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A Method for Measuring Particle Diffusivity in Two-Phase Flow in the Core of a Duct

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A relatively simple, reliable means is described for measuring particle diffusivity in a particle-fluid system in the core of a duct. Particles are injected into the midstream of the duct from a line source positioned normal to the direction of fluid flow. Particle diffusivity is calculated from measurements of the standard deviations of the particle concentration profiles at various downstream distances from the injector. At an air velocity of 10 ft./sec. under room conditions, 1μ oil droplets are found to exhibit a diffusivity of about half that of air alone under the same conditions.

Whenever the diffusion equation is used to describe the behavior of the particle phase of a system in two-phase flow, knowledge of the particle diffusivity, as opposed to the fluid diffusivity, is required. Recent attempts to apply diffusion theory to electrostatic precipitation (*1, 2*) for example, have raised serious doubts regarding the legitimacy of employing the known eddy diffusivities for fluids as reasonable approximations to particle diffusivities, even when the particles in question are of 0.9 specific gravity and as small as 1μ in mean size.

Considerable effort has been expended in determining the diffusivity of particles small enough to be sensibly affected by Brownian motion (*3*). However, comparatively little diffusivity data are available in the case of those larger particles for which eddy turbulence provides the dominant diffusive mechanism. The work of Soo, Ihrig, and el Kouh, in this connection, is noteworthy (*4*). By using stroboscopic illumination, these authors observed the paths of glass microbeads suspended in a turbulent air stream, and on this basis calculated the standard deviation, σ, of the average transverse particle displacement as a function of time, t. The particle diffusivity, D, was then found for large t, from the relation

$$D = \frac{1}{2} \frac{d}{dt} \sigma^2 \qquad (1)$$

The foregoing technique yields useful results. It is, however, subject to the disadvantage of instrumentational complexity, requiring an audio oscillator, electronic counter, multiple timer, camera, photodensitometer, and other equipment.

DIFFUSIVITY BY CONCENTRATION-PROFILE ANALYSIS

Experimental Method

The much simpler method presented here for measuring particle diffusivity is modeled after the wellknown technique of observing the rate of dispersion of a tracer fluid to determine the eddy diffusivity of its carrier fluid (*4*). In the present modification, particles whose diffusivity is to be established are introduced isokinetically through a tube or slit into the core of the duct in question. Particle-concentration profiles are then isokinetically measured by traversing the duct cross section at various downstream distances from the particle injector. Assuming turbulence that is small-scale and homogeneous, and particles of reasonable uniformity, normal-distribution profiles result, whence particle diffusivity is directly calculable from Equation (1).

The experimental arrangement used in this laboratory is shown schematically in Figure 1. Oil mist having particles of log mean diameter 1.0μ and log standard deviation 2.1 is generated by means of nozzle atomization. An automatic traversing sampler probe feeds a light-scattering

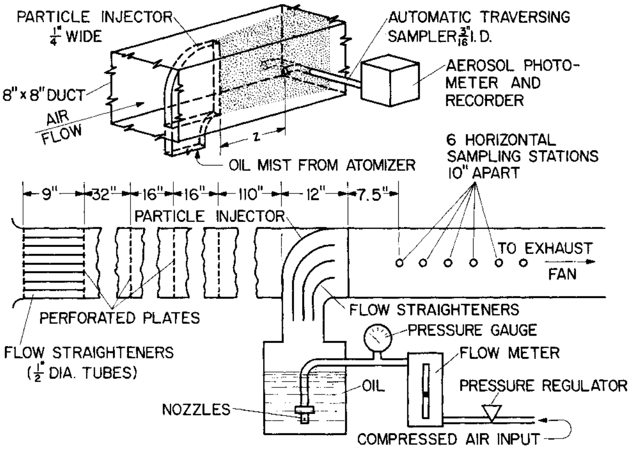

Fig. 1. Experimental duct with oil-mist generating, injecting, and sampling equipment.

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photometer (5), the output of which yields a recording of particle concentration vs. position in the duct cross section. Two perforated plates are mounted at the duct entrance, and three others are in downstream positions as shown. The latter three plates are removable; all are 50% open with ⅛ in. perforations.

Experimental Results

Typical experimental results appear in Figures 2, 3, and 4 showing, respectively, a particle concentration profile, the corresponding cumulative distribution curve, and a plot of the variance σ^2 vs. $t = z/v$, where z is the downstream distance from the particle injector and v is the average axial gas velocity. Measurements were confined to the central two-thirds of the duct over which v and D were considered to be approximately constant.

Table 1 compares three eddy diffusivities measured at room conditions in the duct of Figure 1. The average gas velocity was 10 ft./sec. in all cases.

The eddy diffusivity of particle-free air (Test 1) was measured using helium as a tracer gas (4, 6). A thermal-conductivity detector replaced the aerosol photometer employed in Tests 2 and 3, and so enabled helium-concentration profiles to be obtained.

Since this study is concerned solely with developing an experimental technique for measuring the diffusivity of particles, data other than that required to illustrate the utility of the method are not reported.

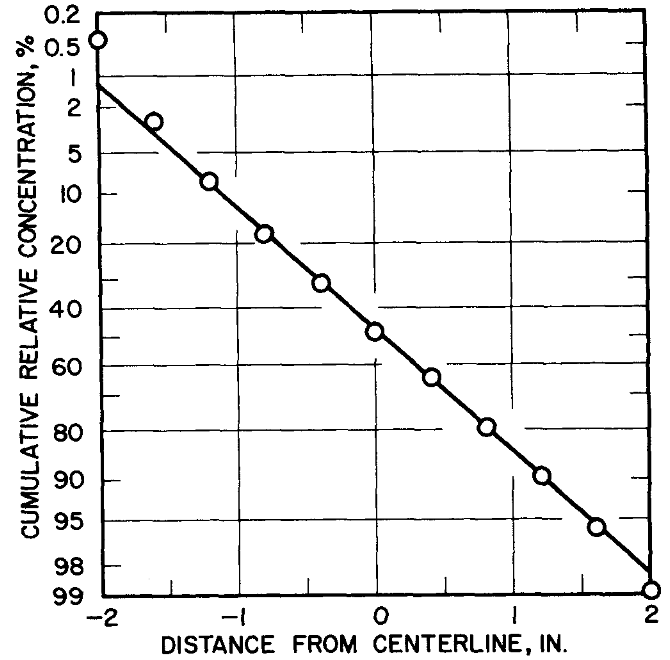

Fig. 3. The cumulative distribution curve for the particle-concentration profile of Figure 2. The above curve shows the percentage of the area under the normal curve of Figure 2, that is to the left of a given value of the abscissa. The standard deviation σ (here 0.91 in.) is the interval on the abscissa corresponding to the difference between 50 and 84% on the ordinate.

TABLE 1.

Test	Type	Technique	Perforated plates	Diffusivity
1	room air	He-tracer method	first two	11×10^{-3} sq. ft./sec.
2	oil mist	this method	first two	6.0×10^{-3} sq. ft./sec.
3	oil mist	this method	all five	3.6×10^{-3} sq. ft./sec.

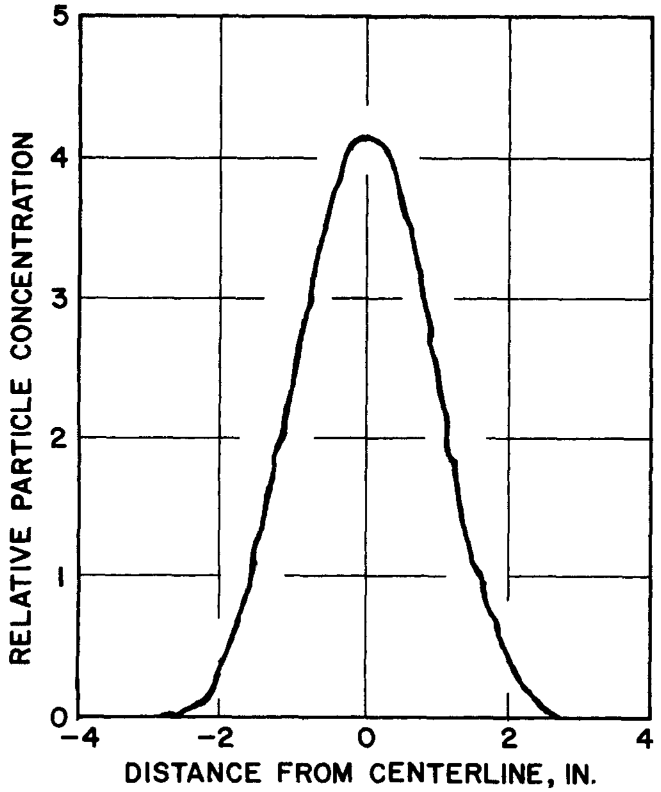

Fig. 2. A typical particle-concentration profile for 1μ oil-fume particles in an 8 in. square duct. The air velocity v was 10 ft./sec. and the wall-to-wall sampling traverse was taken at distance z = 57.5 in. downstream of the particle injector.

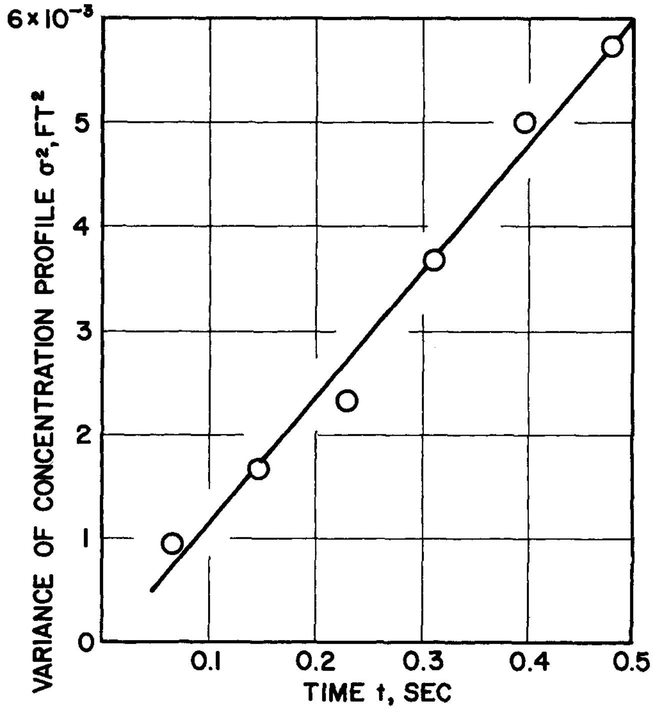

Fig. 4. The variance of the concentration profile σ^2 in terms of the transit time t between particle injector and sampler. At gas velocity v of 10 ft./sec., the position z of the sampler was varied from 7.5 to 57.5 in. downstream of the injector. The uppermost point plotted above is derived from Figure 3. The diffusivity D is given by the above graph and Equation (1) as 6.0×10^{-3} sq. ft./sec.

DISCUSSION

The tabulated results indicate, perhaps surprisingly, that oil mist particles of mean size as low as 1μ exhibit a diffusivity that is only about half that for air alone in the same duct. An increase in the number of perforated plates may plausibly be expected to reduce the scale of turbulence, hence the diffusivity. Indeed, five plates in place of the original two are observed to lower the oil-mist diffusivity further by 40%.

The question of whether the oil mist particles lowered the diffusivity of the air has not been considered. The matter could be readily resolved by simultaneous injection and traversing of helium and particles. We note, however, Soo's finding that with glass beads of diameter below 250μ and loadings of less than 0.06 lb. of solid/lb. of air, the stream turbulence was not significantly affected by the presence of the particles (*4*). The present oil mist concentration at the injector slit was 0.004 lb. of oil/lb. of air.

Various modifications of the described experimental procedure are possible whereby the available ranges of particle size and density may be substantially increased. Thus, the optical density probe described by Soo, et al. (*7*, *8*) can be used in connection with glass microbeads at least as large as 80μ in diameter. Radioactive particles also suggest themselves in this application, the advantage of these being that they will give an indication of concentration dependent on particle mass rather than area as in the optical case.

Although the above considerations have been confined to a particulate-gas system, they are equally applicable to a particulate-liquid system, appropriate changes being made in the instrumentation.

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NOTATION

D = diffusivity, sq.ft./sec.
t = transit time between injector and sampler, sec.
v = average axial gas velocity, ft./sec.
z = distance between injector and sampler
σ = standard deviation of concentration profile, ft.

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Effects of Surfactants on Mass Transfer Inside Drops

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A model is presented to account for reduced mass transfer to drops falling through a continuous phase which contains a surface active agent. The fluid flow patterns are essentially laminar. The reduction in mass transfer is said to be due to a reduction in available interfacial transfer area and to changes in both velocity and pattern of internal circulation. These are shown to be functions of contact time and can be characterized. Experimental values agreed with the theoretically predicted ones with a deviation of less than 10%.

The transfer of heat, mass, and momentum between a continuous phase and drops of a dispersed phase is important in numerous industrial operations. Fractionation, liquid-liquid extraction, and two-phase reactions are common examples. The operations employ streams or clouds of drops, but a fundamental understanding of the effect of each variable on the behavior of a single drop is necessary for an understanding of the performance of multidrop systems. Many investigators have studied various aspects of the transfer mechanism and drop mechanics involved in

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