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Factors Affecting Filter Penetration and Quality Factor of Particulate Respirators

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ABSTRACT

In the present study, a theoretical model was used to examine factors affecting the filtration characteristics of filters used for respiratory protection. This work was designed to support the particulate filter test requirements established in 1996. The major operating parameters examined in this work include face velocity, fiber diameter, packing density, filter thickness, and fiber charge density. Characteristics of the most penetrating particle size were also modeled with the same operating parameters.

The results showed that aerosol penetration through electret filter media increases with increasing face velocity and increasing fiber diameter, and decreases as packing density, filter thickness or fiber charge density increase. Face velocity and fiber charge density have more significant effects on filter quality than the other factors. Filter quality increases with decreasing face velocity or increasing fiber charge density. For electret filters, (1) the most penetrating particle size increases with increasing fiber diameter; (2) an increase in packing density, thickness, or fiber charge density would cause the most penetrating particle size to decrease, and (3) the most penetrating particle size through electret filters increases with increasing face velocity and decreasing filter thickness. On the other hand, for non-electret filter media, the most penetrating particle size increases with decreasing face velocity, and the filter quality factor is not affected by filter thickness.

***Keywords*:** Respirator; Filter; Filtration model.

INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) published the NIOSH Respirator Decision Logic in 1987, the NIOSH Guide to the Selection and Use of Particulate Respirators Certified under 42 CFR 84 in 1996 and the NIOSH Certified Equipment List to help industrial hygienists select the proper approved respirators for a given environment. According to the list certified under the old regulations (30 CFR Part 11) published in 1972, non-powered air-purifying particulate respirators were classified into four categories: single use, dust-mist, dust-fume-mist, and high efficiency particulate air (HEPA) filter. Each type of respirator had to be certified by passing a test using a specified challenge test agent of a given size distribution and mass concentration.

The imperfections and limitations of the laboratory tests that lay behind the previous NIOSH/MSHA certifications (30 CFR Part 11) became obvious as respirator filter manufacturing technology and measurement instruments advanced (Leidel, 1988; Stevens and Moyer, 1989; Chen *et al.*, 1992; Chen *et al.*, 1993), for example, the use of small filter fibers (diameter of 2-3 µm or less) and electret filters made of electrically charged fibers. The major advantage of electret filters lies in the fact that filtration efficiency can be significantly enhanced without increasing pressure drop across the filter. NIOSH promulgated a new set of filter test requirements (42 CFR Part 84) in 1996. This new regulation classified the filters into nine classes (three levels of filter efficiency, each with three categories of resistance to filter efficiency degradation). The selection process for using the new particulate classification is outlined as follows: (1) The selection of N-, R-, and P-series filters depends on the presence or absence of oil particles, (2) Selection of filter efficiency (i.e., 95%, 99%, or 99.97%) depends on the maximum filter penetration that can be accepted, (3) The choice of facepiece depends on many factors such as fit, comfort, the level of protection needed, etc.

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To certify respirators under this new regulation, challenge aerosol size distribution and face velocity were specifically defined. The requirements for aerosol penetration and breathing resistance have also been revised. All filter tests are designed to employ the most penetrating aerosol size, although in actuality this is not accomplished. N-series filters must be tested against a mildly degrading aerosol of sodium chloride (NaCl), with a count median diameter (CMD) of 0.075 ± 0.020 µm and geometric standard deviation (GSD) less than 1.86. R- and P-series filters will be tested against a highly degrading aerosol of dioctylphthalate (DOP), with a CMD of 0.185 ± 0.020 µm and GSD less than 1.66. Note, the "old" categories of dust-mist, dust-fume-mist or HEPA are no longer utilized. The *NIOSH Guide to the Selection and Use of Particulate Respirators* certified under 42 CFR 84 and the *NIOSH Certified Equipment List* should be used to select the appropriate filter and efficiency for a particular exposure situation.

A respirator with perfect filtration but physiologically intolerable resistance to airflow is of no use. Consequently, both the filter penetration and air resistance should be considered when ranking respirators. The filter quality factor, q_f, can be used as an indicator of filter media performance,

$$q_f = \frac{\ln\left(\frac{1}{P}\right)}{\Delta p} \tag{1}$$

where P is the fraction of aerosol penetration and Δp is the pressure drop across the filter. The q_f is also known as the figure of merit and used in previous studies (Kalayci *et al.*, 2006; Wang *et al.*, 2008a, b).

Because of the limitations of the human respiratory system, one of the essential properties of a filter medium to be employed for respiratory protection is low resistance to flow. In practice, an effective filter (one with high filter quality) should have high collection efficiency and low mechanical air resistance. Normally the latter is achieved by lower packing density, thinner filters, or larger fiber diameter, all of which cause lower collection efficiency. Hence, it is critical to determine the optimum balance between these two needs.

In the present study, we analyzed and integrated currently available semi-empirical filtration models to examine the effect of operating parameters on the performance of respirator filters. Better understanding the filtration characteristics of these filter media will help "expedite the incorporation of technological advancements", one of the major purposes of the new 42CFR part 84. Therefore, this work was designed to produce more scientific information that might be used to support and/or criticize the use of the new particulate filter test requirements.

THEORETICAL ESTIMATION OF FILTRATION EFFICIENCY AND PRESSURE DROP

Many aerosol scientists have contributed to the development of modern filtration theories. There are a number of excellent reviews that summarize, compare, and correlate derived theoretical or empirical models with experimental data (Liu and Rubow, 1986; Brown, 1989; Zhang and Liu, 1992; Walsh and Stenhouse, 1997; Barrett, 1998; Romay *et al.*, 1998). With the efforts of air filtration researchers in the past decade, including advances in air filtration modeling and data analysis, filter performance can now be predicted with acceptable accuracy.

In general, air filtration is a complex process. Classical filtration theory begins with an isolated fiber, where the collection efficiency of a fiber is defined by the ratio of the inlet height of the limiting particle trajectory to the fiber diameter. The more modern single fiber theory considers the effect of adjacent fibers. The theoretical aerosol penetration of a particle with n elementary charges, P_n, through a filter is normally expressed in terms of total single fiber efficiency, $E_{\Sigma,n}$, (Hinds, 1999)

$$P_n = \exp\left[\frac{-4\alpha\chi E_{\Sigma,n}}{\pi d_f(1-\alpha)}\right] \tag{2}$$

where α is packing density; χ is filter thickness; d_f is fiber diameter, and $E_{\Sigma,n}$ is given by (Lathrache and Fissan, 1987; Tennal *et al.*, 1991):

$$E_{\Sigma,n} = 1-(1-E_m)(1-E_{e,n}) \tag{3}$$

In Eq. (3), E_m is the total single fiber efficiency due to mechanical force, given as:

$$E_m = 1-(1-E_{dr})(1-E_i)(1-E_g) \tag{4}$$

and $E_{e,n}$ is the total single fiber efficiency due to electrical force, given as:

$$E_{e,n} = 1-(1-E_p)(1-E_{c,n})(1-E_{m,n}) \tag{5}$$

where E_{dr} is due to diffusion and interception (Lee and Liu, 1982); E_i is due to impaction (Hinds, 1999); E_g is due to gravitational settling (Hinds, 1999); E_p is due to dielectrophoretic force; $E_{c,n}$ is due to Coulombic force (Lathrache and Fissan, 1987; Tennal *et al.*, 1991); and $E_{m,n}$ is due to image force (Kanaoka *et al.*, 1987). The above equation is an approximation based on the assumptions that the electret filters have a uniform charge on their fibers and all individual filtration mechanisms are independent. It is assumed that the particle charges are in Boltzmann charge equilibrium, and the interaction terms between the individual mechanisms are not within the scope of the present study. The independent deposition mechanism might be the best assumption since there is still not enough evidence showing that interaction terms tend to overestimate or under-estimate aerosol penetration. A spreadsheet (Microsoft Excel) was used to calculate and integrate the filtration efficiency by each individual filtration mechanism. In previous studies (Chen and Huang, 1998; Huang *et al.*, 2007), the calculation results showed in good agreement with experimental data. The in-depth information of all individual filtration mechanisms has been summarized in previous studies (Chen *et al.*, 1993; Huang *et al.*, 2010) and is not reiterated here.

The ranges of the important parameters used in the theoretical model to depict the effect on the filtration efficiency are: fiber charge density, δ (0–1.2 × 10^{-4} C/m^2); face velocity, V (0.1–30 cm/sec); packing density, α (0.01–0.30); filter thickness, χ (0.05–0.70 mm); and fiber diameter, d_f (1.0–10 μm). All ranges are set to cover the ranges found in commercially available filters (Liu and Rubow, 1986; Kanaoka *et al.*, 1987; Chen *et al.*, 1993; Chen and Huang, 1998). However, systematical examinations of the effects of the fiber size, solidity, and face velocity on q_f for nanofibers could be found elsewhere (Wang *et al.*, 2008a, b). To demonstrate the degree of influence of the aforesaid major parameters, only one factor is varied at a time with the others remaining constant (δ = 0 or 4 × 10^{-5} C/m^2, α = 0.08, χ = 0.2 mm, V = 10 cm/sec).

Pressure drop caused by clean fibrous media was calculated using an empirical equation developed by Davies (1973) as,

$$\Delta p = \frac{\eta \chi V 64\alpha^{1.5}\left(1+56\alpha^3\right)}{d_f^2} \tag{6}$$

where η is the gas viscosity. Eq. (6) accurately predicts the pressure drop for filters having d_f > 1 μm and 0.006 < α < 0.3 (Hinds, 1999).

In order to demonstrate the effect of challenge aerosol size distribution on the filter performance, the particles with varied CMD and GSD were computed based on the probability density of the lognormal distribution (Hinds, 1999).

$$pdf = \frac{1}{\sqrt{2\pi}\ln GSD}\exp\left(-\frac{\left(\ln d_p - \ln CMD\right)^2}{2\left(\ln GSD\right)^2}\right)d\ln d_p \tag{7}$$

where d_p is the particle diameter. A total of 180 nonlinear size intervals covering size range from 4.5 nm to 10 μm were used in the calculation. The overall filter penetration was determined from the sum of P_n × pdf for each size distribution.

RESULTS AND DISCUSSION

Face velocity plays a significant role in aerosol penetration through filter media (Figs. 1(a) and 1(b)). With the addition of electrostatic attractive forces, electret filters (δ = 4 × 10^{-5} C/m^2) clearly perform better than mechanical filters (δ = 0 C/m^2). In general, the effect of face velocity on aerosol penetration is most prominent for aerosol particles < 1 μm. Aerosol penetration increases with increasing face velocity because the dominant filtration mechanisms in this size range are diffusion and electrostatic attraction. Lower face velocity provides longer retention time for aerosol particles leading to lower aerosol penetration. In theory, if the face velocity were to continue to increase, aerosol penetration of particles > 1 μm would decrease to even lower than the value at low face velocity, due to stronger inertial impaction. This cross-over of aerosol penetration curves was quite apparent in previous experimental studies (Chen *et al.*, 1992; Chen and Huang, 1998), but not shown in Fig. 1. This suggests the gap between the theory and experiment findings is more pronounced when dealing with particles > 1 μm.

The effect of face velocity on filter quality is shown in Figs. 1(c) and 1(d). Filters made of electrically charged material consistently show higher filter qualities than mechanical filters made of the same materials but without fiber charge. The addition of electrostatic attraction does not increase pressure drop across the filter medium; therefore, the net increase in filtration efficiency transfers to a gain in filter quality.

The 0.3 μm DOP particle has long been used to challenge HEPA filters because 0.3 μm was regarded as the most penetrating size (MPS) or frequently referred to as collection minimum. However, this statement is incorrect because the photometric method used during respirator certification tests is not capable of measuring light scatter of particles below approximately 0.1 μm. In addition, MPS is affected by filter properties and the face velocity. As shown in Fig. 1(b), the most penetrating size for mechanical filters decreases from 0.5 μm to 0.1 μm when the face velocity increases from 0.5 cm/sec to 30 cm/sec. This shift occurs because smaller particles are more likely to be collected by diffusion, while a higher face velocity will shorten residence time, resulting in higher aerosol penetration. The trend of MPS (with velocity) in electret filter media (Fig. 1(a)) is quite different from that for mechanical filter media (Fig. 1(b)). As face velocity increases (from 0.5 to 3 cm/sec), the MPS first decreases and then increases to become nearly constant at 0.2 μm. The not that new filter test requirements (42 CFR part 84) adopted smaller challenge aerosol particles and higher test flow rates that both lead to higher aerosol penetration, making the new regulation more stringent from the standpoint of filtration efficiency.

With advances in fiber manufacturing technology, fiber size has decreased, providing larger cumulative surface area for aerosol deposition (Liu and Rubow, 1986; Kanaoka *et al.*, 1987). Another advantage of smaller fibers with larger surface area is that the filter can carry more charges, providing stronger electrostatic attraction. Another factor related to fiber diameter is interception, which is defined as the streamline bringing the particle center within one particle radius from the fiber surface, the particle is collected due to interception, given that the particle does not depart from the streamline. Accordingly, the single fiber collection efficiency due to interception is approximately proportional to the ratio of the particle diameter to the fiber diameter. Figs. 2(a) and 2(b) show that aerosol penetration decreases with decreasing fiber diameter, as expected. There is an increase in MPS (with increasing fiber diameter) for both the electret and mechanical filters.

While fiber diameter has been decreasing, the increase in surface area (and thus enhanced aerosol collection efficiency) is at the cost of higher friction or air resistance, which is proportional to the square of the fiber diameter.

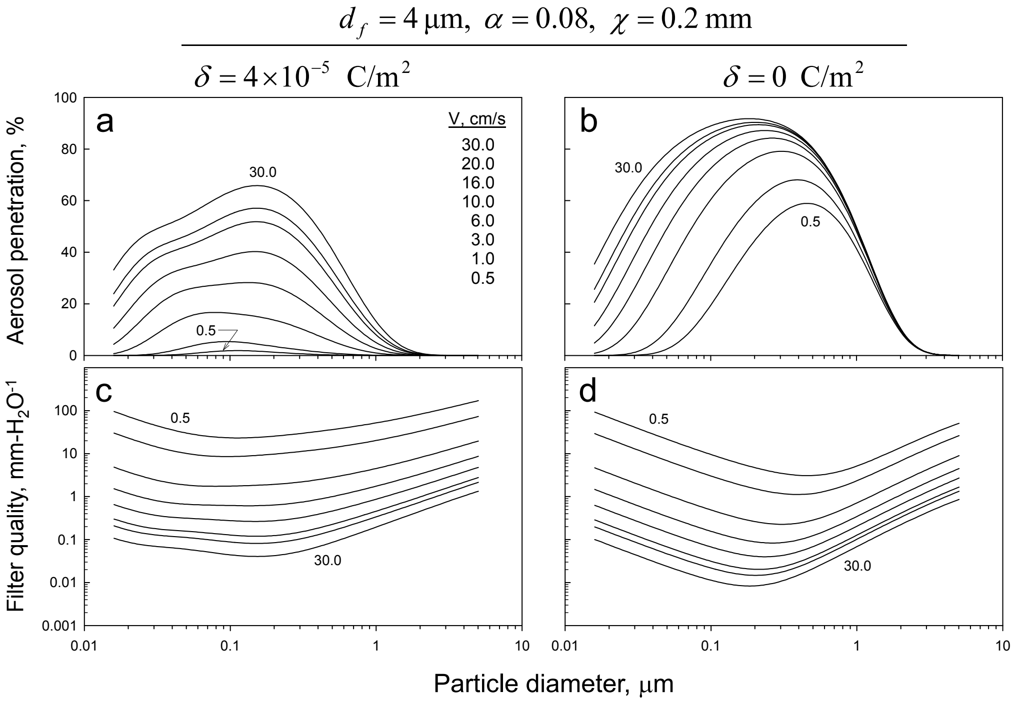

Fig. 1. Effect of face velocity on aerosol penetration and filter quality.

Therefore, the gain in collection efficiency is likely to be over-shadowed by even higher friction, depending on the amount of fiber charge, as shown in Figs. 2(c) and 2(d) with d_f less than 0.2 μm. Note, the data presented in Fig. 2 assumed fixed packing density (0.08), filter thickness (0.2 mm) and face velocity (10 cm/sec). Under these conditions, as fiber diameter decreases, not only does surface area increase, but also the fiber-to-fiber distance decrease, since there are more fibers in the same volume, and the packing density remains unchanged.

As demonstrated in Fig. 2(d), the filter quality of mechanical filters shows a unique pattern. For large particles (> 1 μm), the filter quality factor decreases with increasing fiber diameter, indicating that the gain in collection efficiency due to interception is far more significant than the increase in air resistance due to the larger surface area of the fibers. However, for small aerosol particles (< 0.1 μm), the opposite trend occurs. The quality factor increases with increasing fiber diameter, implying that the benefit of extra diffusion deposition due to the larger surface area achieved by using smaller diameter fibers is not enough to offset the additional frictional force caused by the same smaller fibers. For the same reason, the quality factor of electret filter increases with decreasing fiber diameter, even with the assistance of electrostatic attraction, as shown in Fig. 2(c).

As packing density increases, interstitial space decreases, and thus impaction and interception prevail for larger aerosols. Higher packing density also indicates more filtering material and larger surface area for aerosol deposition. Therefore, as shown in Figs. 3(a) and 3(b), aerosol penetration (through either electret or mechanical filter) decreases with increasing packing density for all particle sizes. The effect of the increase in packing density is more notable in electret filters than in mechanical filters, because the increase in the amount of filtering materials and larger surface area allows the filters to carry more fiber charges. Therefore, electret filters can attain higher collection efficiency due to this extra electrical force capture. The MPS decreases as the packing density increases for both electret filter and mechanical filters, indicating that, comparatively speaking, more large particles are collected due to the addition of filter material.

The packing density of the filters is a one of the major factors affecting both filter penetration and air resistance. Filters with higher packing density not only provide more surface area for aerosol deposition but also induce higher air resistance. As seen in Figs. 3(c) (d < 1 μm) and 3(d) (d < 0.1 μm), the filter quality apparently increases with decreasing packing density, indicating that the use of more porous materials might be more advantageous from the perspective of ease of use or energy consumption. For large particles, the high packing density might speed up the aerosol travel velocity within the filter media, and make the inertial impaction become dominating. Therefore, high packing density filters perform better for large particles from the perspective of quality factor (d > 1 μm for electret and d > 0.3 μm for mechanical filter).

In principle, aerosol penetration decreases multiplicatively with increasing filter thickness because there are more materials providing sites for aerosol deposition, although the shape of the penetration curve should remain the same. However, this inference is true only for mechanical filters (Fig. 4(b)) but not for electret filters, since the MPS of electret filters varies as the thickness increases, as shown in Fig. 4(a). This change in MPS is likely due to the assumption that the distribution of particle charges in dynamic electrical equilibrium follows Boltzmann's law. Hence, particles with high electrical mobility are more

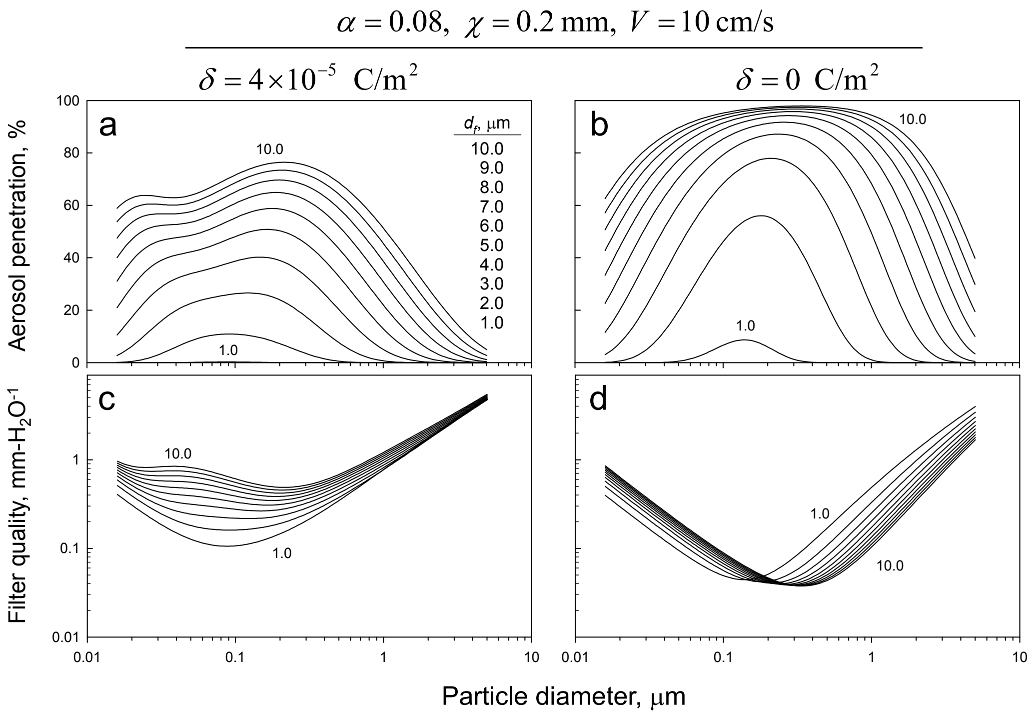

Fig. 2. Effect of fiber diameter on aerosol penetration and filter quality.

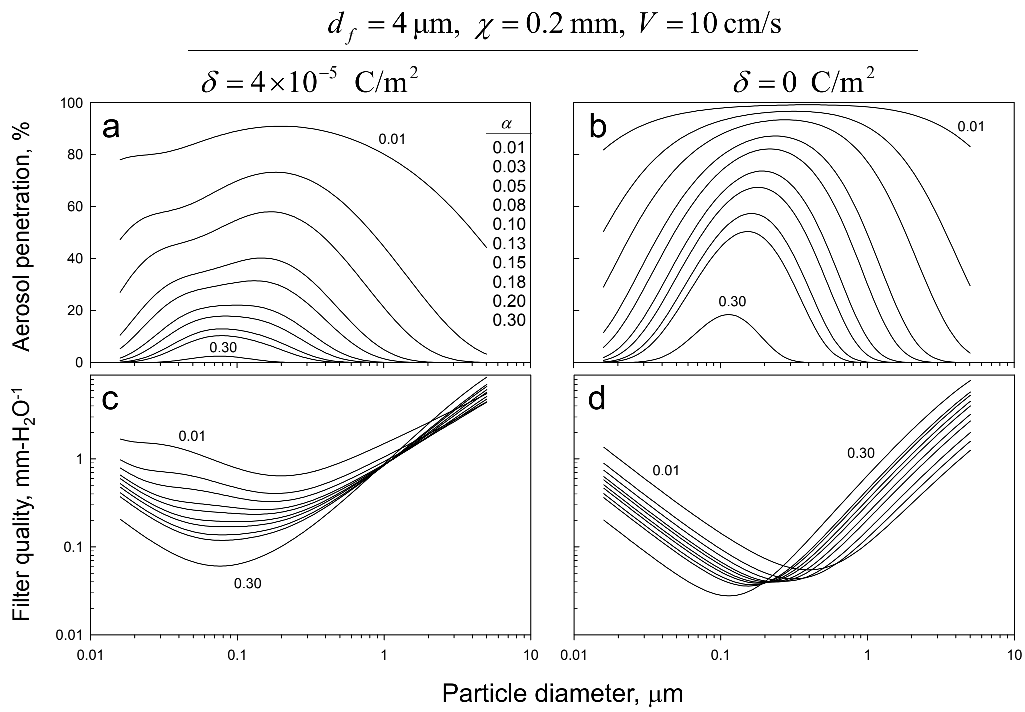

Fig. 3. Effect of packing density on aerosol penetration and filter quality.

likely to be collected by the front layer of an electret filter. The particles penetrating the first layer would be those with lower electrical mobility and would more likely penetrate the following layer, thus providing the shift of the penetration curve and the MPS change.

Fig. 4(d) shows that the filter quality of mechanical filters is independent of filter thickness because, according to Eq. (1), the changes in denominator and numerator cancel out, since aerosol penetration is multiplicative and pressure drop is additive. For the electret filter, the filter quality curves are slightly affected by filter thickness in the aerosol size range from 0.02 to 0.2 μm, as shown in Fig. 4(c). Thinner filters provide higher filter quality because they encounter the aerosol particles with the highest electrical mobility. The rear layer of thicker filters, assuming identical fiber charge density, would work less efficiently compared with the front layer, because the particles are less mobile and will not be collected as easily as the particles collected by the top layer.

Electrostatic attraction also plays an important role in aerosol capture efficiency. As shown in Fig. 5, aerosol penetration decreases significantly with increasing fiber charge density under both face velocities of 3 (Fig. 5(b) and 10 cm/sec (Fig. 5(a)), simulating the medium and heavy workload, respectively. For example, the aerosol penetration of 0.25 μm particles passing through the mechanical filter and the electret filter (δ = 1.2 × 10^{-4} C/m^2) under a face velocity of 10 cm/sec is approximately 90% and 9%, respectively.

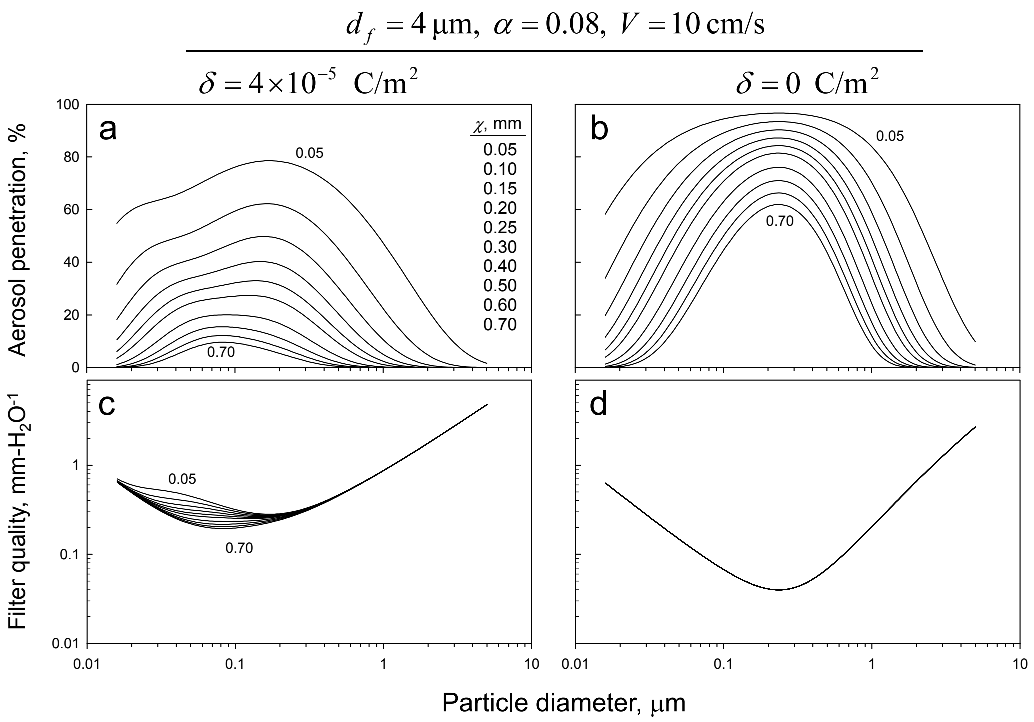

Fig. 4. Effect of filter thickness on aerosol penetration and filter quality.

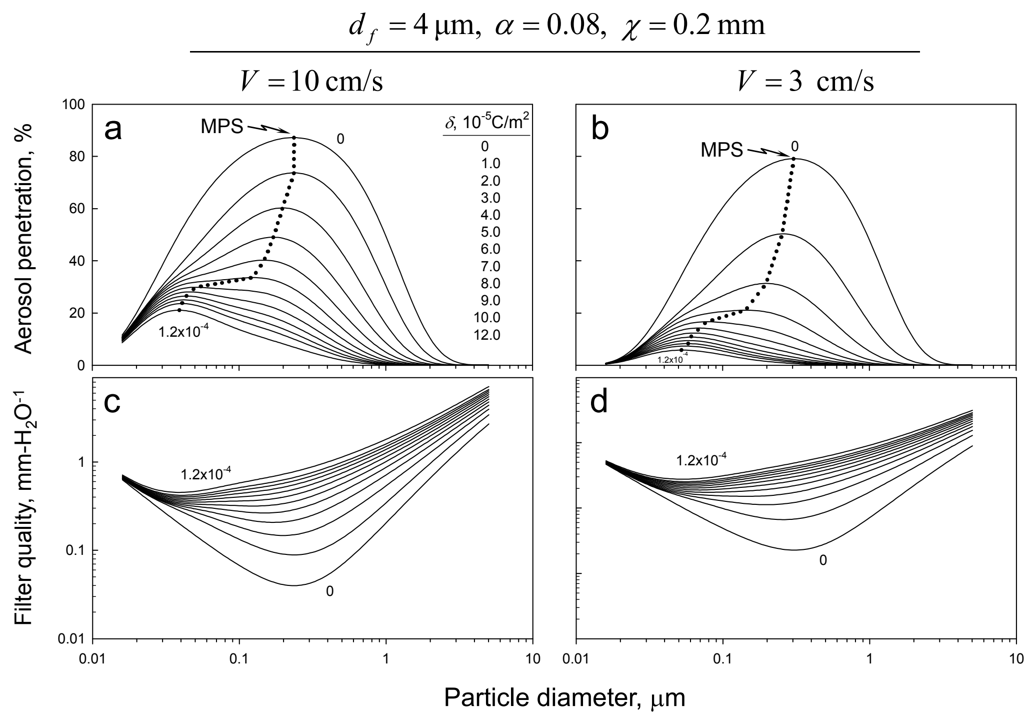

Fig. 5. Effect of fiber charge density on aerosol penetration and filter quality.

Although fractional penetration decreases, the MPS shows a strong trend to decrease with increasing fiber charge density, from 0.3 µm (δ = 0 C/m^2) to 0.04 µm ($\delta = 1.2 \times 10^{-4}$ C/m^2). This trend indicates adding electrical force is particularly effective for particles larger than 0.04 µm. This decrease in the MPS due to the increase in fiber charge density coincides with the move of the challenge aerosol size from fine silica (0.4–0.6 µm) as specified in the old 30 CFR Part 11 to ultrafine NaCl (0.075 µm), as specified in the 42 CRR Part 84. As mentioned above, the air resistance will not be affected by the addition of fiber charges, so the increase in filter quality is solely due to the addition of electrostatic attraction.

Some of the penetration curves for electret filter media show a quasi-bimodal dependence on the particle diameter. This phenomenon that has been discussed in previous studies (Lathrache *et al.*, 1986; Lathrache and Fissan, 1986) is attributed to electrical collection effects. Fig. 6 shows that the most penetrating size depends on charge density, fiber diameter, packing density, filter thickness, and face velocity. For electret filters with a charge density less than about 4×10^{-5} C/m^2, the MPS is in the size range of 0.1–0.5 µm. However, the MPS shifts to 0.02–0.1 µm when the fiber has charge density > 4×10^{-5} C/m^2. Moreover, the shift of the MPS is clearer for filters with larger d_f, less α, smaller χ, and tested at lower V. On the contrary, filter-A composed of submicrometer-scale fibers has a MPS around 0.1 µm and does not vary much with fiber charge density. Thus, it seems reasonable for standard setting organizations to test ULPA (ultralow penetration air) filters with 0.12 µm particles.

The shift in MPS for respirator masks from about 0.3 µm to less than 0.1 µm has been discussed in previous studies (Martin and Moyer, 2000; Balazy *et al.*, 2006; Huang *et al.*, 2007; Eninger *et al.*, 2008; Shaffer and Rengasamy, 2009; Rengasamy and Eimer, 2012). The current 42 CFR Part 84 is a regulation based on the photometric detection method that may not be sensitive for measuring nanoparticles (Eninger *et al.*, 2008). Thus new regulation needs to be developed to address the nanoparticle filtration problem.

In Fig. 7, two theoretical penetration curves of an electret N95 respirator (K) and a mechanical respirator (L) were simulated based on previous experiments. Respirator L was selected because it could be certified as a dust and mist grade respirator using the old 30 CFR Part 11 filter test criteria. The peak penetrations of K- and L- respirator are 4.35% at 0.03 µm and 18.67% at 0.21 µm, respectively. To demonstrate the effect of size distribution of challenge aerosols, various combinations of CMD and GSD were used to penetrate respirators K and L, as listed in Table 1. For CMD near the most penetrating size, aerosol penetration decreased with increasing GSD, because the fraction of aerosol with great penetration became less. When using particles with CMD of 0.055 µm as the challenge aerosols (NIOSH NaCl protocol), respirator-L might be classified as N95 and show a higher efficiency than respirator-K (for GSD ≤ 1.5). However, this misclassification could be prevented by providing the penetration data of submicrometer-sized particles (NIOSH DOP protocol).

CONCLUSIONS AND RECOMMENDATIONS

Factors affecting aerosol penetration, filter quality, and MPS are summarized in Table 2. Penetration increases when face velocity or fiber diameter increases. An increase in packing density, filter thickness and fiber charge density all result in lower aerosol penetration. When filter quality is of major concern, low face velocity is the best choice because it significantly affects the filter quality factor. Increasing fiber charge density results in a notable increase in filter quality and has the additional benefit of not increasing resistance to flow. The filter quality, which strongly depends on the size of the challenge aerosol, is barely affected by filter thickness of charged filter media and not affected by

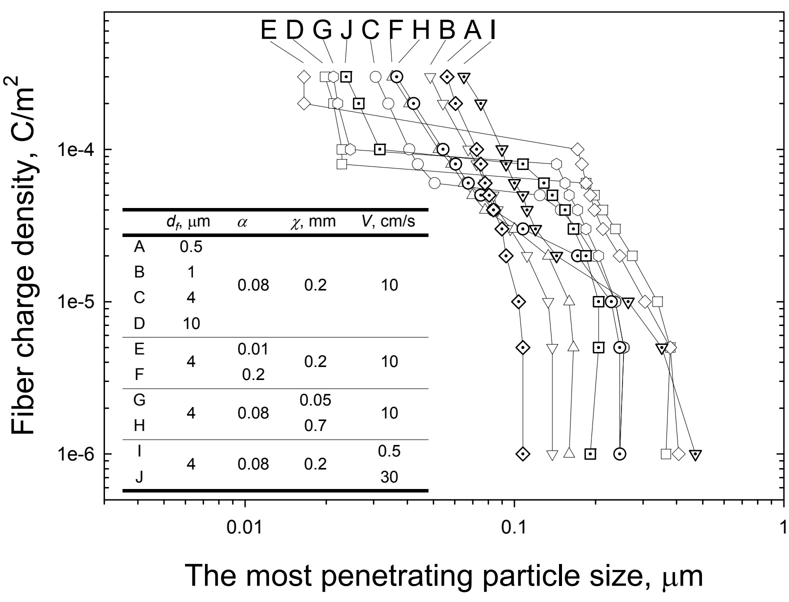

Fig. 6. Effect of charge density on the most penetrating particle size.

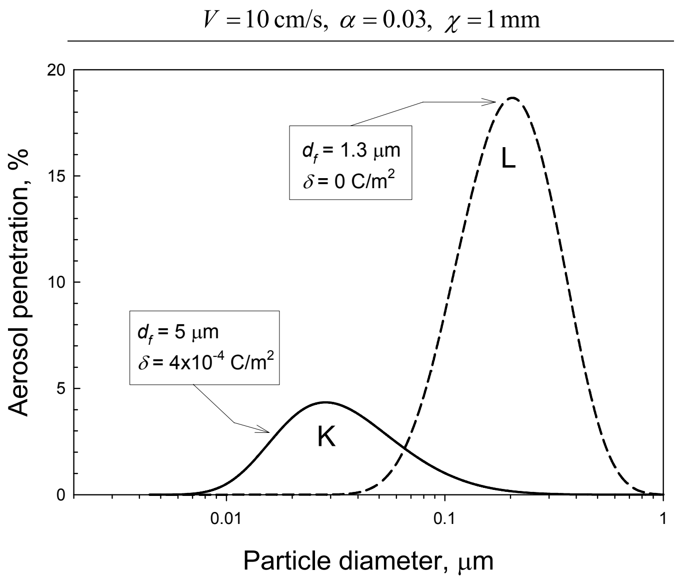

Fig. 7. Aerosol penetration curves of the two simulated respirators: K and L.

Table 1. Penetrations (by count) of aerosol particles with different CMD and GSD combinations through respirators K and L.

GSD / CMD, μm	K			L		
	1.0	1.5	1.86	1.0	1.5	1.86
0.055	2.68	2.71	2.53	1.05	2.39	3.59
0.075	1.75	1.89	1.94	3.71	5.27	6.07
0.095	1.09	1.33	1.48	7.83	8.25	8.21
0.165	0.29	0.42	0.63	17.47	14.29	11.97
0.185	0.21	0.35	0.51	18.38	14.92	12.22
0.205	0.15	0.27	0.42	18.67	14.99	12.23

Table 2. Direction and magnitude of change in aerosol penetration, filter quality, and MPS within the simulated range.

Parameters	Unit	Aerosol penetration	Filter quality	Most penetrating particle size
Face velocity	cm/s	↑	↓↓↓	↑, ↓*
Fiber diameter	μm	↑	↑	↑
Packing density	—	↓	↓	↓
Filter thickness	mm	↓	—	↓, —*
Charge density	C/m^2	↓	↑↑	↓

*: mechanical filter

mechanical filters. The MPS increases as the face velocity for charged fiber media or fiber diameter increase, but decreases when the packing density, the filter thickness or the fiber charge density increases.

Ideally, it would be best if filters used in a workplace could be certified using aerosols of that workplace. However, based on results showing the effects of fiber diameter and packing density on quality factor, we can conclude that there is no universal "best" filter. The most effective filter to be used is closely related to the size of the challenge aerosol particles. However, it is impractical to test respirators for every workplace, where the aerosol size distributions are seldom the same and frequently unknown. In theory, using monodisperse MPS particles as challenge aerosol provides highest and therefore, most accurate filter penetration values. Nevertheless, according to the modeling results, fiber properties (fiber charge density and fiber diameter distribution), filter properties (thickness and packing density), aerosol properties (size distribution and charge density), and challenge face velocity all influence the filter performance (or filter quality). This implies that filter media will have different filtration efficiency patterns with different challenge velocities. Therefore, the current way of certifying respirators with aerosols of one specific size distribution may not be sufficient to reveal the true level of filter protection. Respirator users are also reminded that facepiece leakage can easily exceed filter penetration.

Electret filters are more popular due to their higher filtration efficiency without increasing breathing resistance. The most penetrating size of electret filters is significantly smaller than that of mechanical filters. Therefore, organizations responsible for certifying non-mechanical filters should use challenge aerosols close to the MPS of electret filters. Nevertheless, the results also show that an N95 grade (initial penetration) respirator might not guarantee a proper protection against submicrometer sized particles. Thus, double checking the initial penetration of a N95-certified respirator using the NIOSH DOP protocol could result in a more conservative classification.

In 42 CFR 84, NIOSH raised the limit for inhalation resistance (under continuous flow rate of 85 L/min) to 35 mm of water column height. From the perspective of filter quality, this would allow manufacturers NOT to "expedite the improvement of technological advancements", which is one of the major purposes of 42CFR Part 84. The new regulations apparently drive high filtration efficiency, but the manufacturers could easily fulfill the requirements for collection efficiency by adding more filter media while still meeting the requirements for air resistance.

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