

Penetration of N95 Filtering-facepiece Respirators by Charged and Charge-Neutralized Nanoparticles

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ABSTRACT

Aerosol-based quantitative respirator fit testing relies on the assumption that all particles detected inside the mask arrived there through a face seal leak. When less efficient media is used, this assumption may no longer be valid since a significant number of particles may penetrate the filter media. To address this issue, TSI developed an accessory for the PortaCount called the Model 8095 N95-Companion™, which uses electrostatic principles to select a specific size range of particles that are far from the most penetrating particle size (MPPS). The narrow size range selected by the N95-Companion is centered nominally at 55 nm. Recent studies indicate that the MPPS for commercially available N95 filters is now between 40-60 nm and particle penetrations can exceed 5%. This caused concerns to be raised that the N95-Companion method is not valid for N95 filtering facepiece respirators that use charged fibers. To further quantify the amount of aerosol that penetrates through the N95 filter media and its effect on the fit factor, TSI conducted a study to measure the fractional penetration efficiencies of several commercially available N95 filtering-facepiece respirators using charge-neutralized, positively charged, and negatively charged monodisperse aerosols.

Six different models of NIOSH-certified N95 filtering-facepiece respirators from five different manufacturers were used in this study. Each respirator was mounted on a manikin head and sealed using a silicone sealant applied to the edges to prevent face seal leakage. The manikin was then placed in the center of a 47x24x28 inch test chamber. Charge-neutralized, negatively charged, and positively charged monodisperse aerosols (40, 50, 65, 80, and 100 nm) were introduced into the chamber one at a time. The aerosol concentrations inside and outside the respirators were measured with a TSI 3772 Condensation Particle Counter (CPC). The fractional penetration efficiency of the respirator was calculated as the ratio of C_{mask} and $C_{\text{challenge}}$: $[1 - (C_{\text{mask}}/C_{\text{challenge}})] \times 100$. Percent penetration = $100 \times C_{\text{mask}}/C_{\text{challenge}}$. The penetrations of positively charged and negatively charged aerosols were very similar to each other for all respirators, and were much lower than the penetration of charge neutralized particles. Using charged aerosol (N95-Companion method), all respirators showed penetrations below approximately 0.25% indicating a maximum (with zero face seal leakage) fit factor of 400.

This study showed that the N95-Companion method is a valid method for performing quantitative fit testing on any respirator using NIOSH series-95 or similar filter media.

Keywords: Fit Test, N95 Respirator, Nanoparticles, PortaCount, N95 Companion

INTRODUCTION

Aerosol-based quantitative respirator fit testing relies on the assumption that all particles detected inside the mask arrived there through a face seal leak. This assumption is valid when respirators use high-efficiency filter media such as NIOSH series-100 or series-99. However, when less efficient media such as NIOSH series-95 media is used, this assumption may no longer be valid since a significant number of particles may penetrate the filter media. Any particles that penetrate through the filter are interpreted as face seal leakage, resulting in artificially lower fit factors. In some cases the fit test might fail even if the face seal is perfect.

To address this issue, TSI developed an accessory for the PortaCount called the N95-Companion™ Model 8095 which uses well-known electrostatic principles to select a specific size range of particles that are far removed from the MPPS (most penetrating particle size). The PortaCount Plus Model 8020 and N95-Companion Model 8095 were discontinued in 2008 and replaced by the PortaCount Pro Model 8030 and PortaCount Pro+ Model 8038. The Model 8038 uses the N95-Companion method when operated in N95-mode. The narrow size range selected by the N95-Companion is centered nominally at 55 nm (note: the N95-Companion Model 8095 was designed to use 40 nm (nominal) particles; and the PortaCount Pro+ Model 8038 was designed to use 55 nm (nominal) particles). That size range was selected with the understanding that the MPPS for typical N95 mechanical filters (filtration mechanism is based on diffusion, interception and impaction) is near 300 nm (TSI Inc.) Penetration of 55 nm particles through these mechanical filter media is very low, supporting the assumption that all particles detected using the PortaCount and N95-Companion method inside the mask arrived there through a face seal leak.

Particle filter media currently offered by respirator manufacturers often relies on electrostatic technology to trap particles, in addition to mechanical properties. Filter media that is lower efficiency becomes higher efficiency, with a lower MPPS, when the fibers carry an electrostatic charge. The increase in efficiency is achieved without increasing breathing resistance. Recent studies indicate that the MPPS for commercially available N95 filters is now between 40-60 nm and particles penetration at the MPPS can exceed 5% (Balazy et al., 2006; Rengasamy et al., 2007). This is the same size range that the N95-Companion method uses, causing concerns to be raised in research communities that the N95-Companion method is not valid for N95 filtering facepiece respirators that use charged fibers.

It should be noted that the penetration results from the Balazy et al. and Rengasamy et al. studies may not apply to the N95-Companion method since the test aerosols used in these studies were charge-neutralized (particles with Boltzmann charge distribution), while the N95-Companion method utilizes only negatively charged aerosols. The penetration characteristic of charged aerosols could be quite different from the charge-neutralized aerosols. Lee et al. (2005) studied the filtering efficiency of N95 and R95 respirators operating in unipolarly ionized environments. They found that the aerosol penetration through the N95 and R95 respirators was significantly lower when aerosols were charged.

To further quantify the amount of aerosol that penetrates through the N95 filter media and its effect on the fit factor, TSI conducted a study to measure the fractional penetration efficiencies of several commercially available N95 filtering-facepiece respirators using charge-neutralized, positively charged, and negatively charged monodisperse aerosols.

The study found that the particles that penetrate electrostatic N95 media are primarily zero-charge particles that are unaffected by electrostatic forces, the positively and negatively charged particles are efficiently trapped by electrostatic filter media. The nominal 55 nm particles allowed to pass through the N95-Companion are all negatively charged, while the zero-charge and positive-charge particles are eliminated by the N95-Companion method for both the ambient and mask samples. Since the N95-Companion method uses only the efficiently trapped negative-charge particles, the fit test assumption that

all particles detected inside the respirator must have entered via a face seal leak remains valid. Therefore, the N95-Companion method remains valid.

It should be understood that naturally occurring ambient aerosol particles typically used during respirator fit testing with a condensation particle counter such as the TSI PortaCount carry a mixture of electrostatic charges. Some are positively charged, some are negatively charged, and some carry no charge. Testing with challenge aerosols that are entirely composed of particles that are only positive, only negative or only neutral can only be done in the laboratory.

METHODS

Six different models of NIOSH-certified N95 filtering-facepiece respirators from five different manufacturers were used in this study. Each respirator was mounted on a manikin head and sealed using a silicone sealant applied to the edges to prevent face seal leakage. The manikin was then placed in the center of a 47x24x28 inch test chamber. The experimental setup is shown in Figure 1.

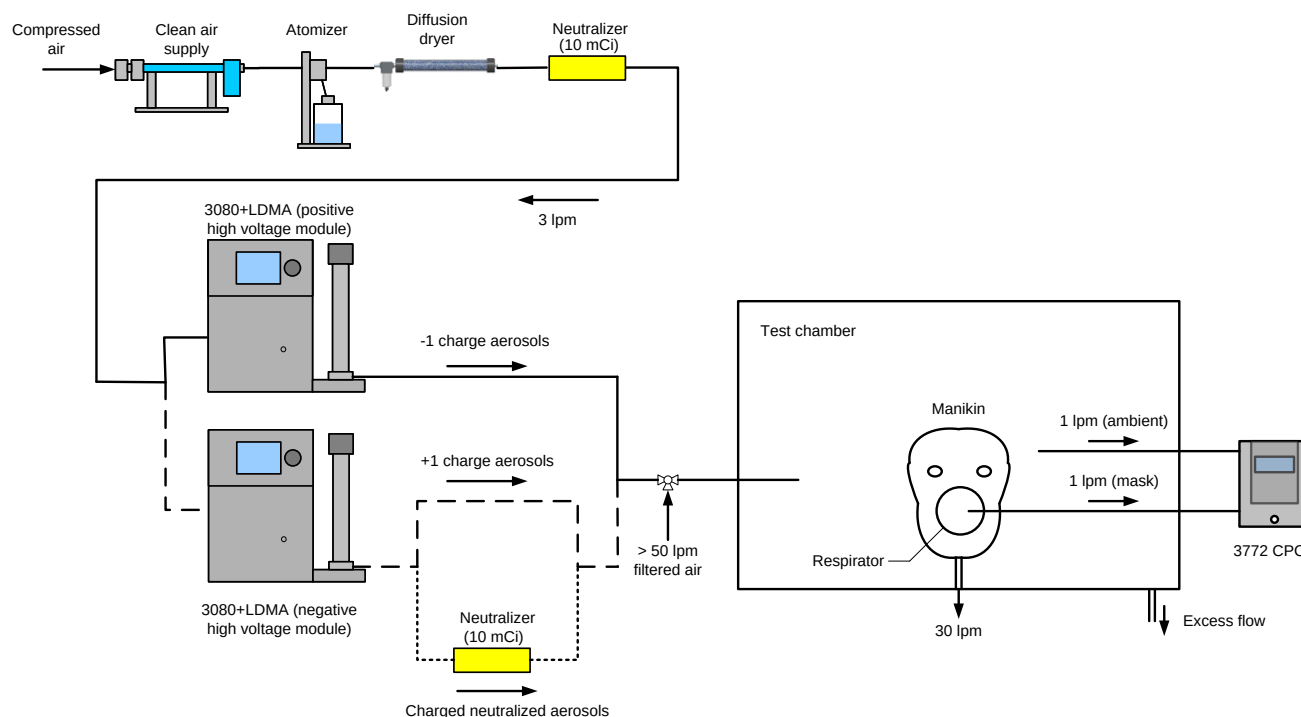


Figure 1. Experimental setup.

Sodium chloride aerosol was generated by an atomizer (TSI 3076 Constant Output Atomizer). A diffusion dryer was then used to dry the aerosols before they were introduced into a 10 mCi Kr-85 neutralizer (TSI 3012A) to remove high charges on the aerosols caused by the atomization process. Two TSI 3080 Electrostatic Classifiers and two 3081 LDMA's were used to generate monodisperse positively and negatively charged aerosols. One 3080 had a negative-high-voltage module to generate positively

charged aerosols while the other one had a positive-high-voltage module to generate negatively charged aerosols. To generate charge-neutralized aerosols, a TSI 3077A 10 mCi neutralizer was placed downstream of one of the 3080s. Note that the charge-neutralized, negatively charged, and positively charged monodisperse aerosols were introduced into the chamber one at a time (3 separate experiments). Before entering the test chamber, the monodisperse aerosols were mixed with at least 50 lpm of filtered air. Since the flow rate from the atomizer was about 3 lpm, the total flow rate entering the test chamber was at least 53 lpm. The flow rate through the N95 respirators was controlled to 30 lpm, which was the typical inhalation flow rate used in the literature. The monodisperse challenge aerosols used in this study were 40, 50, 65, 80, and 100 nm. The aerosol concentrations inside and outside the respirators were measured with a TSI 3772 Condensation Particle Counter (CPC). The respirators were ported with a sampling probe so that 1 lpm of sample flow could be drawn from inside the respirators. The challenge (chamber) aerosol samples were taken at about 1.5 inch away from the respirators. The challenge aerosol concentrations inside the test chamber varied depending on the size of the aerosol generated. To avoid coincidence error due to high concentration measurement, the aerosol concentrations inside the chamber were kept below 7000 particles/cc. This was done by adjusting the volume of filtered dilution air mixed with aerosols. To ensure that the test chamber was properly purged and the aerosol concentrations inside the test chamber were stable and uniform, the following test protocol was used:

1. Before each test, the test chamber was purged for at least 20 minutes. This was done using a blower and HEPA filters installed on the test chamber.
2. Monodisperse aerosols were introduced into the test chamber for at least 30 minutes before any data was recorded.
3. Chamber aerosol concentration data was sampled every second for at least 1 minute with the 3772 CPC (at least 60 samples total).
4. Using the same CPC, mask aerosol concentration data was sampled every second for at least 1 minute (at least 60 samples total). This is mask concentration, C_{mask} .
5. Using the same CPC, chamber aerosol concentration data was sampled every second for at least 1 minute (at least 60 samples total).
6. The aerosol concentration of the test chamber, $C_{\text{challenge}}$, is the average of the two chamber concentrations measured before and after the mask sample.
7. The fractional penetration efficiency of the respirator was calculated as the ratio of C_{mask} and $C_{\text{challenge}}$: ($C_{\text{mask}}/C_{\text{challenge}}$). Percent penetration = $100 \times C_{\text{mask}}/C_{\text{challenge}}$.

RESULTS AND DISCUSSION

The penetrations of positively charged and negatively charged aerosols are very similar to each other for all respirators, and are much lower than the penetration of charge neutralized particles (Figure 2). The much lower penetrations of charged aerosols through the N95 filtering-facepiece respirators are in line with the findings of Lee et al. (2005) and Balazy et al. (2006). Lee also found that the polarity of the charged aerosols has no significant effect on the filtration efficiency of the respirator filters. Therefore, it may be reasonable to make an assumption that the difference in penetration for negatively vs. positively charged aerosols is negligible for all N95 respirator particulate filters that use electrostatic filter media.

The necessity of the N95-Companion method for fit testing N95 respirators is most clearly shown for respirators 3 and 4, with neutralized aerosol penetrations of approximately 1.5% and 2% respectively. If a particle-counting fit test using charge-neutralized aerosol (i.e. no N95-Companion) were to be performed on workers wearing these respirators, the maximum fit factors that could be achieved are 67 and 50 respectively (Fit Factor = $100 / \% \text{Penetration}$). Any face seal leakage would reduce the fit factors even further. Since the OSHA Respiratory Protection Standard 29CFR1910.134 requires workers to

attain a fit factor of at least 100, it's obvious that no one could pass a particle-counting fit test with those respirators without the N95-Companion method.

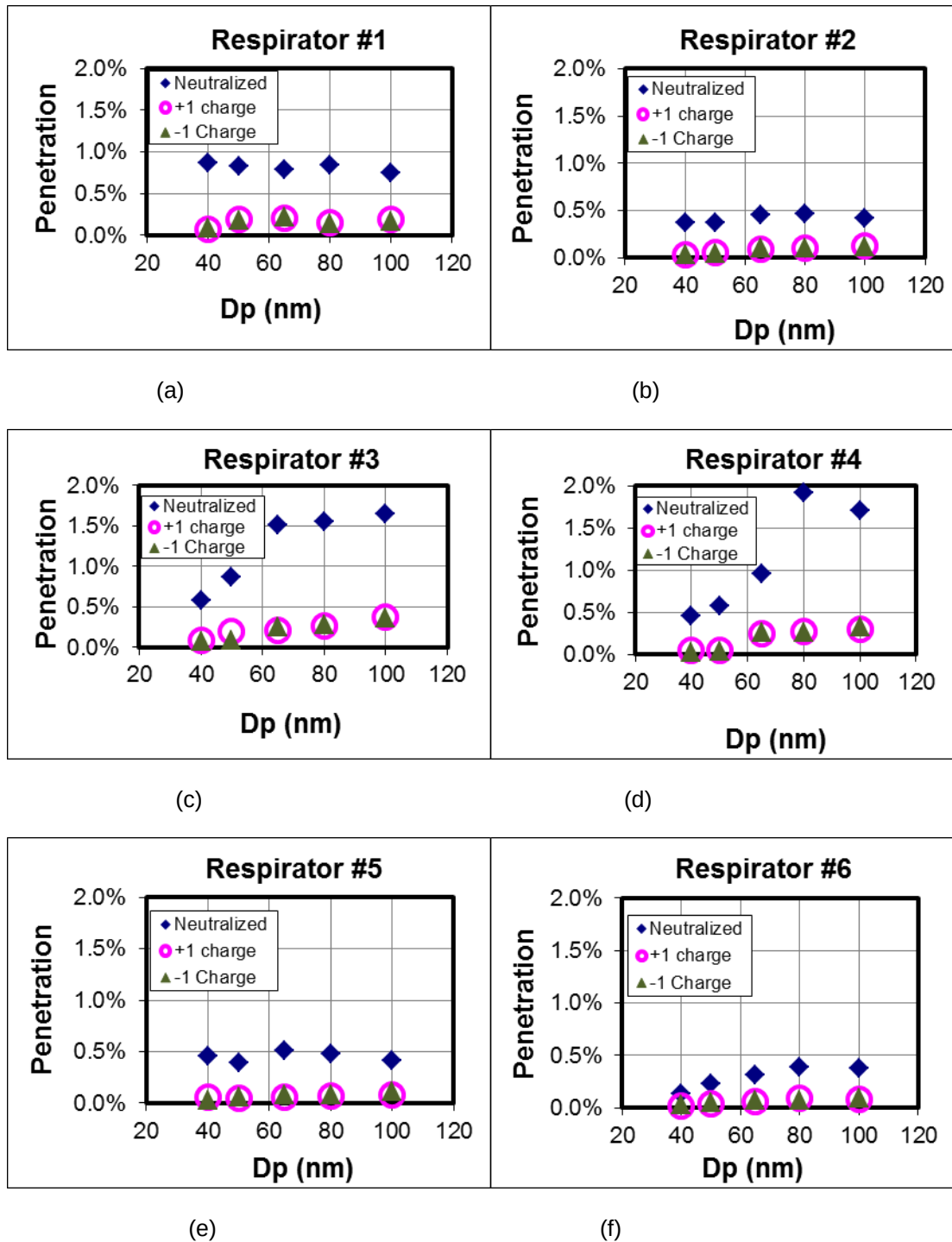


Figure 2. Percent penetration vs. particle size curves for various N95 filtering-facepiece respirators.

Respirators 1, 2, 5 and 6 all showed neutralized aerosol penetrations of approximately 0.5%, indicating a maximum (zero face seal leakage) fit factor of 200. Thus, it would be possible to pass a fit test without the N95-Companion method if the respirator fit extremely well. However, any actual face seal leakage would cause the fit factor to drop below 100. For example, if the filter penetration is fixed at 0.5 %, face seal leakage could not exceed 0.5% or the fit factor would drop below 100 (1% total leakage). This would have the affect of requiring workers to have an actual fit factor of at least 200 to achieve an indicated fit factor of at least 100. Elevating the pass level from 100 to 200 for filtering-facepiece respirators would probably cause a high percentage of workers to fail the fit test, resulting in unnecessary repeat fit testing and/or rejection of good-fitting respirator models.

Using charged aerosol (N95-Companion method) all respirators showed penetrations below approximately 0.25% indicating a maximum (zero face seal leakage) fit factor of 400. During an actual fit test, real face seal leakage could be as high as 0.75% or an actual fit factor of 133 and still pass with an indicated fit factor of 100. Respirators 2, 5 and 6 showed extremely low charged aerosol penetrations which would greatly reduce the difference between actual and indicated fit factors. For example, if filter penetration were 0.1%, an actual fit factor of only 111 (0.9%) would be needed to achieve an indicated fit factor of 100. Thus, the use of the N95-Companion method significantly reduces false fit test failures.

CONCLUSIONS

The N95-Companion method performs quantitative respirator fit testing using nominal 55 nm particles that carry a negative charge. Particles that are in a different size range, or carry a zero or positive charge are discarded. The N95-Companion method works differently for mechanical filters than it does for electrostatic filters. For mechanical filters, the N95-Companion method relies on the conventional particle entrapment schemes of impaction, interception and diffusion to reduce 55 nm particle penetration to insignificant levels. For electrostatic filters, the N95-Companion method relies mainly on electrostatic forces to trap the negatively charged particles and reduce penetration to insignificant levels. NIOSH series-95 respirator filters certified under 42CFR84 may be mechanical or electrostatic, or a combination of both. The N95-Companion method is a valid method for performing quantitative fit testing on any respirator using NIOSH series-95 or similar filter media.

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