Drop Breakup in Turbulent Pipe Flow

G. A. HUGHMARK

Ethyl Corporation, Baton Rouge, Louisiana

The forces controlling drop deformation and breakup have been analyzed by Hinze (*1*). He proposes that three forces per unit area control this deformation and breakup, as

$$\tau, \frac{\sigma}{D}, \frac{\mu_d}{D}\sqrt{\frac{\tau}{\rho_d}}$$

τ is the external force per unit of surface area which acts to deform the drop, and it may be a viscous stress or a dynamic pressure resulting from the continuous phase. The second group represents the surface force that counteracts the deformation, and the third group represents the viscous stresses in the drop. Hinze combined these forces into dimensionless groups and analyzed the limited experimental data for drop breakup that were available at that time.

Sleicher (*2*) and Paul and Sleicher (*3*) have reported experimental data for the maximum stable drop size for two immiscible liquids flowing in a pipe. Two pipe diameters were used and a range of physical properties are represented by the liquids. The continuous phase was in turbulent flow. A small volume fraction of the dispersed phase was used so that coalescence was negligible. These data are of interest because the turbulence properties of pipe flow are well known.

The forces proposed by Hinze can be combined so that the external force equals the sum of the surface force and the viscous stresses of the drop

$$\tau = \frac{\sigma}{D} + \frac{\mu_d}{D}\sqrt{\frac{\tau}{\rho_d}} \tag{1}$$

The dynamic pressure of fluid flow is ρv^2 and, for turbulent flow, the fluctuating velocity may represent the effective velocity if the drop size is large in comparison to the scale of the energy containing eddies. For pipe flow, v_i is approximately 1.3 u^* so Equation (1) becomes

$$1.69\, u^{*2} \rho_c = \frac{\sigma}{D} + 1.3\frac{\mu_d}{D} u^* \sqrt{\frac{\rho_c}{\rho_d}} \tag{2}$$

The drop breakup data for turbulent pipe flow then provide a test of Equation (2). Figure 1 shows the data for the two pipe sizes and the range of physical properties represented by the experimental data. The viscous stress group accounts for a maximum of about 10% of the total force. Equation (2) appears to give a reasonable fit with the experimental data.

An estimate of the scale of the energy-containing eddies can be obtained for the turbulent core of pipe flow from the work of Becker, Rosensweig, and Gwozdz (*4*). Their data indicate that

$$\epsilon = \mathcal{L}_L v_i = \frac{2au_c}{852} \tag{3}$$

Laufer's data (*5*) for the core show $v_i = 0.8\, u^*$. Substitution in Equation (3) yields

$$\mathcal{L}_L = \frac{2a\, u_c^+}{680} \tag{4}$$

The Sleicher data correspond to $u_c^+ \approx 19$, and the Lagrangian integral scales are estimated to be 0.11 cm. for the 1.5-in. pipe and 0.036 cm. for the 0.5-in. pipe. All experimental maximum drop sizes are larger than these estimated scales so the drop diameters do appear to be large in comparison to the scales of the energy containing eddies.

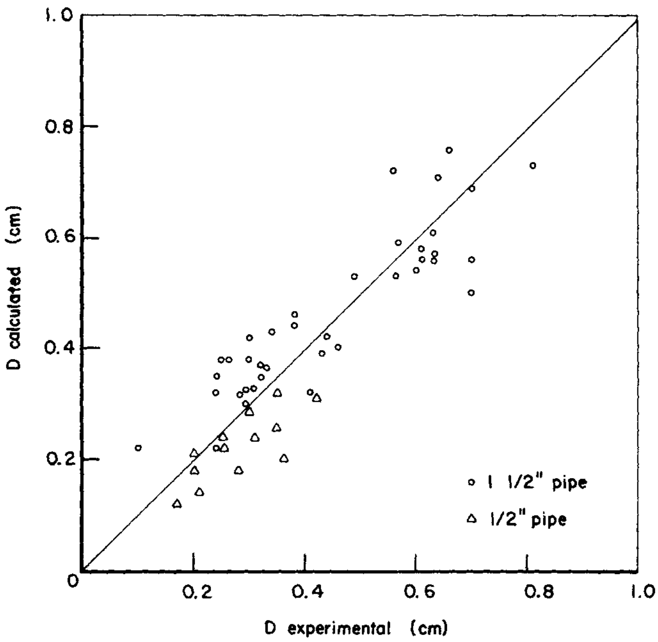

Fig. 1. Drop breakup data for two pipe sizes over a range of physical properties.

NOTATION

- a = pipe radius
- D = maximum drop diameter
- $\mathcal{L}_L$ = Lagrangian integral scale
- u^* = friction velocity
- u_c = centerline axial velocity
- u_c^+ = u_c/u^*
- v = velocity
- v_i = fluctuating velocity
- ϵ = total diffusivity
- μ = viscosity
- ρ = density
- σ = interfacial tension
- τ = surface force per unit area

Subscripts

- c = continuous phase
- d = dispersed phase

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