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The Effects of Stoke's Drag, Electrostatic Force and Charge on Penetration of Nanoparticles through N95 Respirators

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Abstract : NIOSH (National Institute for Occupational Safety and Health) approved N95 respirators are commonly used by workers in construction sites where there is a large amount of dust being produced from sawing, grinding, blasting, welding, etc., both electrostatically charged and not. A significant portion of airborne particles in construction sites could be nanoparticles created beside coarse particles. The penetration of the particles through the masks may differ depending on the size and charge of the individual particle. In field experiments relevant to this current study, we found that nanoparticles of medium size ranges are penetrating more frequently than nanoparticles of smaller and larger sizes. For example, penetration percentages of nanoparticles of 11.5 – 27.4 nm into a sealed N95 respirator on a manikin head ranged from 0.59 to 6.59%, whereas nanoparticles of 36.5 – 86.6 nm ranged from 7.34 to 16.04%. The possible causes behind this increased penetration of mid-size nanoparticles through mask filters are not yet explored. The objective of this study is to identify causes behind this unusual behavior of mid-size nanoparticles. We have considered such physical factors as Boltzmann distribution of the particles in thermal equilibrium with the air, kinetic energy of the particles at impact on the mask, Stoke's drag force, and electrostatic forces in the mask stopping the particles. When the particles collide with the mask, only the particles that have enough kinetic energy to overcome the energy loss due to the electrostatic forces and the Stokes' drag in the mask can pass through the mask. To understand this process, the following assumptions were made: (1) the effect of Stoke's drag depends on the particles' velocity at entry into the mask; (2) the electrostatic force is proportional to the charge on the particles, which in turn is proportional to the surface area of the particles; (3) the general dependence on electrostatic charge and thickness means that for stronger electrostatic resistance in the masks and thicker the masks' fiber layers the penetration of particles is reduced, which is a sensible conclusion. In sampling situations where one mask was soaked in alcohol eliminating electrostatic interaction the penetration was much larger in the mid-range than the same mask with electrostatic interaction. The smaller nanoparticles showed almost zero penetration most likely because of the small kinetic energy, while the larger sized nanoparticles showed almost negligible penetration most likely due to the interaction of the particle with its own drag force. If there is no electrostatic force the fraction for larger particles grows. But if the electrostatic force is added the fraction for larger particles goes down, so diminished penetration for larger particles should be due to increased electrostatic repulsion, may be due to increased surface area and therefore larger charge on average. We have also explored the effect of ambient temperature on nanoparticle penetrations and determined that the dependence of the penetration of particles on the temperature is weak in the range of temperatures in the measurements 37-42°C, since the factor changes in the range from 3.17 10-3K-1 to 3.22 10-3K-1.

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