Investigation of Potential Affecting Factors on Performance of N95 Respirator

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ABSTRACT

With the exponential growth of the nano-technological products and their potential impact on the workers' health and safety, the N95 filtering face-piece respirators (FFRs) are commonly recommended to protect them from the exposure to nano-particles in workplaces. This paper reports the outcomes of a series of experiments carried out to characterize the performance of NIOSH approved N95 filtering face-piece respirators against particles in nano-range: poly-dispersed and mono-dispersed sodium chloride (NaCl) particles were used in this study. In the first experimental set-up, a methodology was developed to test a N95 respirator model, sealed on a manikin head, against 15 to 200 nm poly-dispersed NaCl aerosols as function of flow rate (85, 135, 270 and 360 liters/min), loading time (up to 5 hours), and relative humidity (RH) (10, 30 and 70%). In the second phase, the experimental set-up was adapted to test N95 respirators against mono-dispersed particles (at twelve particle sizes) with a size range between 20 to 200 nm at a constant flow rate of 85 liters/min.

The results from the poly-dispersed aerosol test (PAT) method indicated that the inhalation flow rate had a strong impact on the initial particle penetration; the maximum penetration level through the N95 respirator dramatically exceeded the 5% NIOSH certification criterion at flow rates higher than 85 liters/min. The particle penetrations at the Most Penetrating Particle Size (MPPS), occurring between 30 to 50 nm, were respectively 6.6, 11.7 and 15.3% for the airflow rate of 135, 270 and 360 liters/min. The outcomes of the effect of particle loading on the filter performance showed that, the particle penetration decreased through the N95 respirator for particle sizes below 100 nm.

The mono-dispersed aerosol test (MAT) method was performed at 85 liters/min constant flow rate; the initial particle penetration at the MPPS was below 5% NIOSH certification criterion. Moreover, the initial particle penetration value, measured with (MAT) method was higher than the one measured with (PAT) method at each corresponding particle size.

Keywords: N95 respirator; nano-particle; filter; penetration; exposure

INTRODUCTION

With the exponential growth of the nano-technological products and their potential impact on the workers' health and safety, the N95 filtering face-piece respirators (FFRs) are commonly recommended to protect them from the exposure to nano-particles in workplaces. According to the

Bureau of Labor Statistics and National Institute for Occupational Safety and Health (NIOSH), approximately 2 million people in USA worked with nano-material products (NIOSH, 2003).

In accordance with title Code of Federal Regulations, (42 CFR 84), the National Institute for Occupational Safety and Health (NIOSH) certifies the air purifying respirator filters in three classes of N, R and P with three levels of filter efficiency, 95, 99 and 99.97% for each series of filters. The 'N-series' filters are challenged with poly-dispersed NaCl particles with a count median diameter (CMD) of 75±20 nm and a geometric standard deviation (GSD) not greater than 1.86. In the case of R- and P- series, filters are challenged against dioctyl phthalate (DOP) with CMD of 165±20 nm and a GSD not further than 1.60 (42 CFR 84, 1996).

The NIOSH certification for N, R and P air purifying respirator tests are performed at a constant flow rate of 85 liters/min corresponding to an average breathing rate of an individual performing at a heavy work load using the most penetrating particles size (0.2 to 0.3 µ). The shift of MPPS, for a specific filter system, toward much small particle sizes mainly depends on the magnitude of filtration face velocity, filter type, filtration mechanism, fiber charge density and particle charge distribution (Eninger et al., 2008). Previous studies claim that the NIOSH certification test conditions may not represent the worst case scenario in terms of the collection efficiency (Eninger et al., 2008). Even though the constant flow rate of 85 liters/min used for filter approvals corresponds to an average human breathing at a heavy work load, peak respiratory flow rate could exceed three times the average human flow rate (Janssen, 2003). There have been some suggestions that respirators should be tested at higher flow rates than what is used for filter approvals (Janssen, 2003; Balazy et al. 2006b). Several studies have been conducted to investigate the effectiveness of respirators in the removal of nano-particles under different flow rates. Eninger et al. (2008) evaluated the performance of one model of N95 respirators at flow rates of 30, 85, and 150 liters/min against NaCl particles in the range of 20 to 500 nm. Their results implied that at higher flow rates, the particle penetration would increase due to the shorter residence time through the respirator while the MPPS lies within the smaller particle size <100 nm. Balazy et al. (2006a, 2006b) also measured the NaCl penetration through N95 respirators at flow rates of 30 and 85 liters/min and concluded that the flow rate had a strong effect on the particle penetration through the respirator filters.

The effect of loading time and RH on the respirator performance has not yet been well understood due to the limited investigations. Even though, the particle penetration level mostly propagates with the aid of electrostatic attraction force during the initial stage of filter loading (Baumgartner et al., 1986; Brown et al., 1988; Chen et al., 1993; Martin and Moyer, 2000; Wang et al., 2001), this may change with further particle loading time within different fiber materials and particle sizes. Moreover, despite some studies indicating a lower level of filtration performance with the increase of RH for the electret filters (Ikezaki et al., 1995; Lowkis and Motyl, 2001), Yang and Lee (2005) suggested that RH has no effect on the particle penetration; their studies showed almost the same particle penetration level at RH of 30% and 70% for NaCl particles ranging from 50 to 100 nm.

Though several studies have investigated the performance of respirators against nano-particles, there is a lack of knowledge about the effects of inhalation flow rate, duration of use and relative humidity on the respirator performance to capture nano-particles. Although the majority of previous studies addressed the performance of respirators at low flow rates of 30 and 85 liters/min and that NIOSH certification tests are performed at 85 liters/min flow rate, the inhalation flow rate of more than 350 liters/min is achievable during heavy work load (Janssen, 2003). To our knowledge, no previous studies have investigated the performance of respirators after being loaded with nano-sized particles for several hours, and few studies have evaluated the filtration efficiency of electrets filters with nano-particles at different humidity levels (Mostofi et. al 2010).

With the increasing concern of protecting workers from inhaling nano-particles, it is important to evaluate the effect of inhalation flow rate, period of use, and humidity on the performance of a N95 FFRs.

This paper reports the outcome of a series of experiments carried out to characterize the filtration efficiency of a NIOSH approved N95 filtering face-piece respirator against poly-dispersed sodium chloride particles in the range 15 to 200 nm under different experimental conditions: constant flow rates (85, 135, 270 and 360 liters/min), loading time (up to 5 hours) and relative humidity (10, 30 and 70%). The N95 filtration performance was also studied against mono-dispersed sodium chloride particles in the range 20 to 200 nm.

MATERIALS AND METHODS

A NIOSH approved N95 filtering face-piece respirator (FFR) from 3M model 8210 was used in this study. The FFR was sealed on a manikin head as shown in Figure 1. A silicon sealant was used to avoid any possible leakage: the manikin was then placed inside the test chamber as shown in Figure 2. The N95 FFR was not preconditioned for relative humidity before testing (filters were tested as received from the manufacturer).

Figure 1. Sealed N95 FFR on the manikin head.

Figure 2. Manikin head with the sealed N95 FFR in the challenge chamber.

Experimental Set-ups

Figures 3 and 4 shows schematic diagrams of the procedures used to test respirators against poly-dispersed and mono-dispersed aerosols, respectively.

Poly-Dispersed Aerosols Filtration Tests

Figure 3 is a schematic representation of the experimental set-up used to characterize the filtration performance of the N95 FFRs against poly-dispersed sodium chloride particles. In this set-up, a six-Jet Collision Nebulizer (Model CN25, BGI Inc., Waltham, MA) was employed to generate poly-dispersed sodium chloride particles in the size range of 15 to 200 nm. A diffusion dryer (a silica gel drying system) was used to remove water vapor in the aerosols coming out from the Collision Nebulizer. Particles passed through a neutralizer (Kr-85) (Model 3012A, TSI Inc.), to obtain the Boltzmann charge equilibrium. Depending on the required flow rate in the experiment, some extra dry- filtered flow was added (provided by a mechanical pump) and mixed with the charge neutralized sodium chloride particle flow. The total aerosol stream was passed directly into the test chamber. After allowing the system to stabilize and setting the sampling aerosol flow rate at 1.5 liters/min (i.e. the ratio of sheath air to aerosol flow rates was adjusted at 10:1 on the classifier), the concentration and size distribution were measured alternately twice, at the downstream and at the upstream of the test filter, using a Scanning Mobility Particle Sizer (SMPS, Model 3936, TSI Inc.). The required time for each measurement at each location was 135 seconds. The particle penetration values were determined as a function of particle diameter.

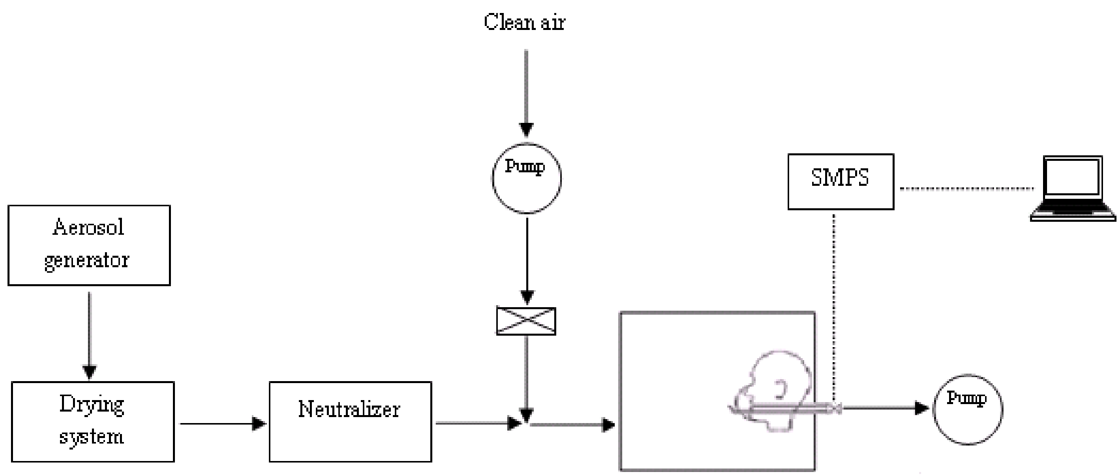

Figure 3. Schematic diagram of experimental set-up: testing N95 respirators against poly-dispersed aerosols.

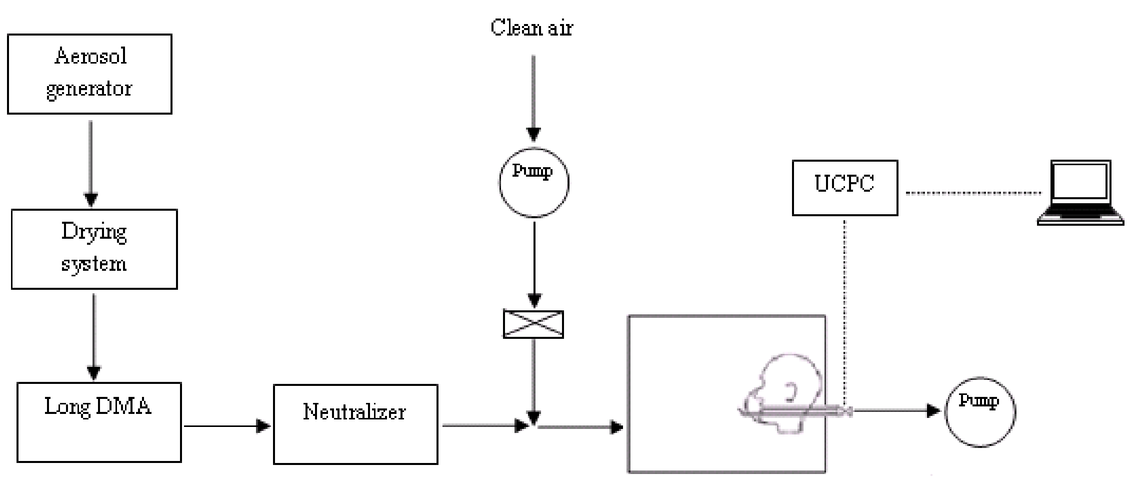

Figure 4. Schematic diagram of experimental set-up: testing N95 respirators against mono-dispersed aerosols.

The operational conditions (temperature, pressure and relative humidity) were monitored in the chamber during the test. The temperature was maintained at ambient temperature (23±2°C) and relative humidity (8±2%). A small mixing fan was also housed at the inlet of the chamber to assure particle concentration homogeneity.

In the experimental set-up, a pressure transducer was used to measure the pressure drop across the N95 filtering face-piece respirator. In addition, to assess the effect of relative humidity on the filter performance, a Humidity Control System (MNR, Model HCS-301, Miller Nelson Research Inc.) was utilized to condition the relative humidity before the total air entered the inlet chamber.

Mono-Dispersed Aerosols Filtration Tests

To challenge N95 respirators against mono-dispersed aerosols, the same testing procedure as discussed above was followed, except that the experimental set-up was adapted to be capable of testing filters with mono-dispersed particles (see figure 4).

After generating poly-dispersed aerosols using the six-Jet Collision Nebulizer (operated at an inlet pressure of 25 psi, using 0.1% NaCl solution) and passing the generated aerosols through the silica gel drying system and neutralizer (Kr-85), a long Differential Mobility Analyzer (DMA, Model 3081, TSI Inc.) was utilized to extract mono size particles before entering the filter test system.

A Condensation Particle Counter (CPC, Model 3775, TSI Inc.) was used to count the particle concentration of each selected mono-sized particle at both the downstream and upstream of the filter. The challenge mono-sized NaCl aerosols were pumped for 2 minutes with CPC at a sampling flow rate of 1.5 liters/min (i.e. the ratio of sheath air to aerosol flow rates was set at 10:1 on the classifier) both at downstream and upstream. To provide a reliable sampling condition, the particle counter instrument (CPC) was allowed to stabilize after switching between the two sampling ports at the downstream and upstream. Consequently, the percentage penetration was measured at each tested mono-sized particle.

Generation of Poly-Dispersed Sodium Chloride Particles

A six-Jet Collision Nebulizer was operated at an inlet pressure of 25 psi, and fed with 0.1% (V/V) NaCl solution to generate poly-dispersed NaCl particles in the 15 to 200 nm range. A filtered air supply (Model 3074, TSI Inc.) was used to provide a clean-dried air entering the system.

Prior to a filtration efficiency test, the generation system was allowed to operate for at least 5 minutes in order to reach a steady state concentration at the upstream of the chamber. To reduce the chance of particle loading, the N95 respirator was bypassed during the stabilization period. Having stabilized the system, the switching valve was adjusted, letting the total aerosol flow pass directly through the test filter. Figure 5 and Table I present the size distribution characteristics of challenge aerosols at flow rates of 85, 135, 270 and 360 liters/min at upstream in the test chamber used to characterize the N95 FFRs.

Table I. The Size Distribution Characteristics of Challenge Aerosols

Total flow rate	**Particle size distribution**		
(liters/min)	**Count median diameter (nm)**	**Geometric standard deviation**	**Number Concentration (#/cm3)**
85	49	1.70	12.3e07
135	52	1.69	9.5e07
270	46	1.72	6.4e07
360	45	1.72	4.3e07

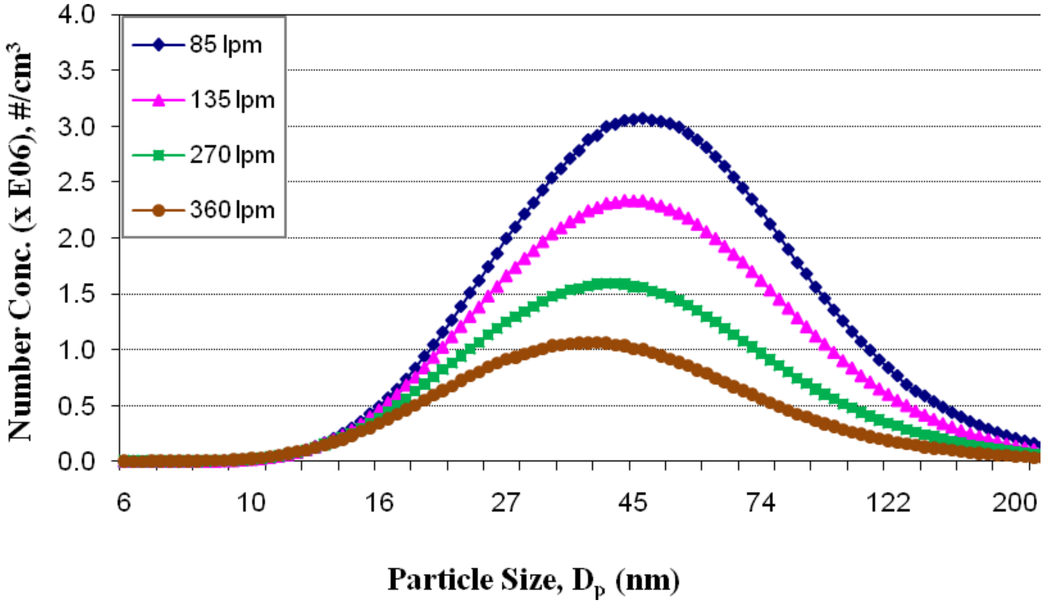

Figure 5. Particle concentration and size distribution of the challenge NaCl aerosols at different testing flow rates.

Particle Penetration Measurement

The particle penetration through the N95 respirator filter was determined as the ratio of the downstream concentration (C_{down}) to the upstream concentration (C_{up}) at each tested particle size (d_p), which is presented as follows:

$$P(d_p) = \frac{C_{down}(d_p)}{C_{up}(d_p)}$$

To ensure that the particle concentration and size distribution reach the steady state condition at the upstream, the scanning was repeated four times alternatively at both downstream and upstream of the filter. The first two measured particle size distribution at upstream and downstream were used to calculate the particle penetration at each size. All the filtration efficiency results reported in this study were versus the electrical mobility diameter which was classified by Differential Mobility Analyzer (DMA, Model 3081, TSI Inc.).

RESULTS AND DISCUSSION

PHASE 1 Particle Penetration against Poly-Dispersed NaCl Aerosols in the Range 15 to 200 nm (PAT Method)

Initial Particle Penetration as a Function of Inhalation Flow Rate

The N95 respirators were challenged with poly-dispersed NaCl aerosols for a period of 5 minutes at four constant flow rates: 85, 135, 270 and 360 liters/min using the experimental set-up described above (see Figure 3).

Figure 6 shows the initial particle penetration values at four constant flow rates when challenged with 15 to 200 nm poly-dispersed sodium chloride aerosols. The test was repeated three times. The mean, peak and standard deviation of initial penetration values were computed at each particle diameter with respect to the flow rate.

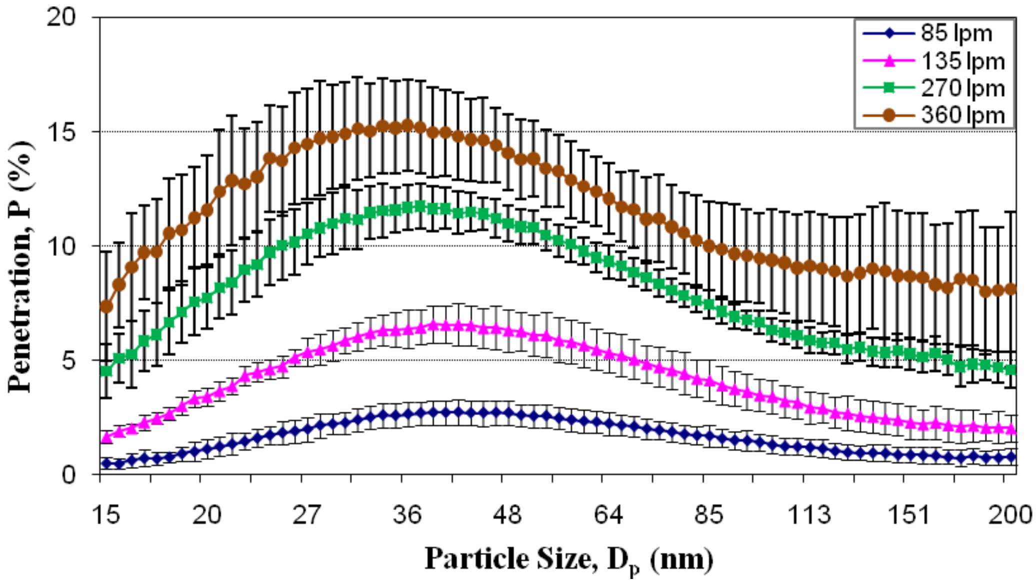

Figure 6. Effect of particle size and inhalation flow rate on initial particle penetration through N95 respirators (n=3). The error bars represent the standard deviations.

Consistent with the results from previous studies, the initial particle penetration was significantly enhanced as the flow rate increased (Balazy et al., 2006a, 2006b; Richardson et al., 2006; Huang et al., 2007; Kim et al., 2007; Eninger et al., 2008). The maximum initial penetration level through N95 respirators dramatically exceeded 5% NIOSH certification criterion at about 1.30, 2.35 and 3.05 times at high flow rates of 135, 270 and 360 liters/min, resepectively. At the MPPS, with the lowest filtration efficiency, the percentage penetrations were 2.7±0.54, 6.6±0.90, 11.7±1.00 and 15.3±1.97% at 85, 135, 270 and 360 liters/min, repectively. The mean initial penetrations were also 1.64±0.72, 4.21±1.60, 8.13±2.43 and 11.46±2.51% at the respective flow rates for the tested particle size range of 15 to 200 nm. However, compared with the obtained results for the particle size range from 15 to 200 nm, these results suggested higher mean initial penetrations for the particle size range <100 nm; 1.89±0.67, 4.82±1.40, 9.13±2.03 and 12.45±2.16% at 85, 135, 270 and 360 liters/min flow rates, respectively (see Table II). Meanwhile, the coefficient of variation for the initial penetration varied from 0.19 to 0.53, from 0.07 to 0.22, from 0.06 to 0.28, and from 0.11 to 0.33 at the respective flow rates.

The mean initial particle penetration at 360 liters/min exceeded that at 85 liters/min by about 7-fold. In addition, according to the obtained results, with the increase of flow rate, the MPPS demonstrated a shift toward small particles; approximately 46, 41, 37 and 36 nm at 85, 135, 270 and 360 liters/min, respectively, which was consistent with the earlier results (Martin and Moyer, 2000; Balazy et al., 2006a, 2006b; Richardson et al., 2006; Huang et al., 2007; Rengasamy et al., 2008a; Rengasamy and Shaffer, 2008b). The shift in the MPPS toward small sizes and the increase in the particle penetration are both due to the fact that, along with the increase in flow rate, the diffusion and electrostatic mechanisms contribute less to the removal of smaller particles as a result of less residence time (Richardson et al., 2006).

Table II. Summary of Particle Penetration, Pressure Drop, and Coefficient of Variation for the Particle Penetration

Q	Pressure drop	Maximum P (15-200 nm)	MPPS (15-200 nm)	P (15-100 nm)	P (15-200 nm)	CV* (15-100 nm)	CV* (15-200 nm)
(liters/min)	(mm H20)	(%)		(%)	(%)	(%)	(%)
85	7.79±0.27	2.7±0.54	46	1.89±0.67	1.64±0.72	0.19-0.53	0.19-0.53
135	13.32±1.03	6.6±0.90	41	4.82±1.40	4.21±1.60	0.07-0.22	0.07-0.34
270	23.79±0.77	11.7±1.00	37	9.13±2.03	8.13±2.43	0.06-0.28	0.06-0.28
360	32.71±0.91	15.3±1.97	36	12.45±2.16	11.46±2.51	0.11-0.33	0.11-0.42

*Coefficient of variation is defined as the ratio of standard deviation to the mean.

Particle Penetration as a Function of Loading Time

The selected N95 respirator was loaded continuously against 15 to 200 nm poly-dispersed NaCl particles at 85 liters/min flow rate for a period of 5 hours. Figure 7 illustrates the effect of loading time on the particle penetration level through the N95 respirator: The test was repeated three times. The mean, peak particle penetrations and also the quality factor for the N95 respirator were determined hourly (once at each hour).

For particles below 100 nm in size, the penetration decreased with the loading time, while the penetration increased with the loading time for particles larger than 100 nm. As summarized in Table III, for particles below 100 nm, the maximum and mean penetration levels were reduced from 2.66±0.21 to 1.48±0.12% and from 1.76±0.70 to 0.87±0.50%, respectively. Meanwhile, an increase in the mean penetration level from 0.71±0.21 to 1.07±0.07% was observed for the larger particles, as shown in Table III.

As observed in Figure 7, the MPPS shifted toward larger particle sizes; from 41 to 66 nm for the tested N95 respirator. This is due the fact that diffusion becomes more dominant to collect NPs while electrostatic attraction force shows less contribution in capturing large size particles (Martin and Moyer, 2000, Wang, 2001; Woon et al., 2008). Moreover, less deviation in particle penetration was identified with further particle loading.

As mentioned earlier, the penetration for the particles between 15 to 100 nm showed a considerable reduction with the loading process, whereas, the penetration gradually increased for the larger particle sizes. Seemingly, this phenomenon could be due to the formation of particle aggregates on the surface of the filter (Wang, 2001; Woon et al., 2008). For the small particles, along with the reduction in the electrostatic attraction force, further loading time generally leads to an increase in capturing the particles, as the deposited particles are similar in size to the approaching particles (Wang, 2001). On the contrary, the captured particles may suppress the collection of particles caused by the electrostatic attraction force, which is a noticeable collection mechanism for the large size particles predominantly between 150 to 500 nm (Wang, 2001). Experimental studies on electret filters demonstrated that the particle collection efficiency relies generally on the amount of electrostatic charge on the filter fiber (Brown et al., 1988; Chen et al., 1993; Martin and Moyer, 2000).

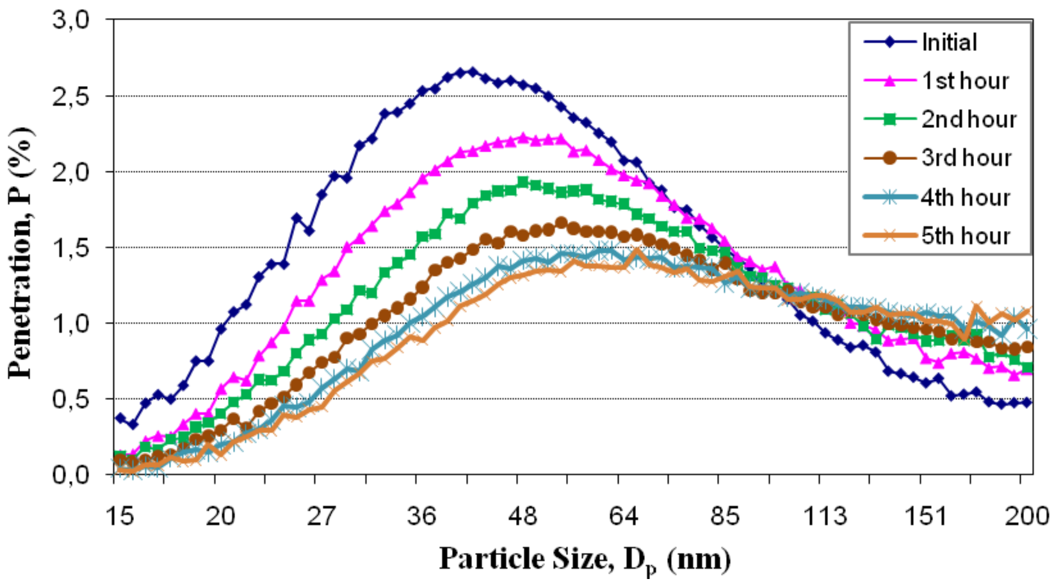

Figure 7. Effect of loading time on particle penetration through N95 respirators at 85 liter/min constant flow rate (n=3).

Table III. Summary of Particle Penetration, Pressure Drop in the Early (A) and Late (B) Stages of Particle Loading

Q	**Particle loading stage**	**Pressure drop**	**Maximum P (15-200 nm)**	**MPPS (15-200 nm)**	**P (15-200 nm)**	**P (15-100 nm)**	**P (100-200 nm)**
(liters/min)		(mm H20)	(%)		(%)	(%)	(%)
85	(A)	7.95±0.57	2.66±0.21	41	1.48±0.77	1.76±0.70	0.71±0.21
85	(B)	10.86±1.27	1.48±0.12	66	0.92±0.44	0.87±0.50	1.07±0.07

Particle Penetration as a Function of Relative Humidity

The respirator was tested against 15 to 200 nm poly-dispersed NaCl particles at flow rate of 85 liters/min at three levels of relative humidity; 10, 30 and 70% for 5 minutes. Figure 8 presents the initial penetration of sodium chloride particles through the N95 respirator at three different levels of relative humidity. Each test was repeated four times for the particles ranging from 15 to 200 nm. The mean, peak and standard deviation of initial penetration levels were determined.

Consistent with the results obtained from the previous studies on electret filters, for particles below 100 nm, the filtration performance decreases slightly with the increase of RH, and this is attributed to the reduction in the charges on the fiber filters and particles (Ackley, 1982; Moyer et al., 1989). However, for the large particle sizes, the penetrations were similar at 10 and 30% RH; whereas they subsequently increased as RH elevated to 70%, see Figure 8.

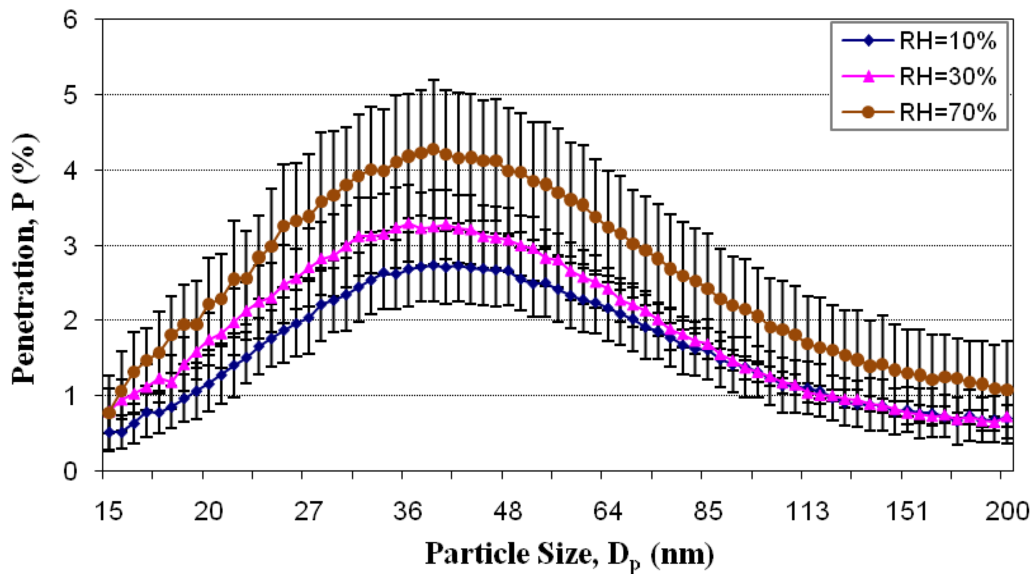

Figure 8. Effect of relative humidity on initial particle penetration through N95 respirators at 85 liters/min flow rate. The error bars represent the standard deviation at each point.

Even if the maximum initial penetration increased lightly with the RH, it did not exceed the 5% NIOSH certification criterion. The penetrations at the MPPS were respectively 2.73±0.47, 3.30±0.50 and 4.27±0.90% at 10, 30 and 70% RH. The mean penetration values were 1.6±0.73, 1.9±0.90, 2.6±1.10% at the respective RH for the particles ranging in size from 15 to 200 nm. It is noteworthy that more mean penetrations are observed for particles below 100 nm in size; 1.9±0.66, 2.3±0.75 and 3.0±0.94% at 10, 30 and 70% RH, respectively, see Table IV.

The initial particle penetration exceeded by an average factor of 1.6 at RH of 70%. With an increase with RH, at the MPPS, no consistent shift was identified. However, the MPPS still occurred in the range between 30 to 50 nm, acknowledging the presence of electrostatic attraction mechanism on the filter particle collection. Table IV provides information on the initial penetrations, MPPS and coefficient variation of the particle penetration.

Table IV. Summary of Particle Penetration for the Respirator's Performance

Q	(RH)	Maximum P (15-200 nm)	MPPS (15-200 nm)	P (15-200 nm)	P (15-100 nm)	CV* (15-200 nm)	CV* (15-100 nm)
(liters/min)	(%))	(%)		(%)	(%)	(%)	(%)
85	10	2.73±0.47	41	1.6±0.73	1.9±0.66	0.17-0.73	0.17-0.66
85	30	3.30±0.50	36	1.9±0.90	2.3±0.75	0.07-0.90	0.09-0.75
85	70	4.27±0.90	39	2.6±1.10	3.0±0.94	0.19-1.09	0.19-0.94

*Coefficient of variation is defined as the ratio of standard deviation to the mean.

PHASE 2 Particle Penetration against Mono- Dispersed NaCl Aerosols in the Range 20 to 200 nm (MAT Method)

Correlation of Mono-Dispersed Vs Poly-Dispersed Particle Penetration

The filtration performance of the N95 respirator was investigated against twelve different mono-sized NaCl particles (20, 30, 40, 45, 50, 55, 60, 80, 100, 120, 160 and 200 nm) at 85 liters/min constant flow rate.

Figure 9 illustrates the particle penetrations through N95 respirators at constant flow rate of 85 liters/min against mono-dispersed sodium chloride particles using the mono-dispersed aerosol test (MAT) method. The figure also shows the results with the measured penetrations at a constant flow rate of 85 liters/min when challenged with poly-dispersed aerosols. The tests with each mono-sized NaCl aerosol were repeated four times. Consistent with results from previous studies with electret filters, the MPPS occurred in the 40 to 100 nm range. Higher initial penetration level was found at each tested particle size with the (MAT) method (see Figure 9). However, in all cases, the initial penetration never exceeded the 5% NIOSH certification criterion at 85 liter/min. The results also revealed no significant relation between the initial particle penetrations, measured with (MAT) and (PAT) methods at each corresponding particle size at 85 liters/min.

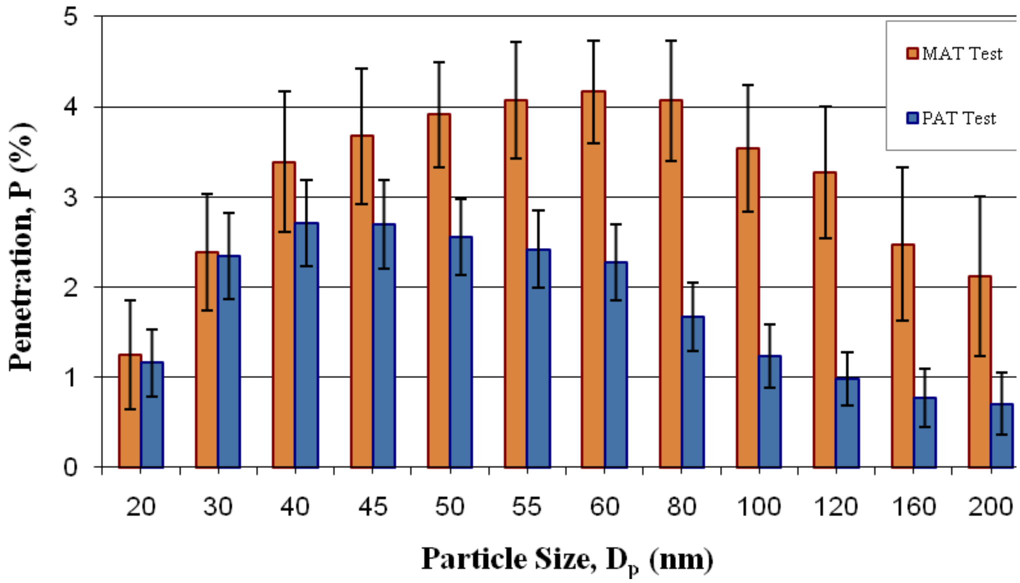

Figure 9. The comparison of mono-dispersed and poly-dispersed particle penetration levels (n=4). The error bars represent the standard deviation at each point.

In addition, as observed in Figure 10, the results showed very low number concentration of nano-particles at the upstream of the N95 respirator, compared with the measured number concentration with (PAT) method at each corresponding particle size at 85 liters/min. Depending on the particle size, the number concentration ranged between 80 to 1600 particles/cm^3. This low number concentration of nano-particles is mainly due to the diffusion losses through the measuring instrument; SMPS, mainly from five parts: impactor inlet, neutralizer, tubing to the DMA and CPC, and tubing between DMA and CPC.

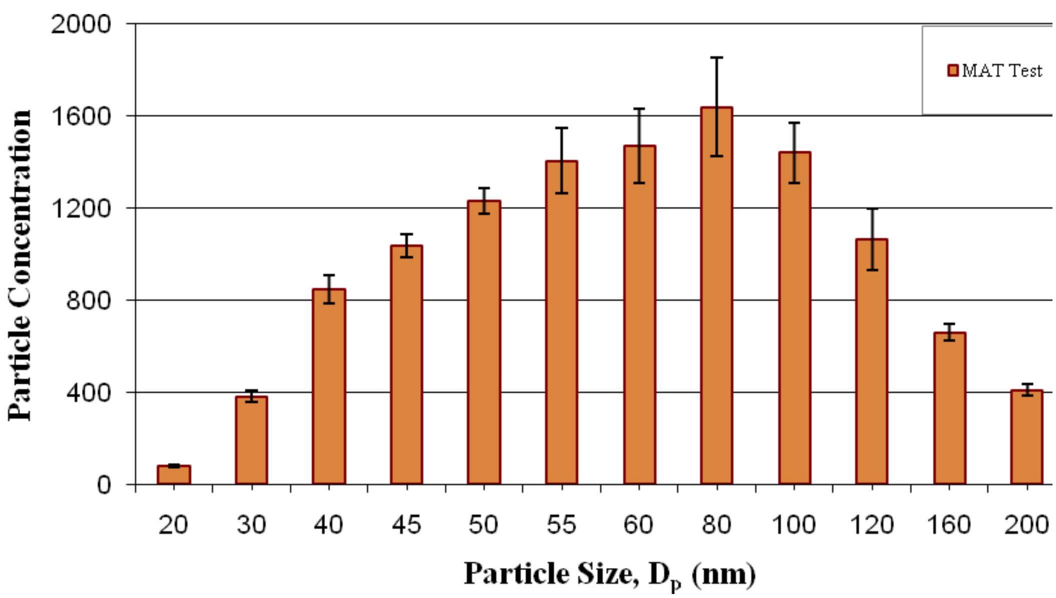

Figure 10. The particle number concentration at each tested mono-sized particles (n=4). The error bars represent the standard deviation at each point.

CONCLUSIONS

The results of this study demonstrated that the filtration performance of a NIOSH approved filtering face-piece N95 respirator dropped with the increase of flow rate; the maximum initial particle penetration dramatically exceeded 5% certification criterion at about 1.30, 2.35 and 3.05 folds at flow rates of 135, 270 and 360 liters/min, resepectively. The MPPS lightly shifted toward small particle sizes with the increase of flow rate, from 46 nm at 85 liters/min to 36 nm at 360 liters/min. The particle penetration through the N95 FFR was found to decrease with further loading time for the nano-sized particles, while increased slightly for the larger sizes. This phenomenon was attributed to the deposition of particles on the fiber filter' surface which clogg the pores of the filter and consequently enhance the collection of smaller particles caused by diffusion. The experimental results also showed that the performance of N95 respirators decreased slightly with the increase of RH level due to reduction in electrostatic charge on the filter fiber at higher RH.

Using mono-dispersed aerosol test (MAT) method; the results revealed the initial particle penetration is less than 5% NIOSH certification criterion. However, it was found that the initial value, measured with (MAT) method, is not related to the initial penetration measured with (PAT) method at each corresponding particle size at 85 liters/min.

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