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Eric P. Vejerano
University of South Carolina, vejerano@mailbox.sc.edu

Jeonghyeon Ahn

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Letter to the Editor

A Letter to Reconsider the Conditions for Testing Decontaminated N95 Respirators for Emergency Reuse to Address Shortage

Eric P. Vejerano*, Jeonghyeon Ahn

Center for Environmental Nanoscience and Risk, Department of Environmental Health Sciences, Arnold School of Public Health, University of South Carolina, Columbia, South Carolina 29208, USA

ABSTRACT

The battle with COVID-19 pandemic has resulted in the shortage of personal protective equipment, particularly, N95 respirators. Healthcare workers who reused N95 respirators may resort to unproven methods of cleaning/sterilization that can severely compromise the respirators' filtration efficiency. A recently issued guideline will test decontaminated N95 respirators against particles with a median diameter of 0.075 ± 0.020 μm at a flow rate of 85 L min^{-1}. For emergency reuse, these conditions may be too stringent. N95 respirators tested at this flow rate had predicted efficiencies of < 69%, assuming complete degradation of their electrostatic coating. Experimental efficiencies were ~15% lower. For emergency reuse, we recommend to either adjust the flow rate closer to normal breathing, or the size of the test particle should reflect that of virus-laden respiratory aerosols (~> 0.5 μm). By reconsidering the test conditions, a substantial fraction of used/decontaminated respirators can be reused.

Keywords: Fine aerosol; SARS-CoV-2; COVID-19.

MAIN TEXT

The shortage of N95 respirators was a critical issue during the early months of the COVID-19 pandemic. At that time, healthcare workers reused N95 respirators that are intended for single use. Some resorted to unproven methods of cleaning/sterilization that can severely compromise the ability of the respirator to capture airborne particles efficiently.

Recently, a guideline has been issued for testing decontaminated N95 respirators (NPPTL, 2020). In the guideline, the efficiency of used/decontaminated respirators will be tested against particles with a median diameter of 0.075 ± 0.020 μm at a flow rate of 85 L min^{-1}. For emergency reuse, the conditions in the guideline for testing used/decontaminated N95 respirators may be too stringent for two reasons. First, for most submicron particles, efficiency generally decreases at higher flow rates (note that efficiency will increase at extremely high flow rates). Second, existing lines of evidence suggest virus-laden respiratory aerosols are > 0.5 μm, which are efficiently captured by filters almost independent of flow rates.

To address the shortage of N95 respirators among healthcare workers, we describe the basis of our recommendation for testing N95 respirators for emergency reuse at the condition that mimics regular use of the respirators and the size of airborne respiratory aerosols. Based on our calculation and experimental measurement, heat/chemically treated N95 respirators will not pass under the condition prescribed in the guideline.

In our calculation, we assumed that heat/chemical treatments destroyed the electrostatic coating. Therefore, the single-fiber collection efficiency of the filter is entirely due to mechanisms of impaction, diffusion, and inertial impaction. Assuming a cross-sectional area of 81 cm^2, the normal breathing flow rate for an adult (5–7 L min^{-1}) (Warner and Patel, 2013) is equivalent to a face velocity (U) of ~1.02–1.43 cm s^{-1}. For a similar condition, the recommended flow rate in the guideline is equivalent ~12× the face velocity (U~17.5 cm s^{-1}) to that during normal breathing. In Table 1, we define low, medium, and high face velocities at values of 1.13, 7.20, 17.5 cm s^{-1}, respectively.

Fig. 1 depicts the calculated total efficiencies for a filter for different particle sizes as a function of face velocity. We chose

* Corresponding author.
Tel.: 1-803-777-6360
E-mail address: vejerano@mailbox.sc.edu

Table 1. Calculated efficiencies for different particle sizes and face velocities.

	Calculated Efficiency, %		
	Face velocity (cm s^{-1})		
d_p, µm	1.13 (low)	7.20 (medium)	17.5 (high)
0.020	99.9	99.9	99.9
0.055	99.9	99.7	95.8
0.075	99.9	98.1	89.0
0.095	99.9	95.2	82.0
0.118	99.9	91.2	75.5
	99.5 ± 2.3[a]		
0.150	99.8	86.2	69.9
0.180	99.5	82.9	67.8
0.300	97.8	82.5	76.9
0.500	98.2	95.3	96.8
1	99.9	99.9	99.9

[a] experimental efficiency of 3M N95 Model 9210 respirators that have been subjected to heat/chemical treatments.

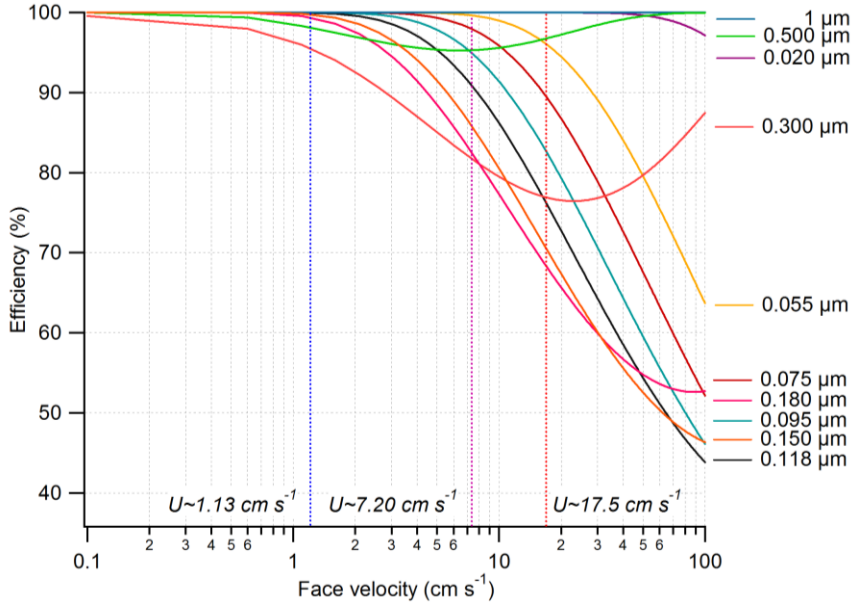

Fig. 1. Dependence of the calculated efficiency for a filter as a function of face velocity (U) for different particle sizes. We calculated efficiency (E) using $E = 1 - e^{\left(-4\alpha E_{\Sigma} t/\pi d_f\right)}$, where α is the solidity or packing density, t is the filter thickness, d_f is the fiber diameter, and E_{Σ} is the sum of the single-fiber efficiencies due to diffusion, interception, and inertial impaction. We used the values of 0.05, 1 mm, and 2.0 µm for α, t, d_f, respectively. The vertical red line is the face velocity using the flow rate in the guideline, assuming a cross-sectional area of 81 cm^2. The vertical blue line is the face velocity we used in our test, whereas the vertical pink line is the face velocity at 35 L min^{-1}. The detail of the calculation is described in the Supplementary Appendix.

particle sizes (d_p) of 0.020, 0.055, 0.075, 0.095, 0.118, 0.150, 0.180, 0.300, 0.500, and 1 µm, to assess the impact of small and large particles that include the range of the particle sizes in the guideline. At the low face velocity, all particle sizes had efficiencies > 95%. At the higher face velocity and for particle size 0.075 ± 0.020 µm, the efficiency was ≤ 95.8%. The efficiencies for particles ranging from 0.055–0.300 µm were 76.9% to 95%; the 0.180-µm particle exhibited the lowest efficiency. At medium face velocity, particles with sizes of 0.075 µm to 0.180 µm will have efficiencies < 90%, while the efficiency for particle size ranging from 0.055 µm to 0.3 µm was 82.5–99.7%. Extremely small particles (0.020 µm) are captured efficiently even at higher face velocity (> 95% at 100 cm s^{-1}) because of their high diffusivity. The measured experimental efficiency agrees well with the predicted efficiencies at the low face velocity (Table 1); for d_p~0.118 µm, the experimental efficiency was 99.5 ± 2.3%, whereas the calculated efficiency was 99.9%. At the high face velocity, the predicted efficiency was at most ~67.8%; the experimental efficiency was ~< 55%. If the SARS-CoV-2 viruses are naked particles floating in the air, ~90 nm in size (Kim *et al.*, 2020), at the high face velocity, only ~83.7% of the particles will be collected.

But when expelled from the respiratory tract by breathing, talking, coughing, or sneezing, viruses are encased in respiratory fluids, therefore, larger (Vejerano and Marr, 2018). Although the information on the size distribution of virus-laden aerosol is limited, existing lines of evidence suggest that viruses are contained in larger respiratory aerosols. Sick individuals expel larger respiratory droplets and aerosols than healthy individuals because of differences in the composition and properties of the secreted mucus (Edwards *et al.*, 2004; Gralton *et al.*, 2011). Also, the type of virus affects their emission. More human subjects (60%) infected with influenza A released the virus in their exhaled aerosols (d_p~0.300–< 5 µm) than those infected (14%) with influenza B (Fabian *et al.*, 2008). But the study did not identify if the viruses were distributed in all size fractions, or only contained in the larger- or smaller-sized fraction. In a similar study, although human subjects infected with rhinovirus released smaller particles (d_p~0.300–0.449 µm) (Edwards *et al.*, 2004), no pathogen has been detected in them (Fabian *et al.*, 2011). In another study, while ferrets infected with the influenza virus expel mostly fine particle sizes within ~0.52–1.54 µm, only ferrets exposed to particles ≥ 1.5 µm became infected (Zhou *et al.*, 2018). Sick ferrets that expelled virus-laden particles > 10 µm infected more healthy ferrets (Zhou *et al.*, 2018).

While breathing may release smaller particles, including the most penetrating particle size (d_p~0.3 µm), findings in the literature suggest that virus-laden respiratory aerosols are > 0.5 µm (Fabian *et al.*, 2011). These fine respiratory aerosols are captured efficiently by N95 respirators, even at higher face velocities. Therefore, we recommend adjusting the size of the test aerosols, or the face velocity should be close to that during breathing. Aerosol labs that can perform filter testing but at lower flow rates can relieve some of the burden experienced by certified testing labs during a pandemic.

DISCLAIMER

Reference to any companies or specific commercial products does not constitute an endorsement by the authors.

SUPPLEMENTARY MATERIAL

Supplementary data associated with this article can be found in the online version at https://aaqr.org/

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