Mathematical study of inhalable fraction in low velocity conditions

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The CFD model and parametrical investigations of the particle inhalable fraction for the human manikin in low velocity air including a calm air case are presented. Obtained dependences of the inhalable fraction on the particle size are compared with experimental data and the aspiration efficiency of a spherical sampler.

The particle inhalability for a realistic human head was studied numerically for low air velocity by Antony&Flynn (2006). Presently, there is little information regarding the human inhalability under calm air condition (Dai et al., 2006). In the present work a realistic digital model of human head and an idealized spherical sampler facing the wind are used to calculate the inhalable fraction of coarse dust particles up to very low velocity values including the calm air case.

In the first model the velocity field of the air flow is found by numerical solution of the Navier-Stokes equations of viscous flow of incompressible fluid using the FLUENT code. To describe the gas flow for the spherical sampler the potential flow model developed by Galeev&Zaripov (2003) is used. The particle motion equations are integrated in the velocity field, which is found numerically or analytically.

In the undisturbed air flow far from the human head and sampler particles move with the velocity $\bar{U}_1 = \bar{U}_0 + \bar{V}_s$, where $\bar{U}_0$ is the air velocity, $\bar{V}_s = \tau \bar{g}$ is the settling velocity, $\tau = \rho_p d^2 / 18\mu$ is the relaxation time, ρ_p and d are the particle density and diameter, μ is the air viscosity. Breathing is simulated by an stationary air suction through the elliptical mouth orifice. On the base of calculating particle trajectories the tube of limiting trajectories is calculated, which divides the sampled particles from the unsampled ones. The cross section area S_p of the tube of limiting trajectories far from the manikin allows to calculate the aspiration efficiency (inhalable fraction) by the formula

$$A = \frac{U_1 S_p}{Q} = \frac{S_p \sqrt{U_0^2 + V_s^2}}{S_m U_a},$$

where $Q = S_m U_a$ is air flow rate through mouth with area S_m, $\bar{U}_0$ is the aspiration velocity.

Some trajectories of particles in the vicinity of the human head at two values of wind velocity are shown in fig.1. The shape and size of the area S_p depends on the ratio of the wind and sampling velocities and the particle diameter. In the calm air case the human head screens a part of particles that could be aspirated. The aspiration efficiency as a particle diameter function is shown in fig.2. The obtained values of aspiration efficiency for moving air agree well with experimental data of Kennedy&Hinds (2002) and the theoretical curve of Anthony&Flynn (2006). Comparison with the criterion for inhalable particulate mass (IPM) aerosol samplers is given. The aspiration efficiency of the spherical sampler in moving air also agrees well with mentioned curves. Thus the model of an idealized spherical sampler can be used to estimate the inhalable fraction in low velocity environment.

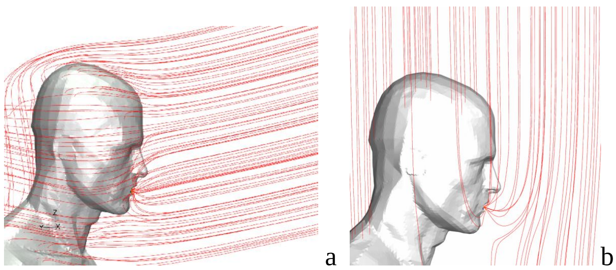

Figure 1. The trajectories of particles at d=37μm for two wind velocities: a-U_0=0.2 m/s, b - U_0=0

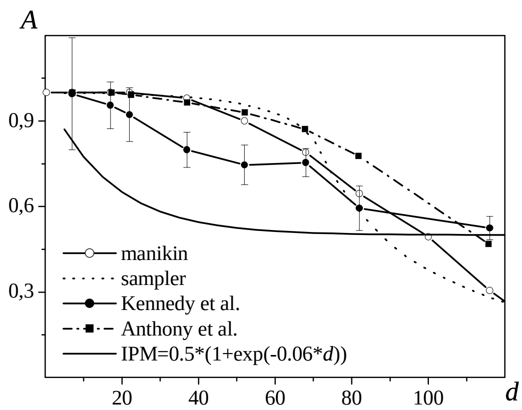

Figure 2. A as a function of the particle diameter d

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