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Inertial and gravitational effects on aerosol deposition in the conducting airways

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Abstract

In most inhaled drug delivery applications, aerosol deposition in the upper airways occurs primarily via impaction. However, the effects of gravity become important as particle size increases and flow rate decreases. Sedimentation can therefore be significant in the smaller airways of the tracheobronchial tree, where velocities decrease due to the large increase in cross-sectional area, as well as the larger airways at low inhalation flow rates. In order to assess the relative importance of impaction and sedimentation, particle transport and deposition is examined under different steady inhalation conditions in a mouth-throat and a bifurcation model, using direct numerical simulations. The results are also compared to computations without the effect of gravity on the particles. Two important parameters characterize particle motion: (i) the Stokes number, Stk, and (ii) the ratio of the gravitational settling velocity to the fluid velocity, V_g^*. The ratio of these two parameters is the Froude number, which measures the relative importance of inertial to gravitational forces. Instantaneous definitions of the Stokes number, non-dimensional settling velocity and Froude number are derived, based on the local flow properties, which provide a more accurate representation of the particle trajectories compared to the reference parameters based on characteristic flow scales. Results show that, in certain regions of the flow, the instantaneous Froude number can be three to four orders of magnitude smaller than the reference value. In these regions, deposition via sedimentation is shown to be significant, and the reference parameter underestimates gravitational effects. In the extrathoracic airways, particles with high V_g^* deposit primarily in the mouth, via sedimentation, while particles with high Stk deposit mainly in the larynx and trachea, via impaction. In the bifurcation, different orientation angles of the airway geometry are shown to result in non-negligible variation in deposition. Impaction is the dominant mechanism for deposition on the carinal ridge, while sedimentation occurs along airway walls at an angle to the gravity direction. In the daughter branches, both impaction and sedimentation contribute to deposition.

Keywords: inhaled drug delivery, impaction, sedimentation, Stokes number, settling velocity, Froude number