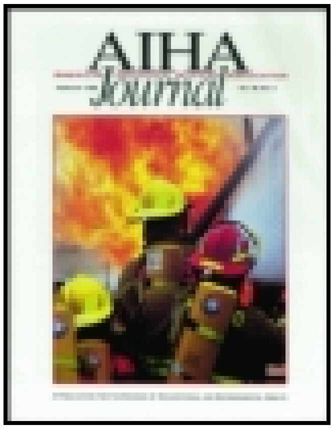

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"Worst Case" Aerosol Testing Parameters: II. Efficiency Dependence of Commercial Respirator Filters on Humidity Pretreatment

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Previous studies have shown that relative humidity has a degrading effect on the performance of commercially available particulate air-purifying respirator filters. That degradation results from a reduction of charge within the filter. This study was done to evaluate the time-dependent effects of relative humidity pretreatment and the reduction of charge on filter penetration against a most penetrating, "worst case" aerosol challenge. Filters of the dust and mist; dust, fume, and mist; paint, lacquer, and enamel mist; and high efficiency types were tested after being pretreated in an environment of 38° C and 85% relative humidity for periods up to 42 days. After various intervals of pretreatment (1, 7, 14, 28, and 42 days), the filters were tested against neutralized worst-case sodium chloride (NaCl) and dioctyl phthalate (DOP) aerosols for percent penetration. The results showed a drop in filter efficiency of approximately 2%–6% depending on preconditioning time, except for the high efficiency filters tested which showed no detectable change.

Introduction

This study was initiated to evaluate the filter preconditioning recommendations made to the National Institute for Occupational Safety and Health (NIOSH) by the American National Standards Institute's (ANSI) Ad Hoc Respirator Committee[1] for the testing of particulate air-purifying respirator filters. These recommendations were incorporated into the proposed revision to *Code of Federal Regulations* Title 30, Part 11 (30 CFR 11)[2] (published as 42 CFR 84[3] in the *Federal Register,* August 27, 1987). The respirator filters tested in this study were challenged with a "worst case" type aerosol, the size aerosol that is most difficult to filter. Filters tested with this worst-case aerosol and prehumidified condition should give an indication of the filter's performance under a wider range of environmental conditions.

The ANSI recommendations called for the preconditioning of the unprotected respirator filter media in an environment of 38° C and 85% relative humidity (RH) for a period of 24 hr before testing the filter media. The preliminary results of that portion of the study[4] showed that after 24 hr in this environment, most filters (with the exception of high efficiency filters) demonstrated a drop in their filter efficiencies of approximately 1.5% to 2%. Although this difference is statistically significant (at an $\alpha = 0.05$), practically speaking, the difference is not great. As a result the study was expanded to look at some of the same respirator filter media after longer exposure times at these same environmental conditions. The expanded exposure times used were 1, 7, 14, 28, and 42 days. Results from all the relative humidity studies are presented.

Background

There have been a few previous studies that have looked at the effect of relative humidity pretreatment on electrostatic filters.[5-7] The first two were performed under contract with NIOSH by the Los Alamos National Laboratory (LANL). The first series of tests performed by LANL[5] tested six resin-impregnated wool felt filters using a 0.6-μm mass median aerodynamic diameter (MMAD) unneutralized sodium chloride (NaCl) particle at a flow rate of 32 L/min (16 L/min for dual filter respirators). The filters were preconditioned in a chamber for a period of 7 days at three different humidities (50%, 75%, and 100% RH at 22.2° C [72° F]). A group of filters was taken out at the end of each day and tested. The results indicated that there was indeed an effect on the filters' performance that depended on the relative humidity level and the number of days the filter was stored at that relative humidity level: the trend being, the higher the humidity and the longer the preconditioning period, the higher the magnitude of penetration.

The second study performed by LANL[6] used a 0.6-μm MMAD unneutralized NaCl aerosol, but with flow rates of 32 and 77 L/min. The filters were preconditioned at 32° C and 90% RH and tested at 7 day intervals, up to 28 days total preconditioning. For the 77 L/min flow rate, NaCl aerosol penetrations for unexposed filters were in the 10%–25% range, but at the end of the 28-day preconditioning period, aerosol penetrations were in the 60%–65% range. For the 32 L/min flow rate, the penetrations ranged from 5%–10% initially to 50%–60% after 28-day preconditioning.

In a study performed by Ackley[7] in 1982, four different types of electrostatic filters were tested using a monodispersed 0.3-μm diameter dioctyl phthalate (DOP) aerosol generated by an ATI model Q127 penetrometer (Air Techniques Inc., Baltimore, Md.). Also, an NaCl aerosol with a 1.0-μm MMAD was used. Both aerosols were unneutralized. The study used filter face velocities of 5.4 cm/sec and 6.5 cm/sec.

This study consisted of a wide range of tests including an oil mist degradation test, a short-term RH degradation test (14-day pretreatment), and a long-term RH degradation test (154-day pretreatment). The study showed that the amount of degradation depends upon the environmental conditions and on the type of filter tested (resin impregnated, electret).

These three studies show that some types of respirator filter material degrade when stored at elevated temperature and humidity. They were not run at worst-case[8] conditions, however. The aerosol particle size that is most penetrating for respirator filters, or the worst-case aerosol, is smaller than the size particles used in these three studies. Also, a worst-case aerosol is "neutralized," or conditioned, to establish a Boltzman charge distribution on the aerosol particles.

Experimental Design

Particulate air-purifying respirator filters from four different manufacturers were evaluated in this study. The types of filters included dust and mist (DM); dust, fume, and mist (DFM); paint, lacquer, and enamel mist (PLEM); and high efficiency (HE) filters and have been identified previously.[8] All filters were certified by NIOSH under the current regulations (30 CFR 11). The filters were tested "as received" from the manufacturer and after preconditioning in a Tenney environmental chamber (Tenny, Union, N.J.) at 38°C and 85% RH for 1, 7, 14, 28, and 42 days. All filters were removed from their packaging and individually exposed to the chamber environment so that the entire surface area was exposed. At least five filters were tested at five different particle sizes that were in the region of the worst-case-size particle, as determined from earlier studies,[8] and the average efficiency determined at each particle size tested. The filters were tested at a continuous airflow rate of 85 L/min. Table I illustrates which filters were tested at each preconditioning time. Of these filters, only the HE filter was solely of the mechanical type.

The filters were tested against various particle sizes of NaCl and DOP aerosols in the range from 0.03 to 0.30-μm count mean diameter (CMD). In all cases the challenge concentration was maintained at less than 10^7 particles per cm^3 to avoid coagulation. The exact concentration did vary over a limited range, but this should not have affected the results since both upstream and downstream concentrations were monitored.

The charge distribution on both aerosols was reduced to a Boltzman charge equilibrium using a Kr-85 source.

Aerosol Generation and Detection

The solid NaCl and DOP aerosol generation system has been completely described in another paper by Stevens and Moyer.[8] The neutralized aerosol then was fed to the test chamber of the filter efficiency test system (FETS),[8,9] which measured count efficiencies. Only one of the three filter sample ports was used in this study since the initial instantaneous penetration was being measured. Thus, short testing times (1-3 min) could be employed to minimize filter loading.

Aerosol Size Measurements

The aerosol size (count mean diameter, CMD) and size distribution (geometric standard deviation, σg) were monitored with a TSI Model 3932 Differential Mobility Particle Sizer (DMPS/C) (TSI, Inc., St. Paul, Minn.). The aerosol was sampled at the point of entrance into the testing chamber. The DMPS measures the aerosol size distribution by the principle of mobility analysis. The DMPS uses an electrostatic classifier and a condensation nucleus counter to measure discrete particle sizes of the aerosol, allowing the instrument to measure accurately the aerosol's distribution.

Results and Discussion

Initial studies showed that a region of minimum efficiency exists for the respirator filters tested.[8] The "as received"

TABLE I
Filters and Days of Preconditioning Studied

Manufacturer/	Filter Type[A]	1 Day		7 Day		14 Day		28 Day		42 Day	
		NaCl	DOP	NaCl	DOP	NaCl	DOP	NaCl	DOP	NaCl	DOP
A	DM	X[B]	X	X	X	X	X	X	X	X	X
	PLEM	X	X	X	X	X	X	—	—	X	X
	DFM	X	X	X	X	X	—	X	—	X	—
	HE	X	—	—	—	—	—	—	—	—	X
B	DM	X	X	X	X	X	X	X	X	X	X
	PLEM	X	X	X	X	X	X	X	X	X	X
C	DM	X	X	X	X	X	X	—	X	—	X
	PLEM	X	X	X	X	—	X	—	—	—	X
	DFM	X	X	X	X	—	—	—	—	—	—
D	DM	X	X	X	X	X	X	X	X	X	X
	PLEM	X	X	X	X	X	X	—	X	—	X
	DFM	X	X	X	X	—	—	X	—	X	—

[A]Filter designations and types described in earlier work.[8]
[B]X = filter tested.

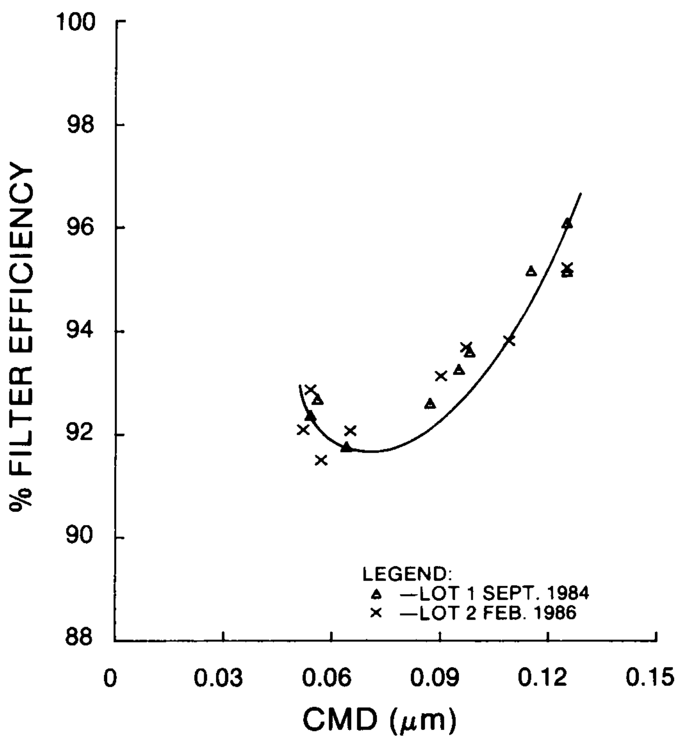

Figure 1—Filter efficiency comparison of two lots of Manufacturer A's DFM filter against NaCl aerosol

filter data from this study and from those previous studies are consistent (Figure 1). Both the region of minimum efficiency and the magnitude of penetration are approximately the same, with differences being attributed to lot-to-lot variability. This demonstrates the reproducibility of this test method over long time periods.

The relative humidity pretreatment generally had the same degrading effect, which resulted in increased filter penetration on all types of filters tested, except the HE filters. Figures 2 and 3 illustrate results for an HE filter against NaCl and DOP challenges before and after RH pretreatment. Note that in Figure 3, the last point seems to indicate an increase in efficiency which is in agreement with earlier results.[8] The high efficiency filter showed no statistically detectable difference between the as-received filters, the 24-hr RH pretreated filters, and the 45-day pretreated filters (t-test at $\alpha = 0.05$). Degradation of HE filters was not expected because these filters rely purely on mechanical filtration to remove particles in the challenge atmosphere.

The other types of filters tested depend to some extent on electrostatic filtration. These types of filters, as discussed earlier, normally will exhibit some degradation when exposed to elevated temperature and humidity, resulting in a decrease in the filter's efficiency. This decrease in efficiency is depicted in Figure 4 for a filter pretreated for 24 hr prior to testing. This decrease in filter efficiency has been reported as being caused by charge neutralization of the filter media caused by moisture.[5-7]

Previous studies[5-7] showed that the filters' efficiency will continue to decline (filters will continue to degrade) if the filters are left in an elevated temperature/RH environment. In fact, the filters will degrade until only the mechanical efficiency of the filter remains. Literature studies[6,7] show that filter efficiency continued to decline as exposure time increased, up to 180 days, at which time the studies were terminated. In the first 20–40 days, however, the greatest percentage change was noted.

Before comparing these data with the earlier studies,[5-7] differences in the experimental design must be taken into consideration. Specifically, the aerosol used in this test is in the worst-case size region, and the aerosol was neutralized (Boltzman distribution) before the filter was challenged. The Los Alamos[6] results, where the test parameters were closest to those used in this study, were obtained at a flow rate of 77 L/min and employed a 0.6-μm unneutralized NaCl particle. DM filters showed a penetration of 10%–25% for the as-received filters. NIOSH's data, employing a worst-case aerosol, measured penetrations of 30%–35%. The three effects which could cause this significant difference are (1) particle size, (2) aerosol charge, and (3) differences in the types of filters tested. A comparison of the studies indicates that there was approximately a 2% drop in efficiency after 24 hr at both the worst-case aerosol size and at 0.6 μm.

Pretreatment for time periods up to 42 days did not show the continuing sharp increase in penetration the earlier studies had shown (Figures 5–7). Increased penetration of only 4% to 6% was noted after 42 days pretreatment. Also, in a preliminary set of experiments where poor control was maintained over the temperature/RH conditions, water droplets formed throughout the chamber walls and on the filter media themselves. At these conditions the PLEM fil-

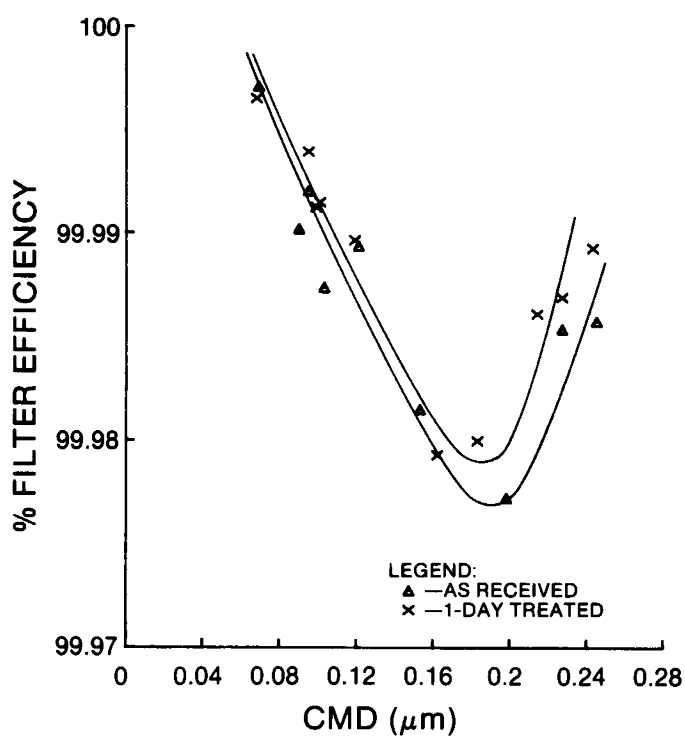

Figure 2—Filter efficiency for Manufacturer A's HE filter at 85 L/min against NaCl aerosol: control and 1-day RH pretreatment

ters showed a decrease in efficiency of approximately 10% (Figure 8) as compared to the 2% difference for the same filters tested under the controlled preconditioning environment (Figure 4). This preliminary run truly could be considered a worst case condition because the filters were basically water logged.

The data collected in this study indicated that there is a trend of increasing difference between some of the pretreated filters' efficiencies and the as-received filters' efficiencies (*i.e.*, Figures 6 and 7) as the particle size is increased. This effect appears to be more pronounced at the longer preconditioning periods. It has been postulated that this effect is caused by the movement from the diffusion region of collection into the interception and impaction region of collection where the collection caused by the electrostatic forces is the dominant mechanism of collection. Hence, the increased difference when the charge on the filter is reduced by humidity pretreatment conceivably could account for a portion of the difference between the Los Alamos study[6] and these data, but this needs to be confirmed further experimentally.

When considering the experimental design of the earlier studies,[5-7] it can be seen that no attempt was made to isolate the two possible simultaneous effects—relative humidity and the aerosol's charge. This study has accounted for aerosol charge effects by conditioning the challenge aerosol with a Kr-85 source. Therefore, the results should reflect only the relative humidity effect. But, to better estimate the contribution from charging, a few preliminary experiments were done. Filters were tested against the DOP aerosol with and without the neutralizer (Kr-85) in line to see how substantial the charging effect was. Two filters were tested this way, and the results are shown in Table II. This DOP data suggest that the charging effect is substantial and may be more important than the relative humidity effect. Future work needs to isolate those effects and monitor their contribution.

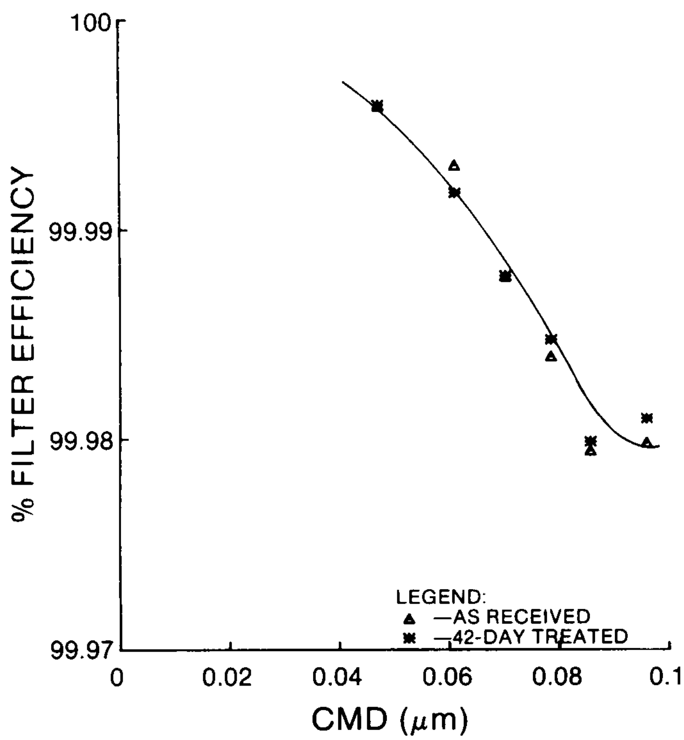

Figure 3—Filter efficiency for Manufacturer A's HE filter at 85 L/min against DOP aerosol: control and 42-day RH pretreatment

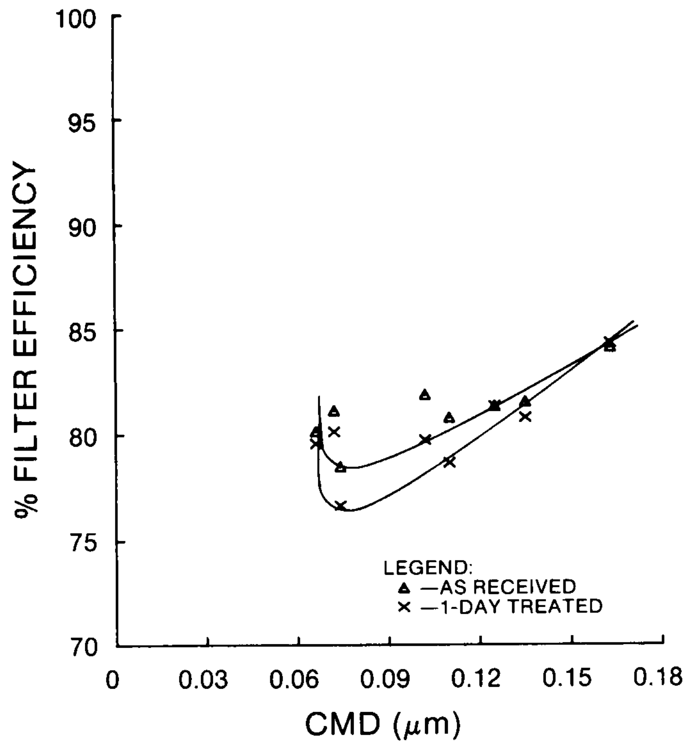

Figure 4—Filter efficiency for Manufacturer A's PLEM filter at 85 L/min against NaCl aerosol: control and 1-day RH pretreatment

Conclusions

The results of this study have shown that respirator filters do show some degradation following unprotected preconditioning at 38° C and 85% RH when tested with a neutralized worst-case aerosol. In general, the longer the preconditioning, the more degradation and penetration which result. It is not unreasonable to expect these filters to be stored for extended periods of time at environmental conditions quite similar to those evaluated in this study. The specific conclusions shown by this study are the following.

- The electrostatic filters tested demonstrated a drop in efficiency of approximately 2%–6% depending on the preconditioning time (from 1 to 42 days).
- High efficiency filters showed no detectable change in their efficiencies when preconditioned at 38° C and 85% RH. They maintained efficiencies of > 99.97% at the worst-case size range.
- It appears from this study, in connection with past investigation, that the effect of particle charge and size is significantly larger than the effect of RH.

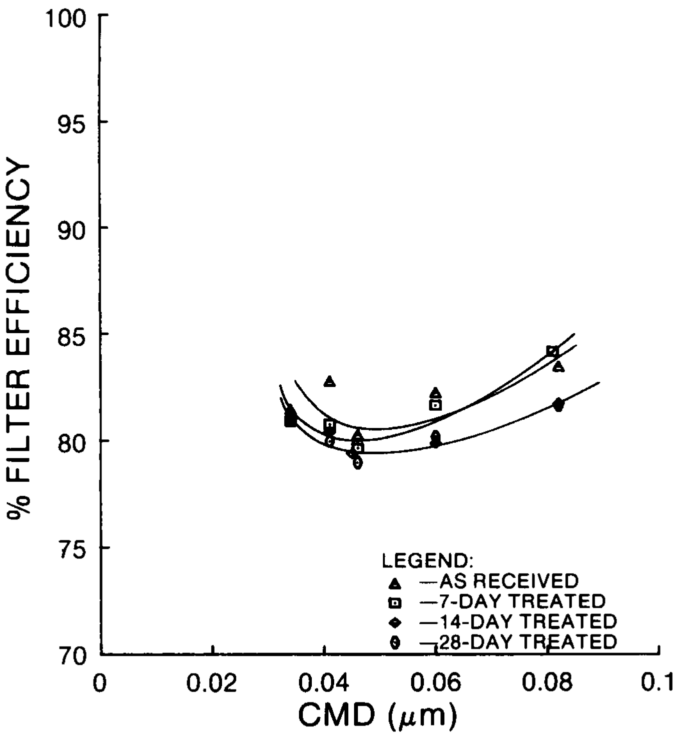

Figure 5—Filter efficiency for Manufacturer B's PLEM filter at 85 L/min against NaCl aerosol: control and various days of RH pretreatment

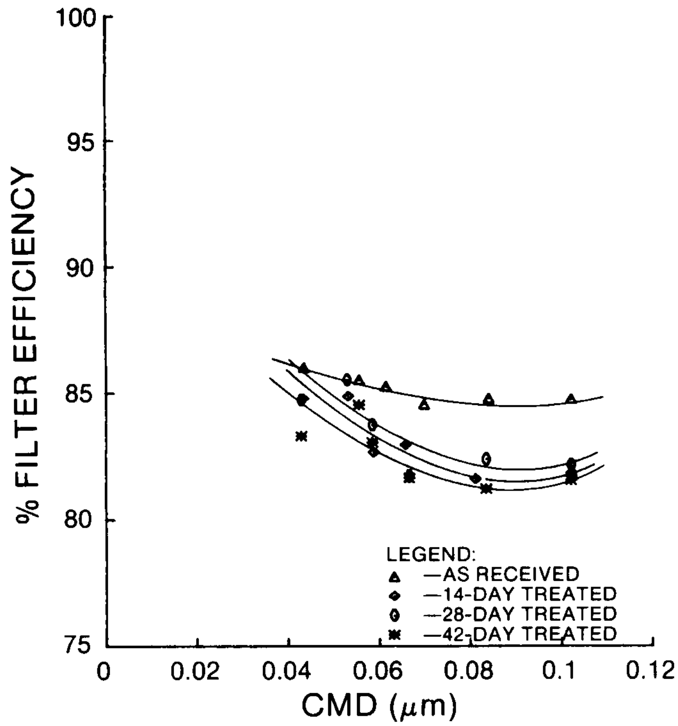

Figure 7—Filter efficiency for Manufacturer D's PLEM filter at 85 L/min against DOP aerosol control and various days of RH pretreatment

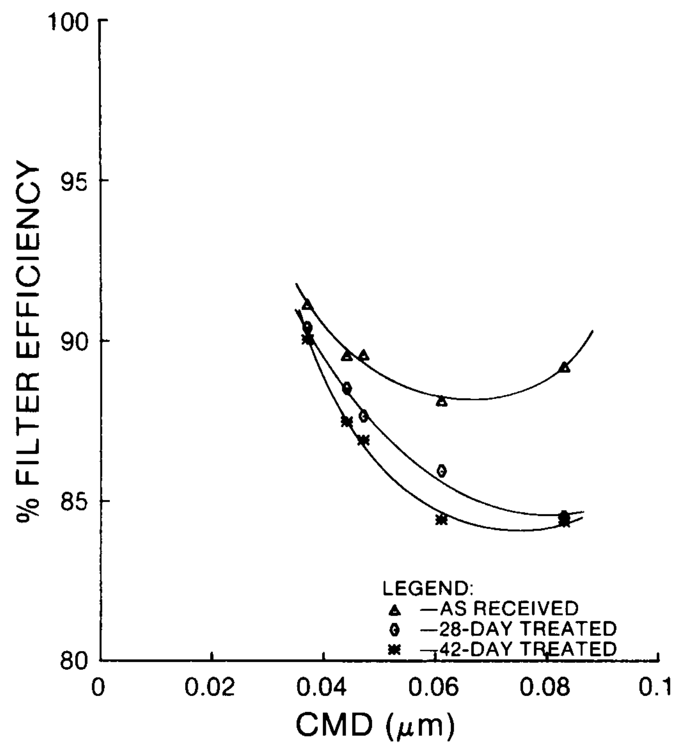

Figure 6—Filter efficiency for Manufacturer D's DFM filter at 85 L/min against NaCl aerosol: control and various days of RH pretreatment

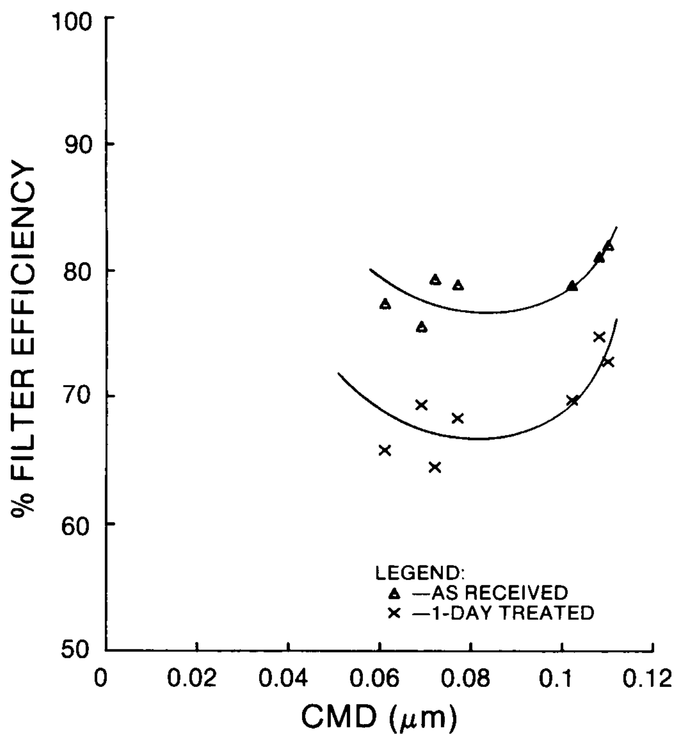

Figure 8—Filter efficiency for Manufacturer A's PLEM filter at 85 L/min against NaCl aerosol: control and "worst case" RH preconditioning

This study has pointed out several areas that need further research in order to better understand the filtration characteristics of particulate respirator filters. As discussed, there appears to be an influence of particle size, in relation to prehumidification time, on the efficiency of the filter in going from smaller size to larger size particles. From this

TABLE II
DOP Filter Efficiency with and without Charge Conditioning/"Neutralization"

	0.045 μm			0.049 μm		
	Charged	Neutralized	Δ%	Charged	Neutralized	Δ%
Filter A	77.03	68.38	8.56	80.62	67.78	12.84
Filter B	79.62	71.13	8.49	84.24	72.56	11.98

study, the data are inconclusive as to how the RH pretreatment affects the region of maximum penetration. That is, does the worst-case particle-size region shift to a larger size for the humidified filters, or is the effect of RH preconditioning of a particular filter constant over a wide range of particle sizes? Also, it is apparent from this study that particle charge, as well as size, is a significant factor in determining the filtering properties of a filter. In fact, the influence of the charge on the particle may well outweigh the effect of filter RH preconditioning. Additional studies need to be performed to separate the effects caused by aerosol charging, size, and filter RH pretreatment.

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