Experimental Study of Nanoparticle Penetration Through Various Filter Media

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Abstract:

The purpose of this study is to investigate the penetration of nanoparticles (3 to 20 nm) though an assortment of filter media. The testing system, composed of a furnace, DMA, and filter holder, produces a monodisperse of neutrally charged, agglomerated silver nanoparticles to impact the filters. An Ultrafine CPC is used to physically count the particles upstream and downstream of the filters. Penetration/filtration efficiency is plotted as a function of particle size and combined with tests conducted by 3M for accuracy.

Introduction:

Our society is technologically advancing at a dramatic rate. As modern technology grows smaller and faster, the issue of nanotechnology in the workplace has in fact become a reality and will one day become commonplace. Recent studies have shown that the health risks corresponding with the inhalation of nanoparticles are significant. As the exposure to nanoparticles increases, it becomes important to protect people and the environment from any harm that these particles may inflict. Therefore, it seems reasonable that the employment of a filtration mechanism would alleviate this dilemma.

Recent investigations of nanoparticle penetration have been conducted and concluded with some rather curious results. It would seem that in the nanoparticle domain, filtration efficiency should continually increase with decreasing particle size. One study shows otherwise [1], claiming that the effects of thermal rebound may be the cause. However, due to the delicacy of the testing system, we believe that something else may have contributed to this effect.

Experimental Procedure:

The production and testing of nanoparticles through a filter medium is as follows. First, airflow is passed through a furnace containing silver. Nanoparticles of many different sizes are created here, and the flow of air exiting the furnace now contains a polydisperse aerosol of nanoparticles. Next, the polydisperse is given a Boltzman charge distribution. Finally, the polydisperse is sent into a Nano Differential Mobility Analyzer (Nano DMA) where only one specific size of particles is extracted. The Nano DMA uses a sheath flow, a slit, and an electric field to select a known particle size, and outputs these identical particles as a monodisperse aerosol. By simply changing the electric field inside the DMA, we can change and know the size of particles that make up the monodisperse. Finally, the monodisperse is neutralized and sent to the filter holder to attempt to penetrate the filter medium.

An Ultrafine Condensation Particle Counter (UCPC) counts the particles before and after the filter for a set amount of time. These counts are recorded as the particle size is swept. The filters are changed after each test set to provide for a broad analysis. Penetration is defined by the number of particles counted downstream divided by the number counted upstream. Filtration efficiency is simply one minus penetration.

We find that penetration is a function of a particle's face velocity, size, and charge, as well as the filter's composition. In order to compare penetration percentages of particles of different sizes, we need to assure that all other variables are held constant. The selected size and charge of the particles will be maintained by the system, while the compositions of the filter media are homogenous. The face velocity will be maintained by ensuring a constant flow rate through the filter via a thermal mass flowmeter.

Since we want to simulate the face velocity encountered with a typical respirator, a 5.3 cm/s value is obtained by setting the flow rate according to the following equation: $Q = U_0A$, where Q = flow rate, U_0 = desired face velocity, and A = cross sectional area of exposed filter.

Still, prior to the testing procedures described above, investigations of the furnace must be made. Particle concentrations must remain constant during the counts. A simple test (Figure 1) shows that a minimum of 1200 seconds (20 minutes) must be allowed for the furnace to warm up to a sufficient consistency. It is also important to provide large concentrations of particles to the filter. Figure 2 describes the size distribution of the polydisperse created by the furnace. Note that particle concentration is a function of both particle size and furnace temperature. Thus, the furnace is adjusted to provide the maximum number of particles without exceeding the range of the UCPC.

Results and Conclusions:

The results from the standard and specialized filter media test each provided similar trend lines. Filtration efficiency was found to continually increase with decreasing particle size (Figure 3), and the error bars shown in the penetration plot (Figure 4) indicate a high degree of accuracy. We also observe that these plots show no effect of the thermal rebound proposed by Balazy et al [1]. We believe that these effects may be due to low particle counts and leakage in the system.

We can that see that the majority of these filters probably do not provide enough protection from a highly saturated volume of air. However, the few on top do seem promising. By the time nanotechnology becomes common in the workplace, filters will prove to provide sufficient protection to employees.

Future Work:

The results provided by this study will be used to develop a mathematical model of penetration through the standard filters. These results will be also be analyzed by the filter manufacturers in the attempt to create a better filter medium. New studies will be conducted to observe the penetration results when the particle's shape and charge are varied.

Acknowledgements:

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References:

[1] Balazy, A., A. Podgorsky and L. Gradon, 2004. EAC Proceeding Vol. II, S967-S968.

[2] Hinds, W.C., 1999. Aerosol Technology: Properties, Behavior, & Measurement of Airborne Particles. John Wiley & Sons, NY.

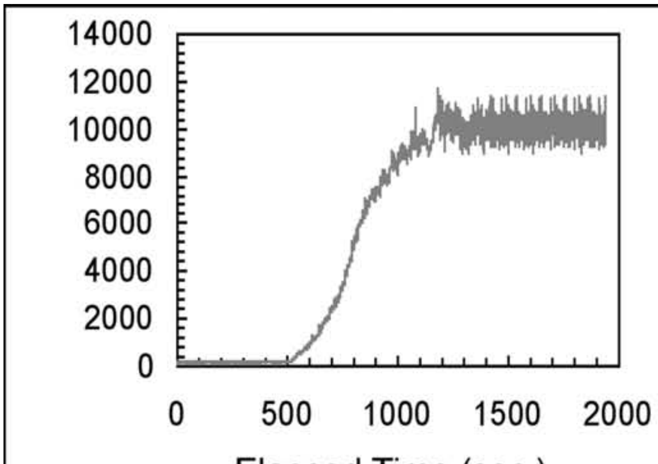

Figure 1

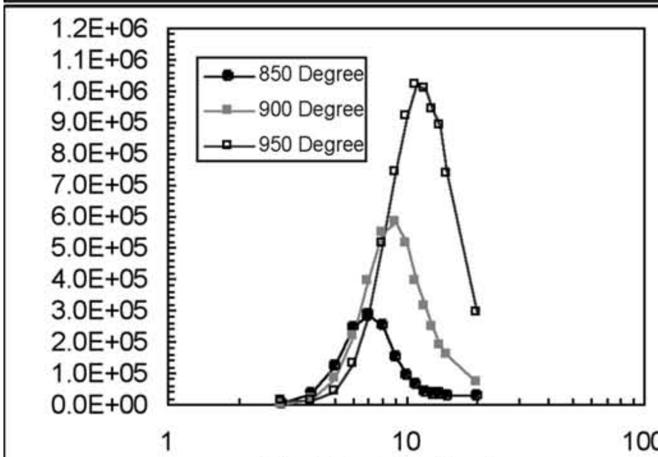

Figure 2

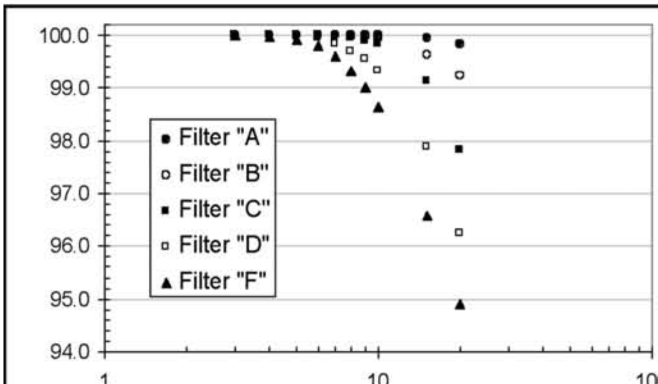

Figure 3

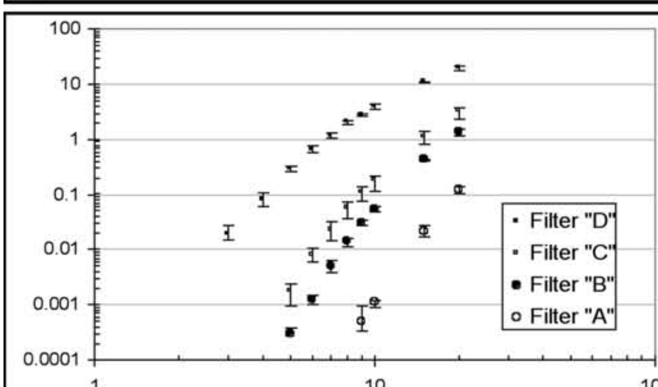

Figure 4

Figure 1: Particle stability due to the furnace.

Figure 2: Particle distributions produced by the furnace.

Figure 3: Filter efficiency vs. particle size for specialized filters.

Figure 4: penetration vs. particle size for standard filters.