Numerical study of the efficiency of a facepiece filtering respirator using a model of an idealized spherical sampler with porous layer

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Keywords: respiratory protection, penetration, filter, faceseal leakage, CFD
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Facepiece filtering respirators (FFRs) are widely used to protect the human breathing system from various aerosol hazards. Inhalation of ultrafine (nano-scale) and fine particles is of concern because small particles penetrate to the lower sections of the respiratory tract and cause adverse health effects. The protection offered by an FFR is often determined by measuring the efficiency of a respirator filter. E.g., the National Institute for Occupational Safety and Health (NIOSH) certifies respiratory protection devices as N95/R95/P95 if the collection efficiency of their filters is at least 95%. In addition to a filter, the respirator performance depends on the fit, which involves a faceseal leakage along the respirator peripheral area (Fig. 1).

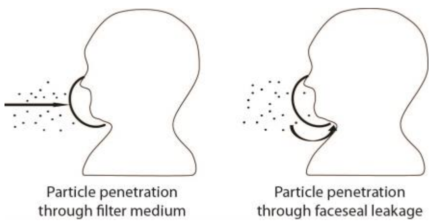

Fig.1. Two particle penetration pathways (Grinshpun et al., 2009)

The penetration of aerosol particles into an FFR (through both pathways) was investigated using a novel model, which involved a spherical porous surface representing the filter and a circular peripheral opening representing the faceseal leakage. The main parameters are presented in Fig. 2 (an idealized spherical sampler approach is adopted here). The model utilized the air viscous flow equations in a free fluid and porous zones that are numerically solved using a CFD code FLUENT.

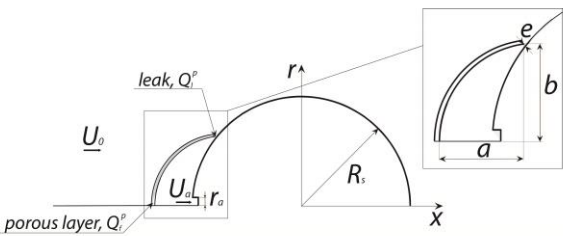

Fig.2. Schematics

The Total Inward Leakage (*TIL*), a quantitative characteristic of the protection provided by an FFR, is defined as the ratio of the particle concentration inside the respirator (C_i) to the actual concentration (C_0):

$$TIL = \frac{C_i}{C_0} = \frac{Q_f^p \eta_f + Q_l^p \eta_l}{C_0 Q_a}$$

where Q_f^p and Q_l^p are the particle fluxes through the filter (porous layer) and the leak, respectively; Q_a is the sampling flow rate; and η_f and η_l are the particle penetrations through the filter and leak, respectively.

The $TIL(d_p)$ results are presented in Fig. 3 along with the data reported by Rengasamy & Eimer (2012) for Q_a = 40 L min^{-1} (d_p is the particle diameter). The experimental data were obtained for the respirator with the two circular orifices (diameter d). The leakage dimensions used for calculating the *TIL* were adjusted for the leak shape (Chen and Willeke, 1992). The experiment and model are in a fair agreement.

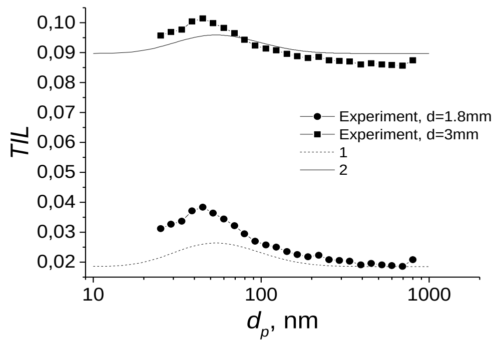

Fig.3. *TIL* as a function of the particle size, d_p. Curves 1 and 2 represent the modeling results obtained at two peripheral openings)

Utilizing the model developed in this effort, we performed a set of parametric studies of the protection provided by an FFR at various breathing flow rates, filter material permeability, as well as for different dimensions and shapes of the faceseal leakage. We determined the critical quantity of the opening area at which the respirator's efficiency falls below a specific targeted value (e.g., 95% for an N95/R95/P95 facepiece).

This work was supported by the Russian Government Program of Competitive Growth at Kazan Federal University and the Russian Foundation for Basic Research (grants No. 15-01-06135, 14-01-31118).

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