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A STUDY OF AEROSOL SAMPLING AT HIGH VALUES OF THE VELOCITY RATIO.

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INTRODUCTION

Aerosol samplers are widely used in health and environmental studies and hence have been a major area of research both theoretically and experimentally. However much of the published experimental data and theory has been limited to a relatively narrow range of the velocity ratio, $R = U_0 / U_S$, where U_0 is the freestream velocity and U_S is the sampling velocity. In recent years, the need to understand aerosol aspiration for a much wider range of values of R than previously considered has increased. For example, wind speeds now found in workplaces, where ventilation is not forced, are typically less than 1m/s, and this results in lower values of R than previously considered. Also, for industrial and environmental hygiene applications, samplers are being designed with lighter sampling pumps, and hence lower sampling velocities, see Vincent *et al.* (1999), which results in higher values of R. Hence in the work presented here a numerical study is made of a thin-walled sampling tube operating over a wide range of values of R. An understanding of the flow and particle behaviour for the simple thin-walled case provides important insights into more complex blunt samplers. Further the effects of gravity upon sampler performance are investigated.

METHODS

In order to make an initial investigation into sampler performance at large values of R, and to compare the results obtained with the available experimental data, a thin-walled sampler has been considered. The sampler, which has a suction velocity U_S, is assumed to be facing the air stream which is moving with an undisturbed uniform velocity U_0. A numerical model has been developed to predict the air flow around and into the sampler. In the model the flow is assumed to be ideal flow and the viscous effects neglected. This greatly simplifies the equations of motion for the flow and significantly reduces the computation time and resources necessary to obtain results. This model has been described in Dunnett and Wen (2002). Once the velocity of the air has been obtained, it is possible to trace the paths of the particles within the flow. In performing this calculation it was assumed that the particles were sufficiently small to cause no disturbance to the flow and that all external forces, except gravity, were negligible. The aspiration efficiency of the sampler can then be determined using the formula

$$A = \frac{A_0 v_{int}}{Q} = \frac{4A_0 \sqrt{U_0^2 + v_s^2}}{\pi D_i^2 U_s} = \frac{4A_0 R \sqrt{1 + \left(St / Fr\right)^2}}{\pi D_i^2}$$

where v_{int} is the initial particle velocity, Q is volume of air sampled per unit time, A_0 is the area enclosed by the limiting particle trajectories in the undisturbed flow, D_i is the inner diameter of the sampler and St and Fr are the Stokes number and Froude number respectively. Where $St = \dfrac{d^2 \rho U_0}{18\mu D}$, $Fr = \dfrac{U_0^2}{gD}$, d is the diameter of the particle, D is the outer diameter of the sampler, ρ is the density of the particle and μ is the viscosity of the air. A study has been made of the behaviour of A as R increase for various situations. Recent experimental data, Paik and Vincent (2002), for the aspiration efficiency of a thin-walled sampler was found to differ increasingly from the widely used semi-empirical model of Belyaev and Levin (1974)

as the velocity ratio R increased above about 6. The numerical model described here was used to investigate this situation in order to gain an understanding of the reasons for this difference. From the results obtained it appears that a major factor influencing the aspiration efficiency as R increases is the reversal of the air flow within the sampling tube. As for large R the air velocity in the sampling tube is significantly less than the undisturbed air velocity, and the limiting streamsurface, separating the sampled air from that which is not sampled, reaches stagnation on the inside wall of the sampler at a short distance from the entry to the sampler. Hence it is possible that particles which cross the sampler face, and hence enter the sampling tube, are then carried back out of the sampler by the reverse flow.
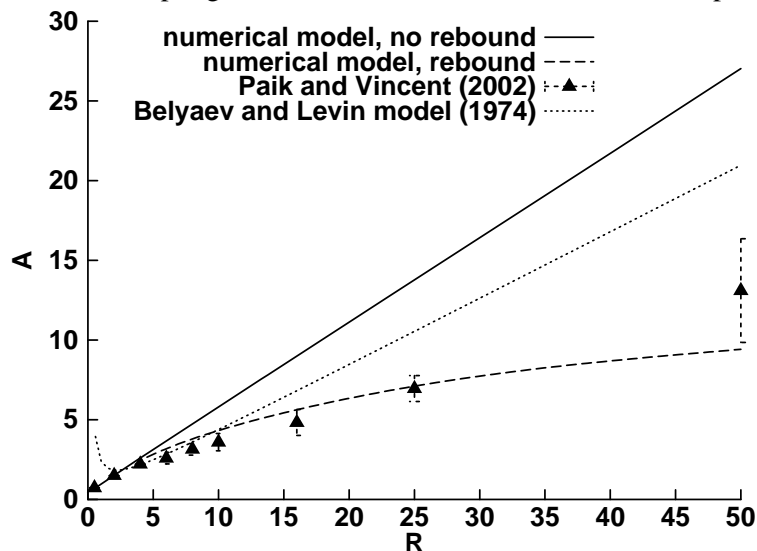

Fig. 1. Variation of A as a function of the velocity ratio R for St=0.351.

Results are shown in Fig. 1 for St=0.351 in order to compare with the experimental data. In the figure numerical results are shown for the cases when (i) all the particles which cross the face of the sampler are sampled, labeled as 'no rebound' and (ii) those particles which strike the internal sampler walls between the face and the point of flow stagnation are carried back out of the sampler by the reverse flow, labeled as 'rebound'. Also shown are the predictions of the model of Belyaev and Levin (1974). As can be seen assuming no particle rebound from the sampler internal walls in the numerical model results in a significant overestimation in the value of A. This is also true of the predictions of the Belyaev and Levin (1974) model. However, taking into account the removal of particles by the reverse flow brings the numerical predictions of A close to the experimental data. The effect of gravity upon the results was investigated but the differences of including and not including gravity were found to be insignificant and hence are not shown.

Other situations have been considered and in all cases the significant factor affecting A is the flow reversal within the sampling tube.

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