 0.68 µm with a σ_g of 1.7. The salt concentration was also measured at nine equidistant points across an empty filter casing. The total salt concentration, as well as the distribution, varied by less than ±3% indicating good mixing.

Flow rates tested were 200 and 1000 cfm (rated flow). Triplicate 20-sec readings were taken at both up and downstream sampling positions. A neutral density filter of 3.0 was used when sampling the upstream concentration, since the excessive light output would flood the PM tube. Background readings were taken by deactivating the atomizer with the HEPA filter in place and sampling at the downstream position.

Results and Discussion

All filters were tested with both the NaCl generator at Lawrence Livermore Laboratory (LLL) and the thermal DOP generator at the Hanford Environmental Health Foundation (HEHF), Richland, Washington. The double-exchange test series involved 12 damaged filters from HEHF, and 10 damaged and 10 stock filters from LLL.

The penetration data are compared in Table 1 and Fig. 3. All points given in the table as <0.001% are plotted as 0.001%. Percent penetration, P, is calculated from:

$$P = \frac{100(C_D - C_B)}{C_U - C_B},$$

where C_D, C_U, and C_B are the downstream, upstream, and background count readings from the scaler-timer. Figure 3 also shows the best first- and second-degree polynomial fits to the data, made using a least-squares plotting routine. The equations for these lines are:

* Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Atomic Energy Commission to the exclusion of others that may be suitable.

$$\log P_{\text{DOP}} = 0.121 + 0.872 \log P_{\text{NaCl}}$$

$$\log P_{\text{DOP}} = 0.244 + 1.099 \log P_{\text{NaCl}} + 0.0659 (\log P_{\text{NaCl}})^2.$$

In general, a linear relationship exists between the results of the DOP and NaCl methods, and the DOP aerosol shows about twice the penetration of the NaCl aerosol ($P_{\text{DOP}}/P_{\text{NaCl}} \approx 2$). Figure 4 shows the penetration ratio of DOP to NaCl over the entire range. Note that as the penetration of NaCl increases, the ratio gradually approaches 1.

Earlier, less-extensive measurements also show greater penetration by DOP^(6,7). The differences between the two methods are generally attributed to the differences in particle size, particle density, electrical charge, filter loading, agglomeration, and shatter on impact⁽¹⁰⁾. Although these variations exist between the two test aerosols, NaCl exhibits sufficient penetration to be used as a material for testing HEPA filters.

The data from Table 1 are plotted in Fig. 5 to compare penetration at 200 and 1000 cfm. Again, a least-squares plotting routine yields the following equations for a first- or second-order fit:

$$\log P_{1000} = -0.356 + 0.795 \log P_{200}$$

$$\log P_{1000} = -0.287 + 0.975 \log P_{200} + 0.0577 (\log P_{200})^2.$$

In general, more penetration is observed for both the NaCl and DOP test aerosols at the 200-cfm flow rate, especially at the higher penetration percentages (0.1 to 3%). This is consistent with theory, which predicts that, as face velocity is decreased, more of the test aerosol passes through holes and imperfections in the filter media.

Summary

We have measured the penetration of 32 HEPA filters by a 0.68- μm polydisperse NaCl aerosol and a 0.3- μm monodisperse DOP aerosol. The DOP aerosol shows about twice the penetration at both 200 and 1000 cfm. The NaCl method was found, however, to be an adequate test method in the penetration range desired. Both aerosols showed greater penetration at the lower flow rate of 200 cfm.

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Table 1. Comparison of HEPA filter efficiency in tests with NaCl and DOP test aerosols.

Filter source and No.	Percent penetration			
	1000 cfm		200 cfm	
	NaCl	DOP	NaCl	DOP
HEHF (Damaged)				
1	0.019	0.030	0.044	0.050
2	0.029	0.066	0.045	0.12
3	0.025	0.076	0.034	0.12
4	0.001	0.002	0.001	0.001
5	0.021	0.066	0.057	0.12
6	0.042	0.074	0.063	0.084
7	0.085	0.040	0.17	0.044
8	1.7	4.0	3.0	6.0
9	<0.001	0.005	<0.001	0.003
10	<0.001	0.004	<0.001	0.005
11	0.030	0.074	0.10	0.120
12	0.35	0.58	0.49	0.88
LLL (Damaged)				
13	0.45	0.75	0.93	1.5
14	0.004	0.014	0.002	0.003
15	0.091	0.28	0.20	0.50
16	0.018	0.032	0.034	0.046
17	0.001	0.018	<0.001	0.026
18	0.008	0.018	0.001	0.002
19	0.003	0.004	0.005	0.006
20	0.020	0.030	0.034	0.042
21	0.13	0.38	0.26	0.68
22	0.095	0.14	0.14	0.22
LLL (Stock)				
23	0.002	0.008 (0.012) ^a	<0.001	0.002 (0.004) ^a
24	0.001	0.004 (0.010)	0.001	0.002 (0.004)
25	0.001	0.006 (0.010)	<0.001	0.002 (0.004)
26	0.002	0.014 (0.016)	0.001	0.004 (0.006)
27	0.001	0.004 (0.008)	<0.001	0.002 (0.002)
28	0.003	0.010 (0.014)	<0.001	0.004 (0.004)
29	0.001	0.004 (0.004)	0.001	0.002 (0.004)
30	0.001	0.006 (0.004)	<0.001	0.002 (0.002)
31	0.001	0.004 (0.002)	<0.001	0.002 (0.002)
32	0.002	0.006 (0.014)	<0.001	0.002 (0.004)

^aResults from manufacturer DOP testing are shown in parentheses.

Fig. 1. System for testing HEPA filters using a NaCl aerosol.

Fig. 2. Particle-size distribution of NaCl aerosol. The count mean diameter is $0.68 \mu m$ with a σ_g of 1.7.

Fig. 3. Comparison of NaCl and DOP penetrations at 200 and 1000 cfm. Points listed in Table 1 as <0.001% are plotted as 0.001%.

Fig. 4. Ratio of DOP to NaCl penetration as a function of increasing NaCl penetration.

Fig. 5. Comparison of 200- and 1000-cfm penetrations using NaCl and DOP aerosols. Points listed in Table 1 as <0.001% are plotted as 0.001%.