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Electrostatic N-95 Respirator Filter Media Efficiency Degradation Resulting from Intermittent Sodium Chloride Aerosol Exposure

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The effects of intermittently loading small masses of sodium chloride aerosol on the filtration efficiency of N-95 filtering facepiece respirators was investigated. The National Institute for Occupational Safety and Health (NIOSH) certifies that N-95 respirators must provide at least 95 percent filtration efficiency against a sodium chloride aerosol challenge as per the respirator certification (42 CFR 84) test criteria. N-95 respirators are specified for protection against solid and water-based particulates (i.e., non-oil aerosols). New N-95 respirators from three different manufacturers were loaded with 5 ± 1 mg of sodium chloride aerosol one day a week, over a period of weeks. Aerosol loading and penetration measurements were performed using the TSI 8130 Filter Tester. Respirators were stored uncovered on an office desktop outside the laboratory. To investigate environmental and temporal effects of filters being stored without sodium chloride exposure, control respirators were stored on the desk for various lengths of time before being initiated into weekly testing. For all manufacturers' respirators, the controls showed similar initial penetrations on their day of initiation (day zero) to those of the study samples on day zero. As the controls were tested weekly, they showed similar degradation rates to those of the study samples. Results show that some of the manufacturers' models had penetrations of greater than 5 percent when intermittently exposed to sodium chloride aerosol. It is concluded that intermittent, low-level sodium chloride aerosol loading of N-95 respirators has a degrading effect on filter efficiency. This reduction in filter efficiency was not accompanied by a significant increase in breathing resistance that would signal the user that the filter needs to be replaced. Furthermore, it was noted that the effect of room storage time prior to initial exposure was much less significant.

Keywords Respirators, Filters, Filter Efficiency, Filter Efficiency Degradation, Sodium Chloride Aerosol

With the enactment of the new National Institute for Occupational Safety and Health (NIOSH) respirator regulations outlined in 42 CFR Part 84 (42 CFR 84), the new negative pressure air purifying particulate filter test criteria changed.⁽¹⁾ As a result the marketplace has experienced an influx of new electrostatic type respirator filters. Most of these new type filters are of the N-series type which are recommended for use only against non-oil aerosols. Three levels of efficiency for the N-series filters are indicated, namely 95, 99, and 99.97 percent efficient. N-series respirator filters are tested against a sodium chloride (NaCl) aerosol according to the NIOSH certification test. The sodium chloride aerosol was thought to be only slightly degrading to the filter's efficiency, whereas dioctyl phthalate (DOP) liquid aerosol is highly degrading. Because N-series filters are tested against sodium chloride, NIOSH only recommends them for use against solid aerosols and water-based aerosols (i.e., non-oil aerosols). The *NIOSH Guide to the Selection and Use of Particulate Respirators Certified Under 42 CFR Part 84* states:⁽²⁾

Generally, the use and reuse of N-series filters would also be subject only to considerations of hygiene, damage, and increased breathing resistance. However, for dirty workplaces that could result in high filter loading (i.e., 200 mg), service time for N-series filters should only be extended beyond 8 hours of use (continuous or intermittent) by performing an evaluation in specific workplace settings that demonstrates (a) that extended use will not degrade the filter efficiency below the efficiency level specified in Part 84, or (b) that the total mass loading of the filter(s) is less than 200 mg

These determinations would need to be repeated whenever conditions change or modifications are made to the processes that could change the type of particulate generated in the user's facility.

The guide also indicates that:

NIOSH will be conducting and encouraging other researchers to conduct studies to assure that these service time recommendations

are adequate. If research indicates the need, additional service time limitations may be recommended by NIOSH for specific workplace conditions.

This article presents the findings of a research study on the efficiency degradation of N-95 respirator filters which have been intermittently exposed to a solid sodium chloride aerosol. We found that intermittent exposure to a solid NaCl aerosol can degrade the filter efficiency of N-series electrostatic filter media used in negative-pressure air purifying respirators.

BACKGROUND

The effects of static charge on workplace aerosols have been investigated and summarized.⁽³⁾ Also, the action of fibrous respirator filter media filtration mechanisms has been addressed.^(4,5) The two main filtration mechanisms being discussed for negative-pressure air purifying particulate respirators are mechanical and electrostatic, or a combination thereof. The electrostatic filters have an inherent mechanical nature but also have a vital static electric charge on the filter's fibers to enhance the attraction and capture of aerosol particles. This type of electrostatic fiber with a built-in charge was originally promoted as a high-efficiency filtration method for polluted air.^(6,7) These papers^(6,7) focus on the production and filtration properties of the so-called electret filter media. These corona-charged split polypropylene fibers had life expectancies of one year or more even at high temperatures and humidity. The filters were tested against sodium chloride and dioctyl phthalate (DOP) and their capture efficiency for submicron particles was as high as 99.5 percent. Further, it was stated that the efficiency only drops by a mere few percent when loaded up to 5 percent (w/w) with aerosol particles.

Changes in the electret filter performance under field type conditions have not been extensively investigated. One study looked at the alteration in filter efficiency caused by exposure to different industrial-type aerosols.⁽⁸⁾ In that study different types of fumes such as lead smelting fume, foundry burning fume, and other industrial dusts were investigated. They presented general characteristics of the degradation process and developed a semi-empirical theory. Included in the study was a resin-wool filter, which has been available for years and exhibits some electrostatic character. They exposed the filters to different amounts of various aerosol loading and then dried, weighed, and tested for pressure drop and sodium chloride penetration using the British Standard (BS4400) method.⁽⁹⁾ The results they presented showed that all the studied aerosols caused a monotonic increase in penetration with load and that the electret materials clogged significantly under these exposure conditions. They also noted that the electret filters showed a broad range of filter penetration characteristics.

Another study on the behavior of electrostatic filter media looked at the loading and filtration characteristics of filtering facepiece respirators made with electrostatic-type filter media.⁽¹⁰⁾ Although electrostatic filter media are capable of high efficien-

cies and low filter resistance, factors like relative humidity, high temperature, industrial aerosols, some chemicals, and aerosol particle size can all have an effect on filter efficiency.^(8,10,11)

EXPERIMENTAL DESIGN

Three different models of N-95 filtering facepiece respirators were included in this study. All filters from each of the three different manufacturers were from the same lot of filters to eliminate lot-to-lot variability. All tests were done employing a TSI model 8130 Automated Filter Tester (TSI Inc., St Paul, MN) with a model 8118 motorized sodium chloride generator. The TSI model 8130 with the 8118 generator produces a solid sodium chloride aerosol which meets the criteria established in 42 CFR 84 for challenging N-series filters. The instrument measures the sodium chloride filter penetration employing a forward light scattering photometer. The challenge aerosol concentration can be determined gravimetrically to quantify the amount of sodium chloride deposited on the filter per unit time. All filters were tested at a continuous airflow of 85 L/min. Further, all filters were tested as received from the manufacturer without any relative humidity pretreatment as required in 42 CFR 84 for N-series filters. Room temperature was employed for all studies.

Three different series of experiments were conducted as part of this study. The first set of experiments consisted of running sodium chloride loading tests on the as received filters until a 200 mg filter loading was obtained. This is the 42 CFR 84 loading test with the exception that the filters were not preconditioned. The second set of experiments consisted of exposing the filters to 5 ± 1 mg of sodium chloride and then storing them at normal office conditions for a week. Following the one week of storage at office conditions, the filters were again tested until another 5 ± 1 mg of sodium chloride was deposited on the filters. This loading and testing procedure was continued weekly to determine the effect of intermittent sodium chloride exposure on the electrostatic filter media penetration. It should be noted that on weeks 3 and 25 testing was not performed due to work scheduling problems.

The final set of experiments consisted of storing as received filters at the same office conditions as the intermittent sodium-chloride-exposed filters. Periodically, one of these so called "controls" was then initiated into the intermittent 5 ± 1 mg sodium chloride weekly exposure scenario with each filter's sodium chloride penetration determined during the loading challenge.

The sodium chloride aerosol particle size and distribution was determined using a TSI model 3932 differential mobility particle sizer (DMPS) or a TSI model 3934 scanning mobility particle sizer (SMPS). These instruments measure the aerosol particle size and distribution of submicrometer aerosols by the electrical mobility method.

RESULTS AND DISCUSSION

The three manufacturers' N-95 filters were first tested according to the NIOSH certification criteria with the exception

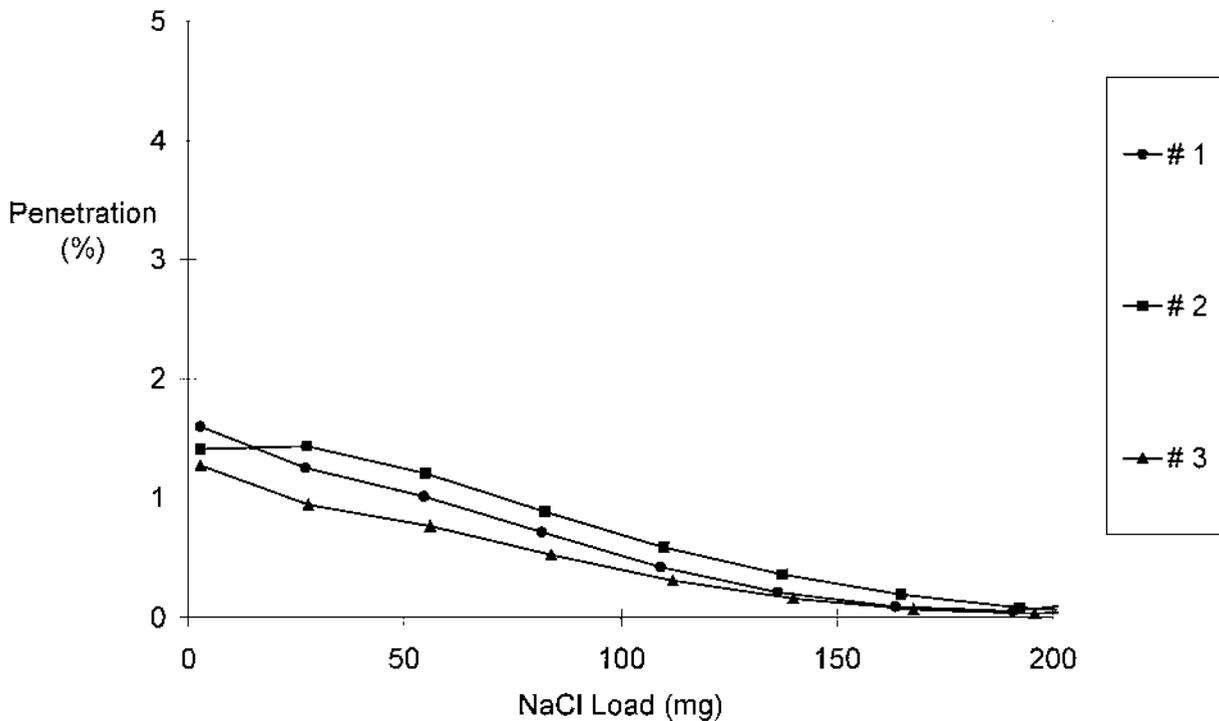


FIGURE 1

Manufacturer A N-95: 200 mg continuous NaCl aerosol loading.

that the filters were tested as received without any relative humidity preconditioning. Figure 1 shows typical sodium chloride loading data for an N-95 electrostatic type filter produced by Manufacturer A. Three filters were tested and performed similarly. The maximum sodium chloride filter penetrations for these N-95 filters were 1.27 percent, 1.44 percent, and 1.60 percent, and these data are consistent with previous data collected on this model filter. Similar data generated for manufacturer B filters give maximum sodium chloride penetration values of 1.68 percent, 1.76 percent, and 1.82 percent. The maximum sodium chloride penetration values for manufacturer C filters were 0.758 percent, 0.841 percent, and 0.908 percent. All filters were NIOSH-certified N-95 filters and the sodium chloride data above are consistent with that fact.

The sodium chloride aerosol used in these studies met the criteria given in 42 CFR 84. Particle size data gave a count median diameter of 0.075 ± 0.020 micrometers with a standard geometric deviation not exceeding 1.86 in all cases.

The intermittent exposure data for manufacturer A N-95 filters are presented in Figure 2. The figure shows the penetration data for three filters at each loading value (weekly 5 ± 1 milligram loading except weeks 3 and 25). As can be seen, the first penetration value at each weekly testing is the higher and the second value is reduced, possibly as a result of filter clogging as suggested by a corresponding increase in filter resistance. This phenomenon was observed for all three manufacturers' N-95

filters. Also, there is a linear increase in filter penetration versus loading.

To allow for a comparison of data, the first weekly penetration values for the three filters from the same manufacturer were averaged. The average initial weekly penetration values for the three different manufacturers' filters are displayed on a single plot. Figure 3 shows the three different manufacturers' N-95 weekly initial filter penetrations as a function of time against the intermittent sodium chloride challenge aerosol.

The same data are shown in Figure 4 where the filter penetration is plotted versus the sodium chloride challenge loading in milligrams. The filters have their own distinct intermittent loading versus penetration curve. Manufacturer C's was the filter with the highest resistance to degradation with sodium chloride loading. Manufacturer A and B filters show a considerably larger effect due to the intermittent sodium chloride exposure. In fact, the manufacturer C filter maintains a value of less than 5 percent sodium chloride penetration whereas the other two manufacturers' filters exceed the 5 percent level, which is the test criteria for a 200-mg continuous sodium chloride filter load of N-95 filter media. At an intermittent average sodium chloride loading of approximately 45 milligrams, manufacturer A filters exceed the 5 percent level. Manufacturer B filters exceed 5 percent sodium chloride penetration at an average sodium chloride intermittent loading of approximately 65 milligrams. Manufacturer C filters were still below 5 percent sodium chloride penetration after

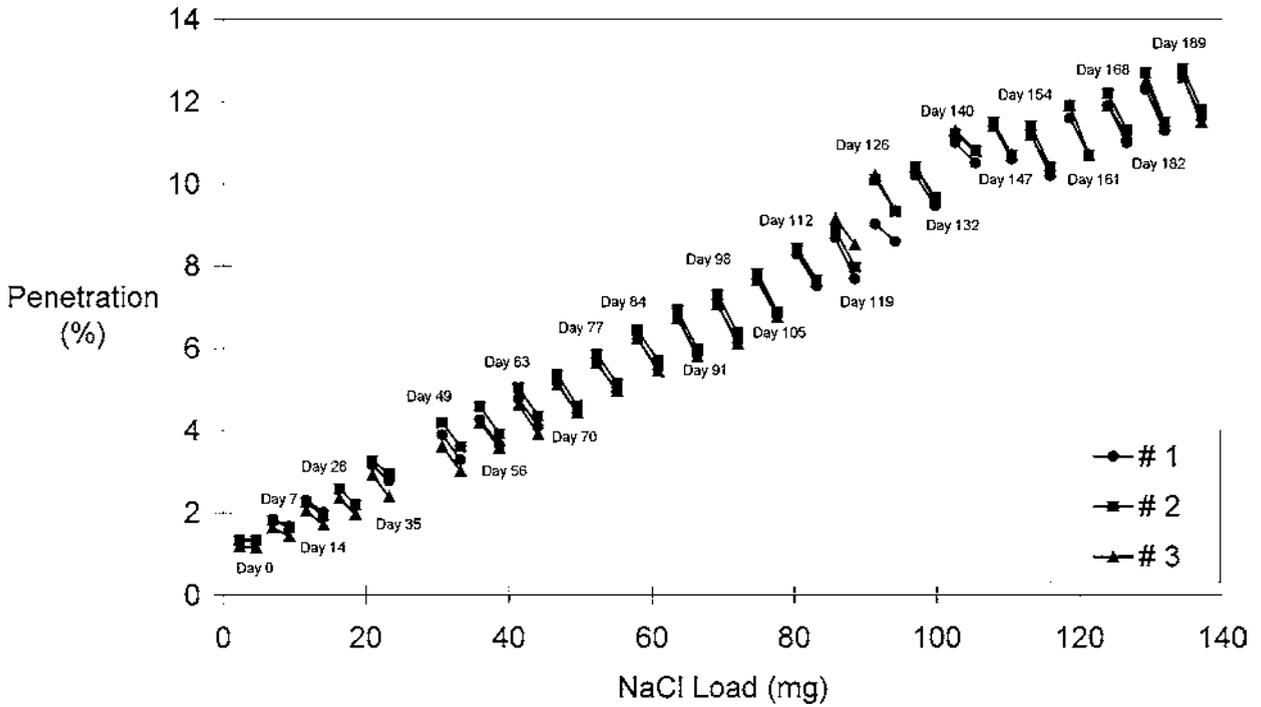


FIGURE 2

Manufacturer A N-95: filters stored open to office atmosphere (5 mg weekly NaCl aerosol loadings).

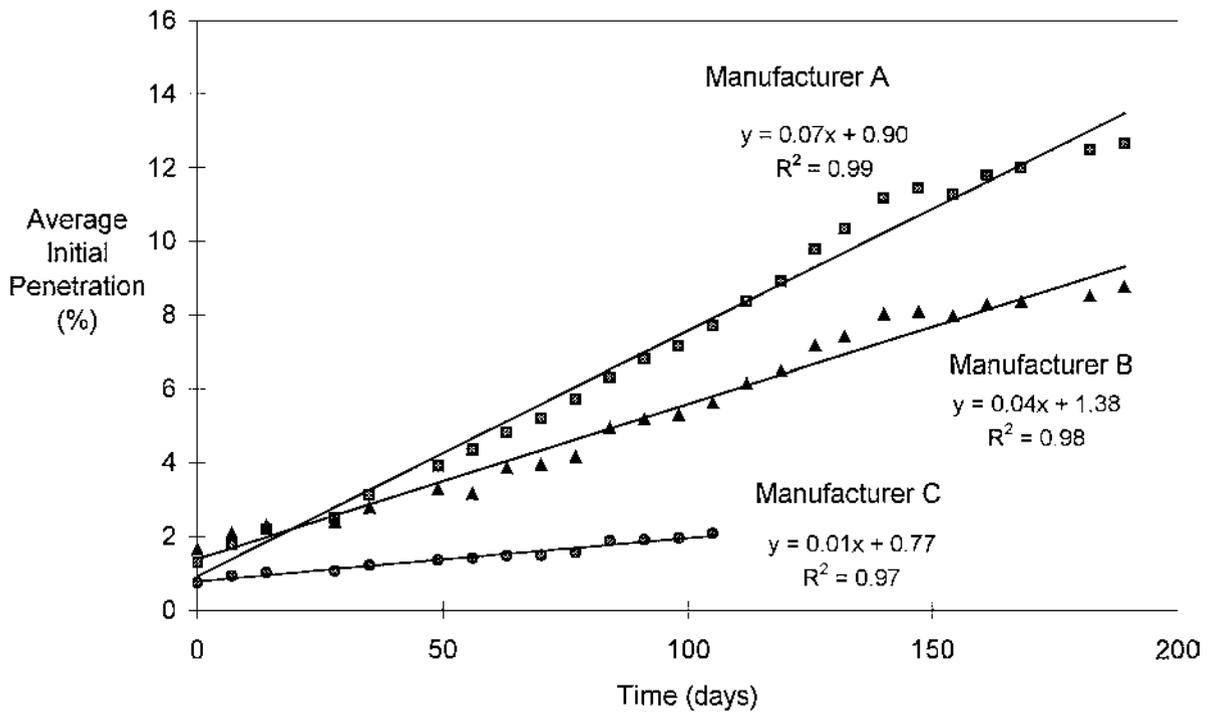


FIGURE 3

Average sodium chloride penetration for the three manufacturers' N-95 electrostatic filters: time vs. penetration for intermittent loading.

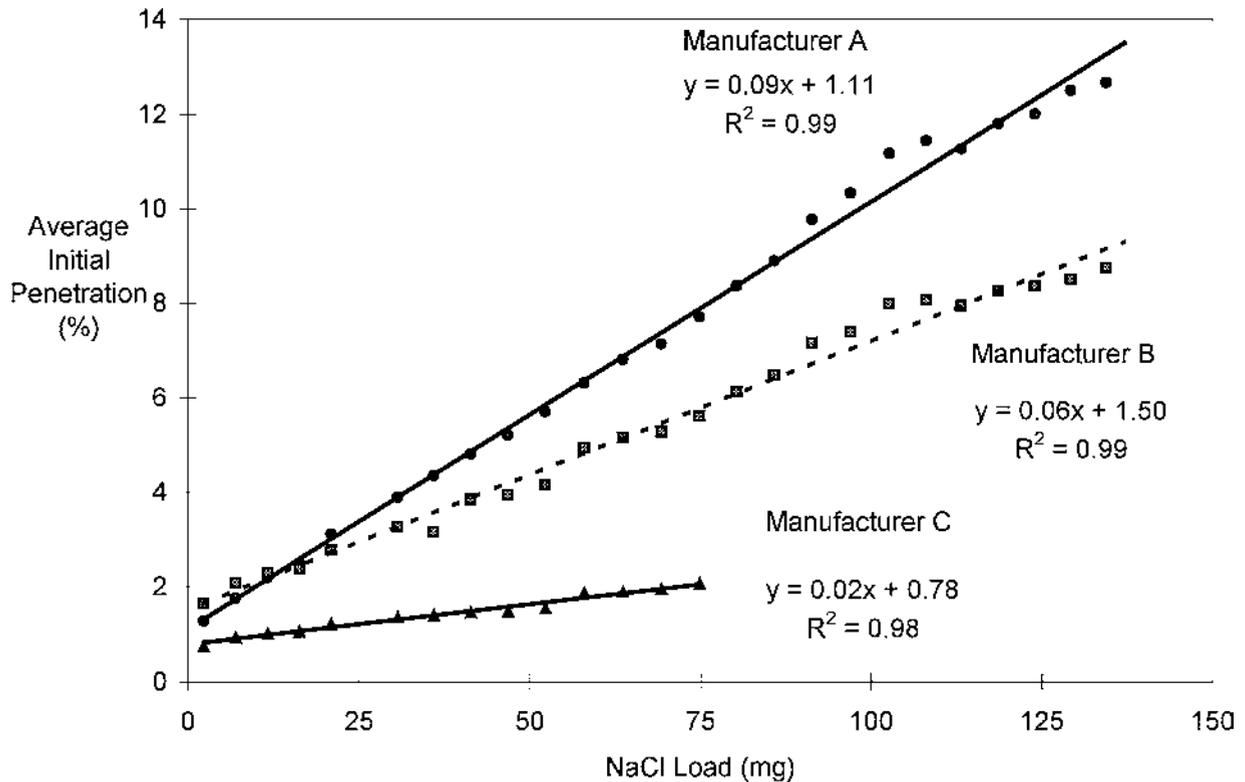


FIGURE 4

Average sodium chloride penetration for the three manufacturers' N-95 electrostatic filters: load vs. penetration for intermittent loading.

approximately 78 milligrams of sodium chloride contacted these filters during intermittent loading. Thus, these data suggest that intermittent loading may be an important criterion in judging filter performance.

Figure 5 shows a plot of breathing resistance as a function of intermittent sodium chloride aerosol loading for the three different manufacturers' N-95 filter models. To allow for a comparison of the data, the first weekly resistance values for the three filters from the same manufacturer were averaged. The data indicate that for all three models, there is minimal increase in average breathing resistance over the intermittent loading period. The average breathing resistance for manufacturer A's filters increased from an initial value of 12.9 to a final value of 14.6 mm H₂O. Average breathing resistance for manufacturer B's increased from 14.3 to 17.4 mm H₂O, and the average breathing resistance for manufacturer C's increased from 14.7 to 15.6 mm H₂O. The low filter resistance values of electrostatic filters is one of their greatest advantages. However, in this particular case, the lack of resistance increase when filter degradation has occurred means that the users may not be able to determine when the filters need to be replaced. This suggests that another mechanism may be needed to identify when decreased filter efficiency occurs.

To ascertain what effect the storage at the office conditions was having on the filters, so-called "controls" were employed.

The controls were allowed to sit at the office conditions for various lengths of time before initiation into the intermittent sodium chloride exposure scenario. Controls were drawn from all three manufacturers' N-95 filters. Figures 6, 7, and 8 depict these data for manufacturers A, B, and C N-95 filters, respectively. The three figures show the same data trends. Namely, the storage at office conditions has a minimal effect on the filter's efficiency characteristics. However, as soon as the intermittent 5 ± 1 mg sodium chloride exposure study is instituted, the filters begin to be adversely affected. This reduction in filter efficiency is probably due to a reduction in the electrostatic mechanism of particle capture because this effect is not observed for strictly mechanical filters.

Manufacturer A data presented in Figure 6 show that the average initial sodium chloride penetration value was 1.28 percent for the three initial filters entered into the intermittent sodium chloride 5 ± 1 mg exposure scenario on day one. The initial values for the controls varied from a low of 1.53 percent (91 days office storage) to a high of 2.09 percent (147 days office conditions). Manufacturer B (Figure 7) data gave initial values for the controls that varied from a low of 1.57 percent (91 days office storage) to a high of 2.07 percent (70 days office storage), and an average for the three initial penetration values of 1.64 percent. Manufacturer C (Figure 8) data gave initial values for

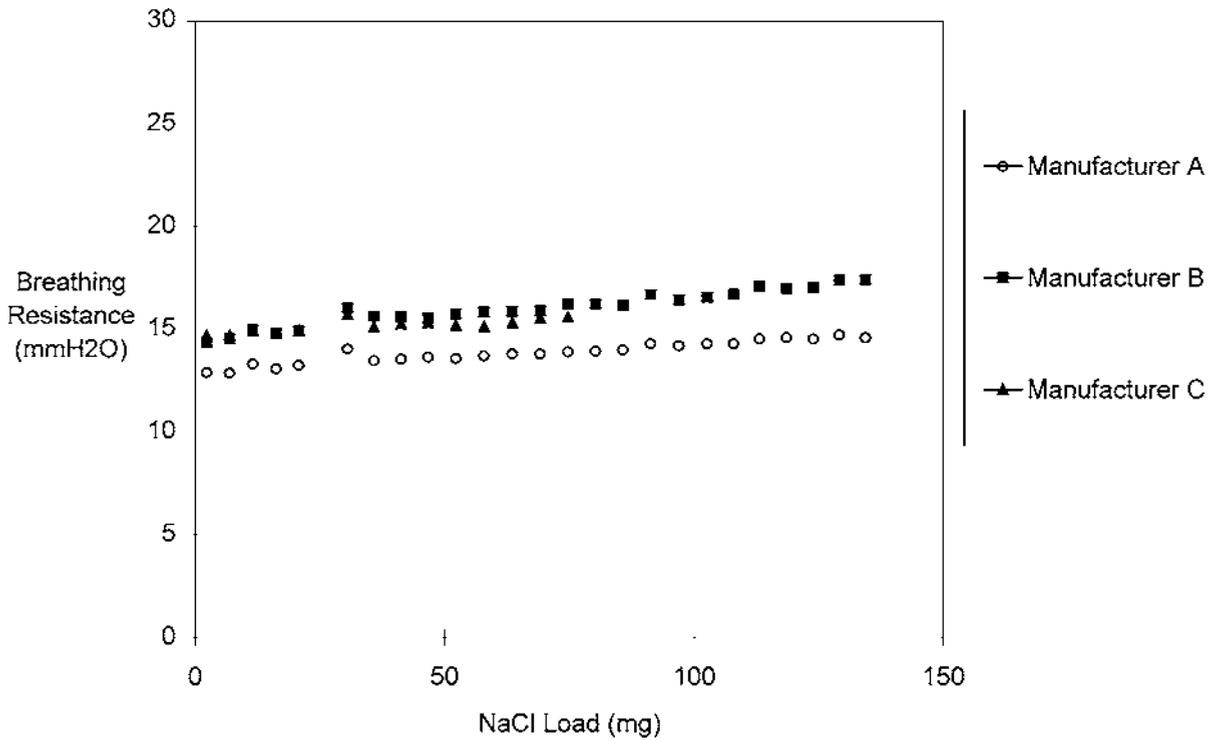


FIGURE 5
Average breathing resistance for N-95 filters.

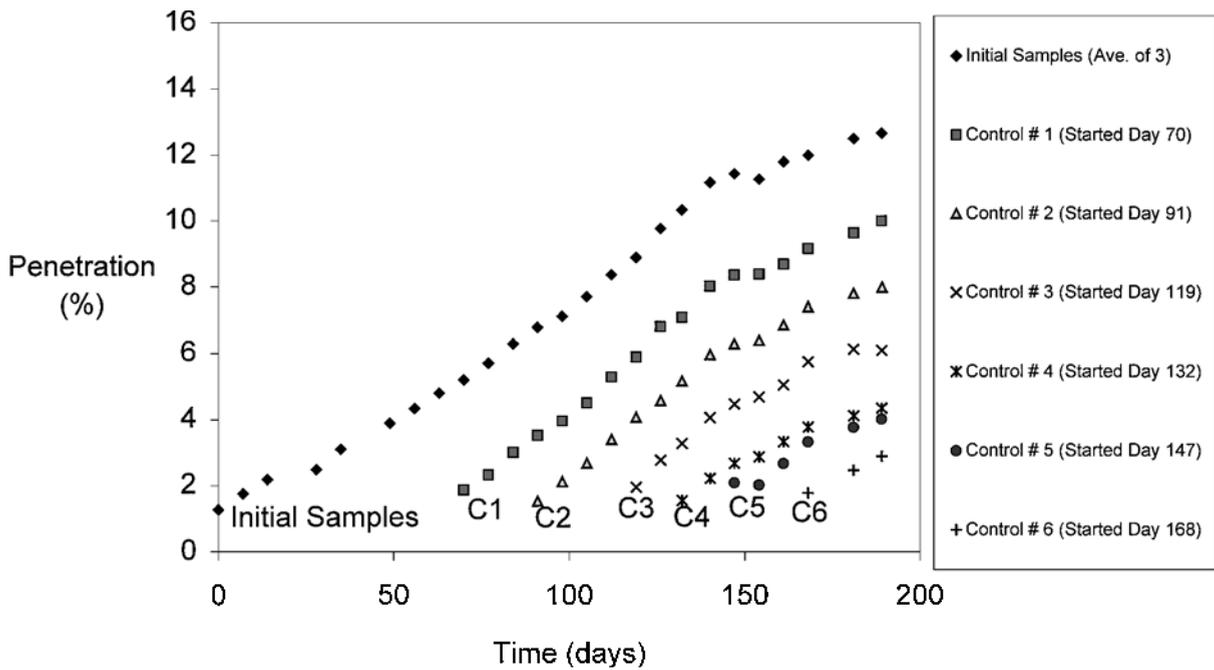


FIGURE 6
Manufacturer A: N-95 filtering facepieces initial samples and controls.

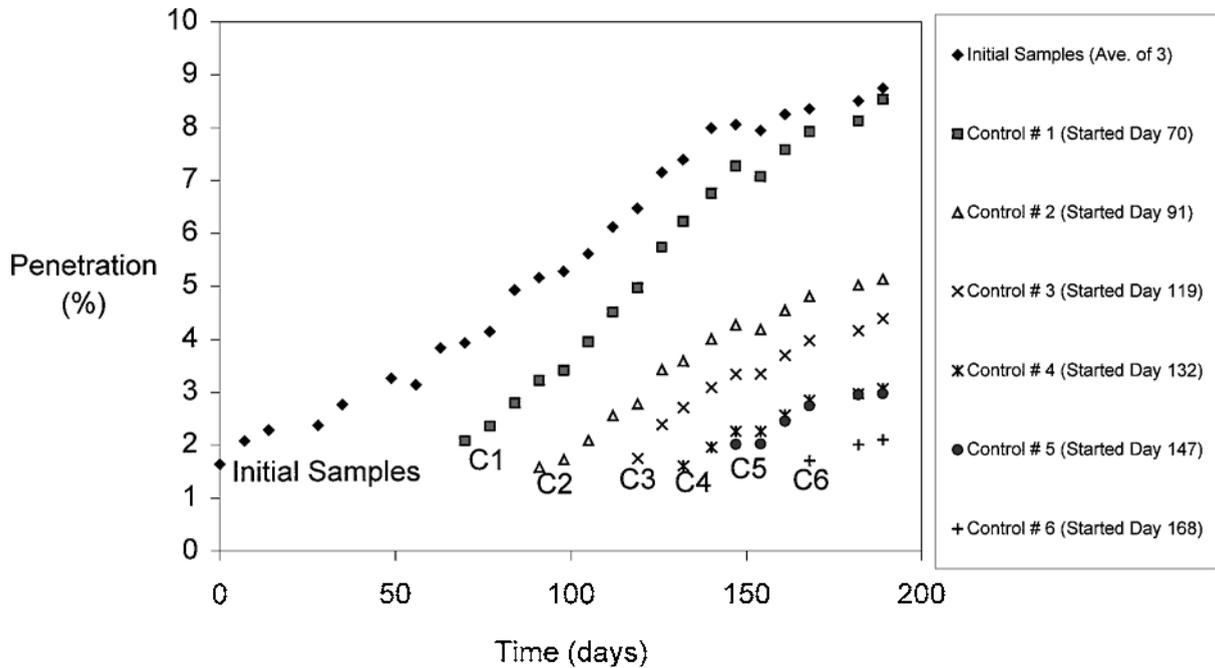


FIGURE 7

Manufacturer B: N-95 filtering facepieces initial samples and controls.

the controls that varied from a low of 0.661 percent (132 days office storage) to a high of 0.94 percent (91 days office storage), and an average for the three initial penetration values of 0.74 percent. The effect due to the office storage is negligible

compared to the reduction in filter efficiency due to the intermittent 5 ± 1 mg sodium chloride loading scenario. More important is the fact that relatively low total sodium chloride aerosol loads can have a very pronounced effect on filter efficiency reduction.

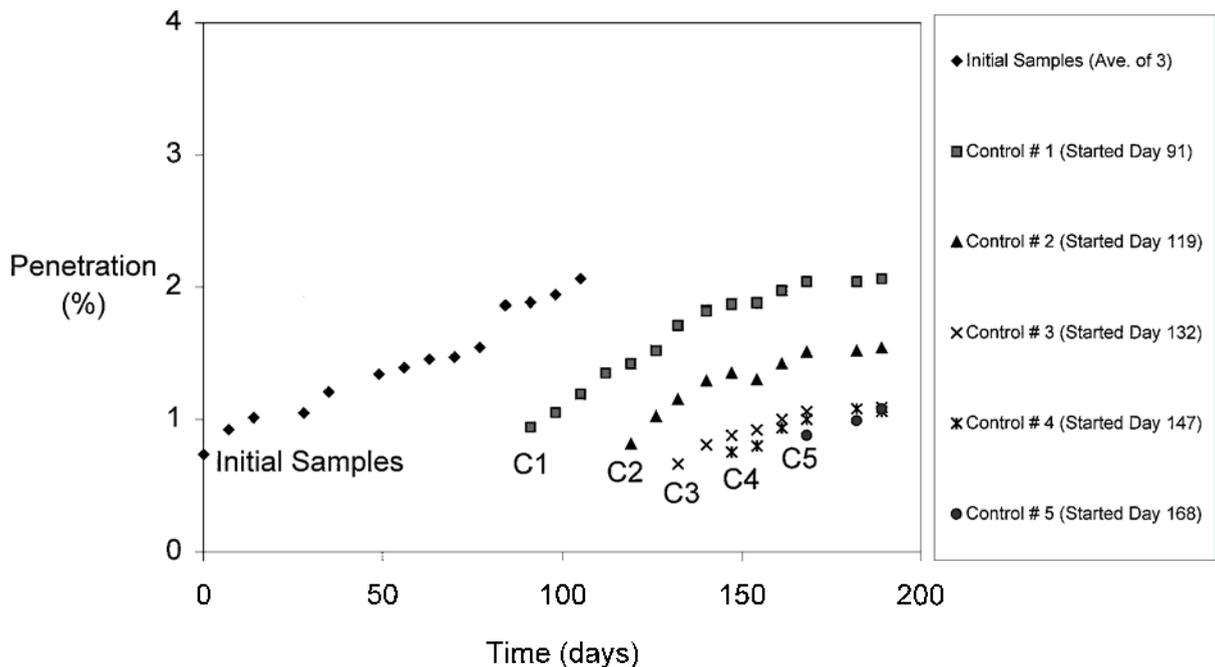


FIGURE 8

Manufacturer C: N-95 filtering facepieces initial samples and controls.

TABLE I
Effect of 15-second water dip^A on filter efficiency of N-95 series filters

Filter treatment	Filter manufacturer A				Filter manufacturer B				Filter manufacturer C			
	Maximum initial penetration (%)	Initial NaCl load (mg)	Initial penetration after 20 days storage following initial NaCl load ^B (%)	Maximum initial penetration (%)	Initial NaCl load (mg)	Initial penetration after 20 days storage following initial NaCl load ^B (%)	Maximum initial penetration (%)	Initial NaCl load (mg)	Initial penetration after storage following initial NaCl load ^B (%)	Maximum initial penetration (%)	Initial NaCl load (mg)	Initial penetration after storage following initial NaCl load ^B (%)
	New #1	1.13	15.5	2.45	2.29	15.5	3.65	0.895	26.1	1.3	0.895	26.1
New #2	1.16	15.5	2.71	2.35	15.5	3.58	1.01	26.1	1.35	1.01	26.1	1.35
Water dipped #1	1.94	15.5	3.29	1.97	15.5	3.30	0.854	28.4	1.35	0.854	28.4	1.35
Water dipped #2	1.88	15.5	3.52	2.41	15.5	2.67	0.781	28.4	1.24	0.781	28.4	1.24

Note: New filters stored 21 days, water-dipped filters stored 20 days

^A Filters were completely submerged in distilled water for 15 seconds and were tested following air dry.

^B Filters stored at room temperature and humidity.

One of the concerns regarding electret-type filters was their stability at high humidity conditions. Early reports indicated that at high humidity conditions, the loss of charge can be significant.⁽⁶⁾

To determine the ultimate (worst case) effect due to water, a comparison was done between new filters and new filters which were dipped for 15 seconds in a beaker of distilled water. The water-dipped filters were allowed to air dry overnight before testing. Both the new filters and the water-dipped filters were tested for filter penetration employing the TSI Model 8130 Filter Tester. This extreme water treatment was performed to ascertain what, if any, effect it would have on these N-95 series electrostatic filters. The data for the three manufacturers' N-95 series filters are presented in Table I.

These data show that the effect of the water dip is minimal for manufacturers B's and C's filters. There appears to be an increase in the filter penetration values for the manufacturer A filters when comparing the new to the water-dipped penetration values. Manufacturer A filters showed the most rapid intermittent degradation rate. Similarly, the penetration values determined three weeks post-dipping for manufacturer A also show an increase in filter penetration compared to the new filters stored under identical conditions minus the water dipping. The three-week post-dipping penetration data for manufacturer B and C were similar to the penetration values for the new filters stored under identical conditions minus the water dip. Thus, it appears that the water dipping has a minimal effect on filter penetration as compared to the sodium chloride exposure.

CONCLUSIONS

Although the degrading effects of aerosols on the efficiency of electrostatic particulate filters have long been known, this is the first study to indicate that temporal effects can play a role in electrostatic filter degradation. That is, the amount of electrostatic filter degradation resulting from exposure to aerosols does not just depend upon the amount deposited on the filter, but, also, on the time over which that aerosol deposition occurs. Two of the three filter models showed that sodium chloride filter penetrations exceeded 5 percent, with total loading of approximately 45 and 65 milligrams which is far lower than the continuous loading of 200 milligrams used for certification. One manufacturer's filter (manufacturer C) gave a sodium chloride penetration of less than 5 percent throughout its exposure to intermittent 5 ± 1 mg sodium chloride loads. This intermittent

degradation phenomenon is important because use of these devices could easily be envisioned under use conditions that follow a similar type intermittent exposure scenario. Further, because the reduction in electrostatic filter efficiency is not necessarily accompanied by a significant increase in breathing resistance the user may not receive an indication or warning that the filters need to be replaced.

Additional research is needed to understand the mechanism responsible for the effects observed in this study, and how the workplace performance of specific respirator models may be affected by the effects observed in this study.

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