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Experimental studies of the aspiration efficiencies of blunt aerosol samplers at large angles to the wind

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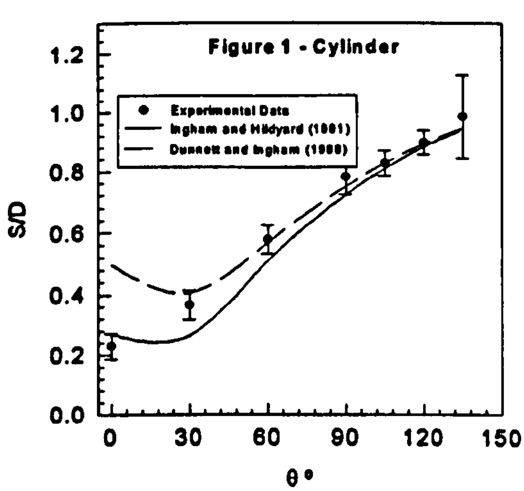
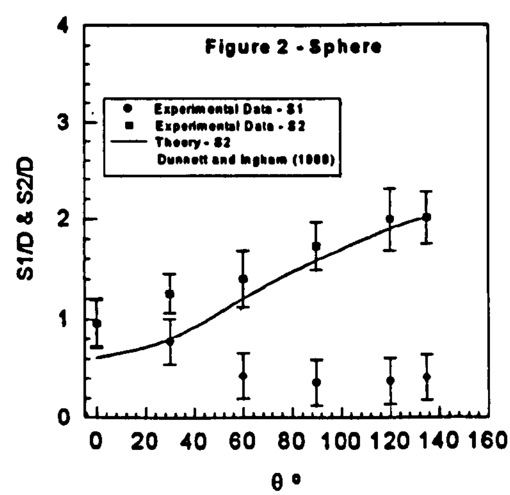
Introduction

Practical aerosol sampling in workplaces and the atmospheric environment involves the use of devices of complex shape with entry orifices whose orientation (θ) with respect to the wind can range over the full 360°. For such systems, simple models of aspiration efficiency like those developed for thin-walled samplers are inadequate for describing sampling performance. Models based on considerations of the flow about bluff bodies with aspiration have enabled progress to be made, both in semi-empirical modelling and in numerical simulations (as reviewed by Vincent, 1989 and 1995). However, further progress requires new experimental data by reference to which improved models can be developed.

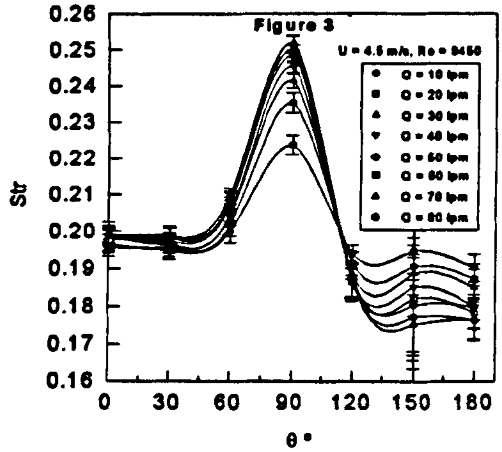
Flow studies

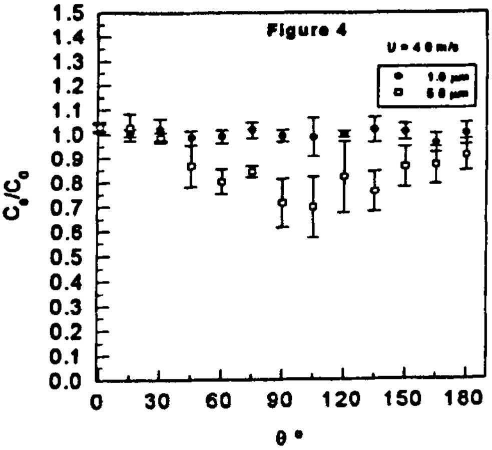
Wind tunnel experiments were conducted, using a simple 2-dimensional cylindrical sampler with a slot entry and a 3-dimensional spherical sampler with a single circular entry. The aim was to generate new information about the nature of the air flow about blunt samplers as a function of wind speed (U), sampling flow rate (Q), sampler geometry and - most importantly - orientation with respect to the wind direction (θ). Flow visualization was carried out using a modified version of the 'smoke-wire' method, enabling the visual identification of the positions of flow stagnation on the surface of the sampler body which define the dividing streamsurface between the air which is aspirated and that which passes by outside the sampler. The data were obtained in the form of the width of the stagnation region, described by S for the 2-dimensional case and by S_1 and S_2 for the spherical case. Typical results are plotted in Figures 1 and 2 as functions of θ for a single value of the non-dimensionalised flowrate parameter, $\phi_c = Q/D_cUL_c = 0.07$ for the cylindrical sampler (where D_c = 3 cm is its diameter and L_c = 25 cm its length) and $\phi_s = 4Q/\pi UD_s^2 = 0.16$ for the spherical sampler (where D_s = 6.35 cm is its diameter). Also shown on these graphs are the corresponding curves calculated from theory (for conditions where theory currently exists). Agreement with experiment is quite good, even for θ as large as 140°.





For the cylindrical sampler, measurements were also made of the near wake vortex shedding frequency (f), using a fine hypodermic needle inserted into the near wake region and connected to an electronic micromanometer. As shown in Figure 3 for the cylindrical sampler at $U = 4.5$ m/s and a Reynolds number (Re) of 9450, the non-dimensional Strouhal number ($Str = D_c f/U$) is seen to be strongly dependent on ϕ_c and θ. This may have interesting effects on particle transport in the aerosol sampling situation. Such vortex shedding was prominent for the cylindrical body, but much weaker (and hence neglected) for the spherical body.





Aspiration efficiency

Measurements of aspiration efficiency were conducted using polydisperse test aerosols generated from Arizona Road Dust for the spherical sampler (where the diameter of the sampling orifice was 0.635 cm and $Q = 5$ l/min). The aspirated particles were detected as a function of particle aerodynamic diameter (d_{ae}) using an aerodynamic particle sizer (APS), and were plotted as a function of θ. The results for particles with $d_{ae} = 1$ and 5 µm, and for $U = 4$ m/s, are shown in Figure 4, in the form of the ratio C_θ/C_0 where C_θ is the sampled concentration at the angle θ and C_0 that for $\theta = 0°$. These results show clearly that, for particles large enough to exhibit inertial behaviour, C_θ/C_0 (representing aspiration efficiency) falls progressively for θ in the range up to 90° and then rises thereafter. The results in Figure 4 are in quite good agreement with the semi-empirical models for aspiration efficiency at $\theta = 90°$ and 180° proposed by Tsai and Vincent (1993).

Concluding remarks

Such studies are shedding new light on the types of theoretical model that might be developed for the more adequate description of aspiration efficiency. In the first instance, it appears that relatively simple potential flow models might be applicable, even for large sampler orientations with respect to the wind. The development of such models aims eventually to enable more effective future progress in the design of new practical samplers consistent with the latest particle size-selective, health-related sampling criteria and in the interpretation of practical results obtained using current devices.

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