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RECENT DEVELOPMENTS ON AEROSOL DEPOSITION ON SURFACES: MODELLING AND EXPERIMENTS

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INTRODUCTION

Aerosols act as the carriers of chemical and biological pollutants in the atmosphere which have the potential to cause adverse health effects and material damage and also affect weather and climate. For these reasons, increasing emphasis is being laid in recent times on understanding their behaviour in the environment. A distinguishing feature of aerosol particles as opposed to trace gases is their ability to adhere to surfaces upon contact mainly because of the short range London-van der waal-Hamaker forces. As a result, particles transported to the surface (by molecular diffusion and turbulence in fluid motion) to within a few nanometer distances, deposit on them. The deposition mechanism is of significance in almost all applications of aerosols: lung deposition, removal in outdoor and indoor environments, nuclear aerosol plate-out in transport and containment systems, radon progeny equilibrium, pollution control strategies, microelectronics applications and material synthesis. Thus, understanding the mechanics of particle deposition is of vital importance in aerosol research.

In view of the fact that large populations reside in the indoor environment for a considerable part of their time, exposure to particulates in the indoor air requires special attention (Nazaroff, 2004). Human activity like use of fossil fuels for cooking is an important source of aerosols in indoor air. In addition, ingression of outdoor particles occurs through free or forced ventilation systems. Further, there is the possibility of resuspension of deposited particles. In the context of radiation exposures to general public, a major part of the dose arises from the inhalation of radon and thoron progeny aerosols in indoor air. Although not strictly an indoor issue, nuclear aerosol studies focus on deposition in confined environment and include special forces due to thermophoresis and diffusiophersis. In this article we discuss the experimental and modelling studies aimed at understanding particle deposition in indoor environment.

Deposition Models

Broadly speaking, there are four main components which govern particle deposition. First is the structure of the wall surface (Abadi et al, 2001), the second is the fluid mechanical characteristics at the gas surface layer (Shimada et al, 1993), the third is the size and electrical charge of the particles (Lai, 2004) and the fourth is the external forces to which the surface-gas-particle system is subjected to. The early developments focused on the effect of gravity, Brownian diffusion and inertial impaction. In its most general form, one can formally express the deposition velocity, i.e. the flux per unit concentration of particles in the core of the fluid, by a general formula that clearly separates the effects of drift motion normal to the surface from the diffusive motions:

$$V_{eff} = \frac{V_{drift}}{1-\exp\left[-V_{drift}/V_{diffusion}\right]},$$

where V_{drift} is the velocity due to forces towards the surfaces and $V_{diffusion}$ is the velocity due to diffusion alone. Since the drift velocities are expressible in terms of the external forces through Stoke's-Einstein relationship, the essential problem lies in evaluating the diffusional flux.

Even in relatively quiet, unventilated rooms, existence of small temperature differences due, for example, to differential wall heating by sunlight, would introduce weak convective flows. The flows will be further accentuated by external ventilations. Since the flow velocities at the surface should be zero, hydrodynamic stresses will develop which will in turn introduce eddy currents in the fluid whose intensity will rapidly increase as one moves away from surface. The eddy currents will be transmitted to particles as turbulent diffusion. Crump and Sienfeld (1981) applied the model of quadratic variation of turbulence diffusion coefficient with distance to obtain a formula for the deposition velocity. The turbulent diffusivity is estimated through the rate (k_e, s^{-1}) of dissipation of turbulent energy at the boundary layer. It has been extended to include more general power-laws of turbulent diffusivities.

In order to arrive at a better understanding of the structure of the turbulent boundary layer, numerical simulation techniques are being increasingly adopted (e.g. Beiggen et al, 2005). These indicate varying power-laws for turbulent diffusion coefficient in the viscous sublayer near the wall which have been summarized in the form of a 3-layer model (Lai and Nazaroff, 2000). This model yields a somewhat complicated expression for the deposition velocity but its chief advantage is that it is based on a measurable parameter, friction velocity of the fluid, u*.

As an application of deposition mechanism, the theoretical models have been extended to predict the removal rate of particles using unipolar ionizers (Mayya et al, 2004). Studies have shown that ionizers have better effect in poorly ventilated rooms and at higher particle concentrations and for sizes in the range of 0.1-1.0 μm. Another application has been towards the development of deposition based sensors for direct monitoring of radon and thoron progeny (Mishra and Mayya, 2007). The deposition mechanisms in this case include effects due to coarse and the nano-clusters of fine fractions. Recent theoretical studies based on the current turbulence models have shown that for thoron progeny more than 60% of deposition occurs due to fine fraction which activity-wise, is only about 2%.

Experimental studies

Experimental techniques for deposition velocity measurements have focused on the decrease of aerosol concentrations in chambers. The direct fluxes on surfaces are estimated by fluorescent spectroscopy and analytical techniques. Lai (2004) presented a summary of various studies on the deposition velocity as a function of size. It has been noted that there is considerable scatter, differing by orders of magnitude, in the deposition velocities of particles in the size range of 0.1-1 μm by different investigators. There is only broad agreement with theory in respect of the shape of the deposition curve having a minimum at around 0.2 μm.

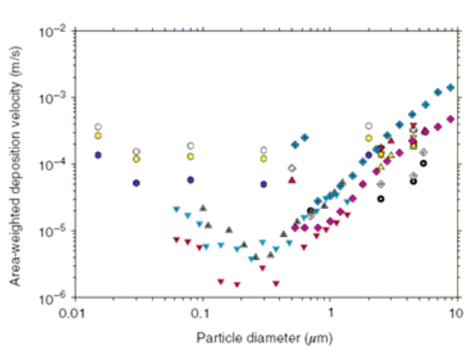

Fig.1: Summary of experimental measurements of deposition velocity (Lai, 2004).

A comprehensive set of measurements of the deposition velocity of radon and thoron progeny aerosols were carried out in BARC using absorber mounted nuclear track detectors. The studies were made in medium sized rooms and small chambers using a small fan as a mixing element. The studies focus essentially on particle sizes less than 200 nm in which most of the activity resides. Particle sizes and concentrations were monitored using SMPS and low pressure impactors. U* was estimated using fan parameters. It has been found that the effective deposition velocity for thoron progeny species is about 0.08 m/h in indoor situations. For radon progeny the deposition velocity was roughly twice that for thoron progeny. Face-down deployment showed about 25% less deposition velocity than face-up deployment. These results were in remarkable agreement with model predictions. The study aims to provide a technique for passive detection of progeny aerosols directly in the environment.

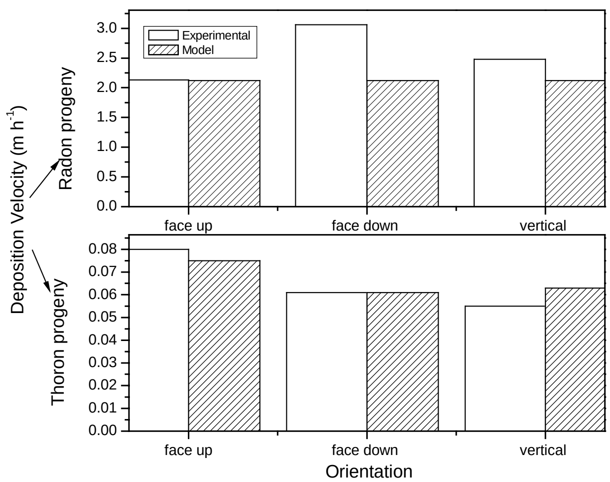

Fig.2: Radon and thoron progeny deposition velocity estimates

Conclusion

Although the theory of particle deposition has advanced to a considerable extent, agreement with experimental data in realistic situations over the entire size range is far from satisfactory. The uncertainties are likely to be due to the combined effect of experimental difficulties in characterising the various parameters as well as incompleteness of the processes in the models. In the case of radon and thoron progeny aerosols, recent experiments at BARC have shown good agreement with Lai-Nazaroff models. There is a great deal of work to be done on the interaction of fluid mechanical, electrical and thermal aspects in governing the particle deposition on surfaces.

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