STUDIES OF COLLOIDAL PARTICLES; SCAVENGING OF
AEROSOL PARTICLES BY A FALLING MACROSCOPIC PARTICLE

Final Report

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ABSTRACT

Collection efficiencies of falling water drops ranging from 0.094 to 0.254 cm in radius for silver chloride aerosol particles in nitrogen ranging from 0.15 to 0.6 μ m in radius have been measured. The drops accelerated for distances ranging from 30 to 515 cm prior to entrance into the scavenging chamber. Results were extrapolated to terminal velocity.

The results for the slower moving drops (30 cm acceleration distance) agreed roughly with the predictions of a theory based upon collection by Brownian diffusion. However, near terminal velocity, Brownian diffusion theory did not account for the results. Instead, for each value of particle radius α , the collection efficiency was a sharply increasing function of the impaction parameter P . Results by other workers for particles of different density agreed approximately with our values, provided comparisons were made at the same values of $\alpha \rho^{1/2}$, where ρ is the particle density.

Calculations of washout coefficient indicated that the half-life of 0.1- μ m aerosol particles is of the order of one day for moderate rainfall rates. However, this result is strongly dependent upon the particular rain-drop size distribution.

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SUMMARY

The primary event in the removal of atmospheric aerosol by precipitation is either rainout, in which the aerosol particle attaches itself to a cloud drop, or washout, in which the attachment is to a falling raindrop. The mechanism is complicated. The uptake of aerosol particles by cloud drops may be due to 1) particles having been incorporated into the drops as condensation nuclei, 2) Brownian diffusion, or 3) the movement of particles due to water vapor gradients (Facy effect).

For washout, it is first necessary to characterize the fluid flow around the falling raindrop and then to estimate the trajectory of the aerosol particle through the flow field. The ideal flow fields for rigid spheres may be deformed somewhat due to internal circulation as well as flattening of larger drops. The result is expressed as the collection efficiency, which is the fraction of particles within the trajectory of the falling drop that is actually captured.

It is convenient to conceive the collection occurring as a result of (i) direction interception, (ii) inertial impaction, (iii) Brownian diffusion, (iv) thermophoresis, and (v) diffusiophoresis. Actually, these processes are all coupled, although one or more of them may predominate for various regimes of particle size, drop size, particle density, hydrodynamic field, temperature field, and diffusion field. The analysis is usually only applied to the upstream side of the drop, since the effect of the wake on the downstream side is still open to speculation. There is also the question of the coalescence efficiency, the probability that an encounter of a particle with a drop will result either in penetration or sticking to the surface. And finally, there is the influence of electrical charge on the drop, on the particle, or on both. Indeed, for all of this, theory can hardly be expected to provide successful prediction of particulate washout.

There have been many field data published on the concentration of admixtures in precipitation, but these have not been particularly helpful in elucidating the primary scavenging mechanisms. The concentrations are present as a result of complicated processes both of rainout and washout, and involve the size spectrum of the cloud droplets, the raindrops and the aerosol particles, as well as the variety of meteorological parameters which are hardly ever well defined for any particular field observation. It is a gross understatement to suggest that attempts to infer a model for scavenging from such data are, at best, precarious.

There is a need for accurate predictions of washout of particulates by detailed laboratory measurements of collection efficiencies with respect to both particle size and drop size. Inertial impaction predominates for particle radii $> 1 \mu\text{m}$, and the few experimental efforts have concentrated upon this upper range of size (Richardson, 1960). Efforts in the submicron range, where Brownian diffusion might be expected to play a role, have been more recent, but these have been sparse (Engelmann and Slinn, 1970).

Our own work is directed to the $0.1\text{-}\mu\text{m}$ particle size range. It is characterized by an ability to prepare stable aerosols of remarkably uniform, spherical silver chloride particles, whose size distribution is determined quite accurately by light scattering and which can be chemically analyzed using a highly sensitive colorimetric technique.

Collection efficiencies of falling water drops ranging from 0.094 to 0.254 cm in radius for silver chloride aerosol particles in nitrogen ranging from 0.15 to 0.6 μm in radius have been measured. The drops accelerated for distances ranging from 30 to 515 cm prior to entrance into the scavenging chamber. Results were extrapolated to terminal velocity.

The results for the slower moving drops (30 cm acceleration distance) agreed roughly with the predictions of a theory based upon collection by Brownian diffusion. However, near terminal velocity, Brownian diffusion theory did not account for the results. Instead, for each value of particle radius α , the collection efficiency was a sharply increasing function of the impaction parameter P . Results by other workers for particles of different density agreed approximately with our values, provided comparisons were made at the same values of $\alpha\rho^{\frac{1}{2}}$, where ρ is the particle density.

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LIST OF PUBLICATIONS AND REPORTS

Previously Submitted

Renewed Proposal 5/1/71-4/30/72

NYO-3847-2 Progresss Report--Studies on Colloidal Particles;
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