

INSTANTANEOUS RESPIRATOR FILTER PENETRATION OF CHARGED AND NEUTRALIZED LEAD FUME AND SILICA AEROSOLS

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ABSTRACT

NIOSH tests and certifies respirator filter media according to Title 30 Code of Federal Regulations, Part 11 (30 CFR 11). Subpart K of those regulations specify that a silica dust test and/or lead fume test will be used to test and certify Dust and Mist; and Dust, Fume, and Mist particulate air purifying respirator filter media. Studies at NIOSH have shown that an aerosol particle of a certain size can be identified as the most penetrating particle ("worst case size"). Commercial filter media of various types have been studied and the filter's performance against a "worst case" sodium chloride (NaCl) and dioctyl phthalate (DOP) aerosol evaluated. This investigation was done to complement that study and by determining how one manufacturer's particulate filters performed against the existing certification aerosol challenges using the same detection techniques used in the "worst case" aerosol studies. The results of this study were compared with results obtained employing the most penetrating size DOP and NaCl aerosols. Only initial penetration values were determined and no loading effects were considered. Also, both neutralized (Boltman charge distribution) and unneutralized aerosols were used in order to assess the contribution due to charging.

Introduction

NIOSH currently tests and certifies respirator fil-

ter media in accordance with the regulations set forth in 30 CFR 11. Subpart K of those regulations specify that a silica dust, silica mist, lead fume and/or dioctyl phthalate (DOP) aerosol be used to test respirator filter media. Alternative challenge aerosols being considered include sodium chloride (NaCl solid aerosol) and DOP (liquid aerosol). Presently only high efficiency filters are certified with an approximately 0.3 μm DOP aerosol but its use for other filter classes is under consideration.

This study was undertaken to determine the initial instantaneous penetration of Dust and Mist (DM); Paint, Lacquer and Enamel Mist (PLEM); and Dust, Fume and Mist (DFM) respirator filter media against silica dust and lead fume aerosols. These data results are compared with earlier results that employed the most penetrating or "worst case"⁽¹⁾ size DOP and NaCl aerosols. Thus a direct comparison between the initial penetration values using the present certification aerosols and the "worst case" aerosol is possible. Also, the silica dust and lead fume aerosols were neutralized (Kr-85 radiation source) in some experiments in order to assess filter collection due to charging.

Background

An earlier study by NIOSH⁽²⁾ compared the filter penetration of NaCl, DOP, silica dust and lead fume with a variety of filter media as well as presenting some initial results on relative humidity and charging effects. That study suggested that DOP and NaCl would be reliable aerosols for measuring the effi-

ciency of respirator filter media and their degradability. The results of that study showed:

- 1) The silica dust test is not a sensitive indicator of the relative efficiency of respirator particulate filters since the penetration of all filter types ranged from .06% for high efficiency (HE) filters to .07% for dust and mist (DM) filters. This was attributed to the large size of the silica dust particles as specified in the regulations.
- 2) The lead fume test seemed to be somewhat more differentiating than the silica dust test. In this case the DM filters showed 8.8 - 14.2% penetration while the DFM and HE filters gave penetrations of < .63%. The differences in the DFM and HE filter results were not statistically significant.
- 3) The lead fume and silica dust aerosols were difficult to generate and maintain at a stable mass concentration and particle size over the entire length of the respective test runs (90 minutes for silica dust and 312 minutes for lead fume).
- 4) The instantaneous penetration of the silica dust and lead fume aerosols could not be determined at any given time during the test since these efficiencies are a time weighted average over the total test time as determined gravimetrically.

The above findings when considered in conjunction with the results from this study indicate that smaller, more penetrating aerosols would be more discriminating and would make a better test system. However, it should be noted that these studies all relate to attempts to find respirator filter tests that are or relate to "worst case" testing criteria and are not necessarily indicative of measured efficiencies against a "real world" type aerosol.

Experimental Method

The silica dust and lead fume aerosols are described in 30 CFR 11 Subpart K (11.140-4 Silica Dust Test and 11.140-6 Lead Fume Test). 30 CFR 11-140-4 silica dust particle size criteria are as follows: geometric mean of .4-.6 micrometers and a standard geometric deviation not to exceed 2. The lead fume aerosol is generated by impinging an oxygen-gas flame on molten lead (30 CFR 11-140-6(d)). The aerosols generated in the certification test chambers were withdrawn, diluted to $\sim 2 \times 10^4$ particles/cc and employed for testing. In some cases a Kr-85 radioactive source was placed in line to reduce the aerosol's charge to a Boltzman distribution.

Dust and Mist (DM); Paint, Lacquer and Enamel Mist (PLEM); and Dust, Fume and Mist (DFM) filters from a single lot of one manufacturer's filters were employed. Individual filters were tested at two flow rates $16 \pm .3$ lpm and 85 ± 1.4 lpm. The initial instantaneous penetration was determined 2 minutes after

Table 1

Initial Instantaneous Filter Efficiency for
Respirator Filters Against the Silica Dust Aerosol

Filter Type	Flow Rate lpm	# Filters Tested	Percent Efficiency	SD
DFM	16	10	99.42	.16
	85	6	98.49	.18
PLEM	16	20	99.36	.07
	85	6	96.11	.25
DM	16	22	98.12	.67
	85	6	96.03	.58

Table 2

"Worst Case" Aerosol Particle Size Region and Range of Minimum Percent Efficiency for DOP and NaCl Aerosols

Filter Type	Flow Rate lpm	DOP		NaCl	
		Minimum Efficiency %	Worst Case* Particle Size ym	Minimum Efficiency %	Worst Case* Particle Size ym
DFM	16	98-99	.13-.15	98-99	.12-.15
	85	87-88	.14-.16	91-92	.11-.13
PLEM	16	88-89	.15-.17	92-93	.15-.17
	85	76-77	.135-.155	77-78	.12-.16
DM	16	88-89	.12-.14	87-88	< .111
	85	74-75	.085-.105	69-70	.125-.169

* Mass Median Diameter

exposure to the challenge aerosol by means of the TSI Filter Efficiency Test System (FETS) which has been described by Remiarz et al. ⁽³⁾ This instrument which was built for NIOSH under contract contains a continuous flow Condensation Nucleus Counter (CNC, TSI model 3020). The CNC (Agarwal and Sem ⁽⁴⁾) can measure concentrations as high as 10^7 particles/cm³ and using its single-particle counting ability, can measure concentrations down to 10^{-2} particles/cm³. When used to measure the particle concentrations both upstream and downstream of a filter, the CNC's large dynamic range allows filter count efficiencies as

high as 99.99999+% to be measured. This instrument's sensitivity and dynamic concentration range of measurement was necessary in order to detect the differences in filter efficiency as well as to cover the large range of concentrations anticipated in measuring both upstream and downstream concentrations. In addition to measuring efficiencies, the system measures respirator flow rates and pressure drops. The three parameters can be monitored over time to obtain respirator loading data. Up to three respirators can be tested simultaneously and automatically. The instruments are interfaced to a dedicated micro-

Table 3

Initial Instantaneous Filter Efficiency for Respirator Filters Against the Lead Fume Aerosol

Filter Type	Flow Rate ipm	# Filters Tested	Percent Efficiency	SD
DFM	16	13	98.23	.29
	85	7	89.13	.98
PLEM	16	10	91.82	.82
	85	5	81.63	1.29
DM	16	10	91.64	1.33
	85	7	80.11	.86

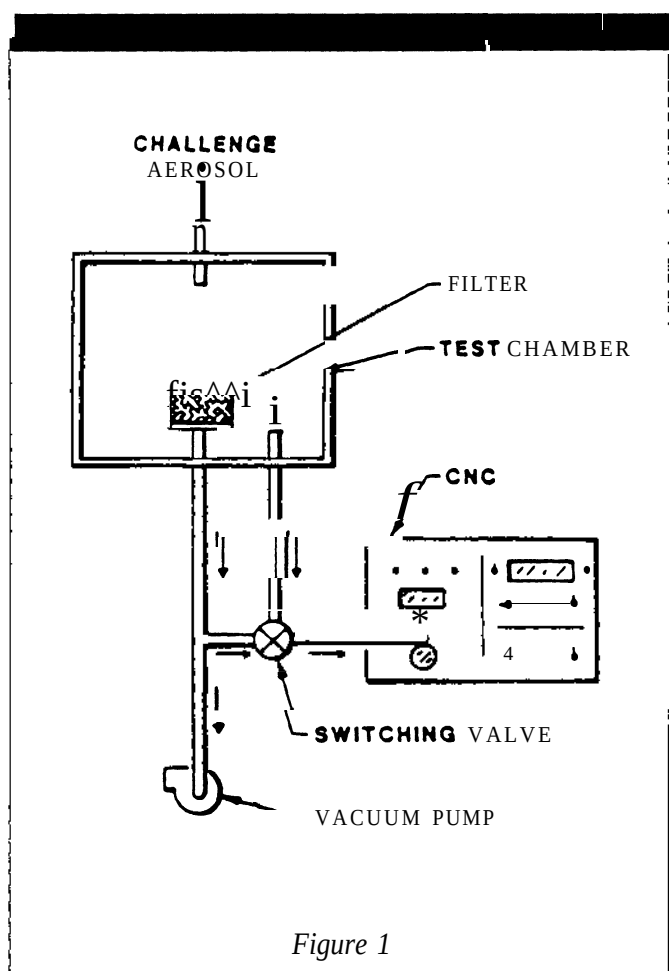


Figure 1

computer system which monitors, reads, and controls the instruments. Extensive data analysis and presentation is done by the microcomputer system, includ-

ing cross-correlations between the various tested parameters. In these studies only one respirator was tested at a time since the initial instantaneous aerosol penetration was the parameter of primary interest. A simplified schematic diagram of the FETS as used in this study is shown in Figure 1.

Results And Discussion

The initial instantaneous percent efficiency values for the DM, PLEM, and DFM filters studied against the certification silica dust aerosol are presented in Table 1. These data show that the DM filters at 16 lpm (equivalent to 30 CFR Part 11 requirement for this filter configuration) gave an initial instantaneous count efficiency of 98.12%. Presently DM filters are required to have a mass efficiency of > 99% when tested according to 30 CFR 11.140 which is a 90 A minute test (time average gravimetric test). The instantaneous penetration results for the silica dust are considerably less than those obtained using a "worst case" particle size aerosol and 87-88% efficiency at 16 lpm with an NaCl challenge aerosol as shown in Table 2). When the flow rate through an individual filter was increased to 85 lpm an efficiency value of 96.03% was obtained. The results obtained with the "worst case" challenge aerosol size t_{85} 1pm were as follows: 74-75% efficiency with DOP and 69-70% efficiency with NaCl. These results indicate that the

Table 4
Comparison of Initial Instantaneous Count
Efficiency Differences for Silica Dust and Lead Fume
Versus "Worst Case" DOP and NaCl Aerosols

Filter Type	Flow Rate lpm	Relative % Efficiency Differences for "Worst Case" Aerosol	
		vs. Silica Dust	vs. Lead Fume
DFM	16	.42 - 1.42	-.77 - +.23
	85	6.49 - 11.49	-2.87 - +2.13
PLEM	16	6.36 - 11.36	-1.80 - +3.82
	85	18.11 - 20.11	3.63 - 5.63
DM	16	9.12 - 11.12	2.64 - 4.64
	85	21.03 - 27.03	5.11 - 11.11

Table 5

Initial Instantaneous Filter Efficiency for
Respirator Filters Against a "Neutralized" Silica Dust Aerosol

<u>Filter Type</u>	<u>Flow Rate 1pm</u>	<u># Filters Tested</u>	<u>Percent Efficiency</u>	<u>SD</u>
DFM	16	10	99.33	.16
	85	5	95.53	.15
PLEM	16	24	98.83	.21
	85	5	91.04	.65
DM	16	21	98.67	.40
	85	7	94.35	1.40

percent penetration for "worst case" aerosols increases more rapidly with increasing flow rate than for the larger silica dust aerosol. These differences are due solely to the significantly larger particle size of the silica dust. The silica dust particles are rather larger compared to the "worst case" aerosols and it is therefore surprising that the "worst case" values were of the same magnitude as the certification mass efficiencies. The PLEM and DEM filters gave higher efficiency values than the DM filters as one would expect. The DM filters should be much more efficient against smaller fume particles. As expected, they do possess the best filter efficiency characteristics of those studied.

Table 3 presents the efficiency results for the same filter lots when tested against the certification lead fume aerosol. The certification program requires

that DFM filters have a mass efficiency of >99% when tested according to 30 CFR 11.140-6 (312 minute time weighted average gravimetric test). No instantaneous efficiency values are obtainable by this test method. The data shows that the DFM filters at 16 lpm (equivalent to 30 CFR 11 requirements for this filter configuration) gave an initial instantaneous count efficiency of 98.23%. The "worst case" particle size aerosol gave 98-99% efficiency at 16 lpm with both DOP and NaCL challenge aerosols as seen in Table 2. When the flow rate was increased to 85 lpm an initial instantaneous efficiency value of 89.13% was obtained. The results obtained with the "worst case" challenge aerosol at 85 lpm were as follows: 87-88% efficiency with DOP aerosol and 91-92% efficiency with NaCL aerosol. As anticipated, when the smaller particle size lead fume aerosol was used for testing rather than the silica dust

Table 6

Initial Instantaneous Filter Efficiency for
Respirator Filters Against a "Neutralized" Lead Fume Aerosol

<u>Filter Type</u>	<u>Flow Rate 1pm</u>	<u># Filters Tested</u>	<u>Percent Efficiency</u>	<u>SD</u>
DFM	16	13	97.78	.50
	85	7	88.50	1.01
PLEM	16	10	92.98	.75
	85	5	79.76	1.22
DM	16	10	93.12	.90
	85	5	80.93	1.34

Table 7

Relative Initial Instantaneous Count Efficiency
Difference for Charged and "Charge Conditioned"
(Neutralized) Silica Dust and Lead Fume Aerosols

Filter Type	Flow Rate 1pm	Change in Percent Efficiency Silica Dust*	t-test**	Change in Percent Efficiency Lead Fume*	t-test**
DFM	16	.09	N	.45	S
	85	2.96	S	.63	N
PLEM	16	.53	S	-1.16	S
	85	5.07	S	1.87	S
DM	16	-.55	S	-1.48	S
	85	1.68	S	-.82	N

* Positive values indicates neutralizer gave lower efficiency values

** This column reflects the results of a statistical t-test performed on the data at an $\alpha = 0.05$ level.

N Indicates that there is not sufficient evidence to detect a difference between the two sets of data.

S Indicates that there was sufficient evidence to detect a difference between the two sets of data.

aerosol, the DM and PLEM percent efficiency dropped considerably: 16 1pm DM filter efficiency dropped from 98.12% to 91.64% and the PLEM filter efficiency dropped from 99.36 to 91.82%. This fact is further dramatized when one looks at the 85 1pm data where the DM efficiency went from 96.03% to 80.11% and the PLEM efficiency dropped from 96.11% to 81.63%.

The comparison of instantaneous count efficiency with the results for the silica dust and lead fume aerosols are presented in Table 4. This table shows that there are greater differences in the efficiency results when the silica dust results are compared to the "worst case" than when the lead fume results are compared to the "worst case". This difference is due to the aerosol's size with the "worst case" aerosol being smaller than the lead fume aerosol (0.16 μm determined by Sem). Furthermore, there is a significant increase in percent penetration for both the silica dust

and lead fume aerosols as the flow rate is increased from 16 to 85 1pm. Table 4 exemplifies the significant effect that both particle size and flow rate have on the initial instantaneous filter efficiency value determined for commercially available respirator filter media.

The second part of this study considered the effect of charge on the filter's initial penetration to silica dust and lead fume aerosol when a Kr-85 radiation source was placed in line to reduce the aerosol charge to a Boltzman distribution. The results obtained for the charge conditioned "neutralized" silica dust aerosol are presented in Table 5 and the lead fume results are presented in Table 6. In order to assess the effect due to charge, the values obtained for the "non-neutralized" aerosols in Tables 1 and 2 were compared to the "neutralized" aerosol results. Table 7 shows these comparisons and also indicates the statistical significance of the differences. It can be seen that the effect

TABLE 8
Filter Efficiency Using "Neutralized" and
"Non-Neutralized" DOP Challenge Aerosol

	0.045 μ			0.061 μ		
	"Charged"	Neutralized	$\Delta\%$	"Charged"	Neutralized	$\Delta\%$
DM Filter	85.90	75.03	10.87	81.39	76.73	4.66
PLEM Filter	87.14	77.25	9.89	82.50	78.49	4.01

* Different lot than for earlier results.

due to charge on these efficiency values are at most 1-2%. It is also evident that the aerosol charge is more apparent on the silica dust than on the lead fume and thus has more of an effect on the efficiency. This is due to the aerosol generation methods and/or to the nature of the two aerosols in that the silica is capable of retaining a higher charge than the lead fume. The evaporation/condensation aerosol generation procedure employed for lead fume would be expected to provide a smaller charge than on the fluidized bed type generated silica dust aerosol.

A preliminary study revealed that aerosol charge had a large effect on the efficiency of filters against a "worst case" DOP aerosol at 85 1pm. The results presented in Table 8 show that an 8-13% increase in percent efficiency resulted when the aerosol was not conditioned with the Kr-85 source so as to reduce the aerosol's charge. Thus it appears that the effect of the aerosol's charge on percent penetration is related to and dependent on the aerosol's particle size. This indicates that the filtration mechanisms are also dependent on the aerosol's charge as well.

Conclusions

This study shows that particle size has a dramatic effect on the initial filter efficiency determined. As the particle size is reduced in going from the silica dust to the lead fume aerosol, the filter's percent efficiency decreases (Table 4). This decrease indicates that the lead fume is more penetrating and thus more of a discriminating test aerosol than the silica dust. Table 4 also reveals that the "worst case" particle size aerosol gave

significantly lower efficiency values for all filter types and flow rates except for the DFM filters tested at 16 1pm. This confirms that the "worst case" aerosol is more penetrating and a more discriminating test aerosol than either silica dust or lead fume. Finally, the effect of aerosol charge on the percent filter efficiency was investigated. The effect due to charge reduction on the silica dust and lead fume aerosol was not nearly as large as the charge effect observed with the "worst case" particle size aerosol. Finally, the differences seen in the percent penetration between the 16 1pm and 85 1pm data was substantial. These flow results are in agreement with earlier NIOSH⁽¹⁾ findings.

References

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