Spray Formation by Wind Shear

In annular flows in vertical pipes, the mass of liquid carried as droplets in the gas core is often substantial. Consequently considerable effort has been devoted to studies of the entrainment of droplets from the liquid layer on the pipe wall (Butterworth and Hewitt, 1977, Whalley 1987). In many annular flows the droplet concentration in the gas core increases with elevation as illustrated in figure 1.

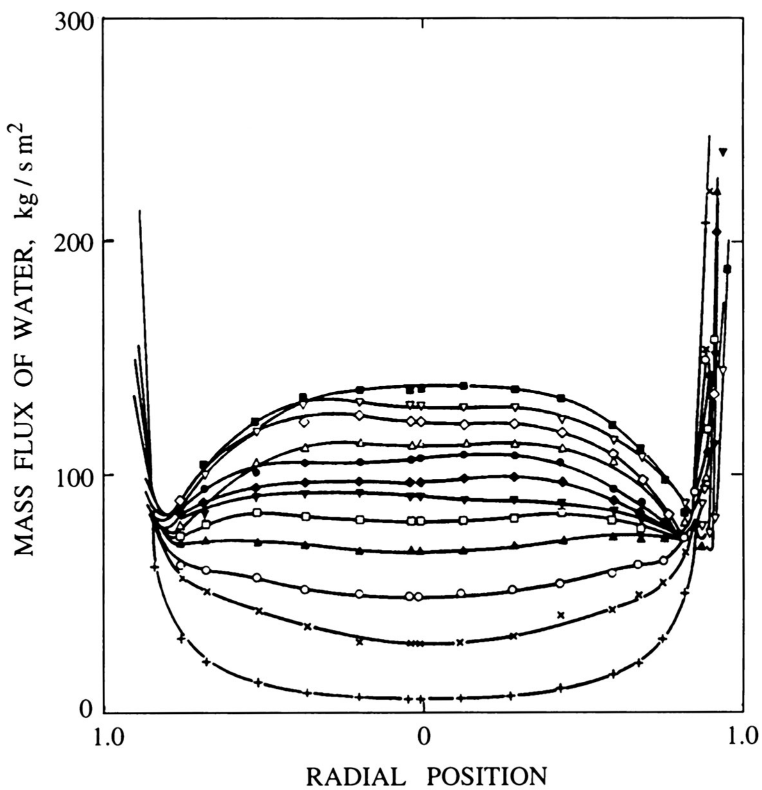

Figure 1: Droplet concentration profiles in the gas core of a vertical annular pipe flow (3.2cm diameter) illustrating the increase with elevation from initiation (lowest line, 15cm elevation; uppermost line, 531cm elevation) (from Gill *et al.* 1963).

In steady flow, the mass flux of droplets entrained into the gas core, G_L^E should be balanced by the mass flux of deposition of droplets onto the wall liquid layer, G_L^D. Hutchinson and Whalley (1973) observe that droplets are torn from the liquid surface when the wind shear creates and then fractures a surface wave as sketched in figure 2. They suggest that the velocity of ejection of the droplets is related to the friction velocity, $u^* = (\tau_i/\rho_L)^{\frac{1}{2}}$, where τ_i is the interfacial stress and that the entrainment rate, G_L^E, therefore correlates with $(\tau_i\delta/S)^{\frac{1}{2}}$, where δ is the mean liquid layer thickness. They also speculate that the mass deposition rate must be proportional to the core droplet mass concentration, $\rho_L\alpha_L$. As shown in figure 3, the experimental measurements of the concentration do, indeed, appear to correlate with $(\tau_i\delta/S)^{\frac{1}{2}}$ (a typical square root dependence is shown by the solid line in the figure).

McCoy and Hanratty (1977) review the measurements of the deposition mass flux, G_L^D, and the gas core concentration, $\rho_L\alpha_L$, and show that the dimensionless deposition mass transfer coefficient, $G_L^D/\rho_L\alpha_L u^*$, correlates with a dimensionless relaxation time for the droplets defined by $D^2\rho_L\rho_G u^{*2}/18\mu_G^2$. This corre-

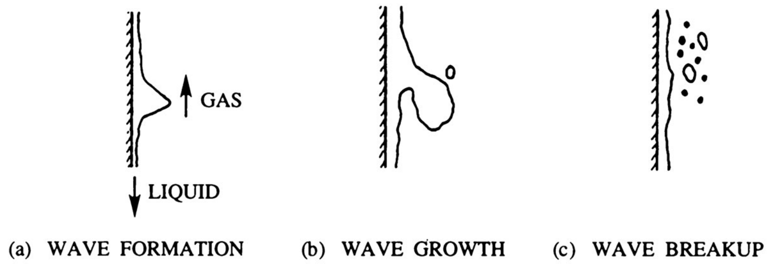

Figure 2: Sketch illustrating the ejection of droplets by wind shear in annular flow in a vertical pipe. From Hutchinson and Whalley (1973).

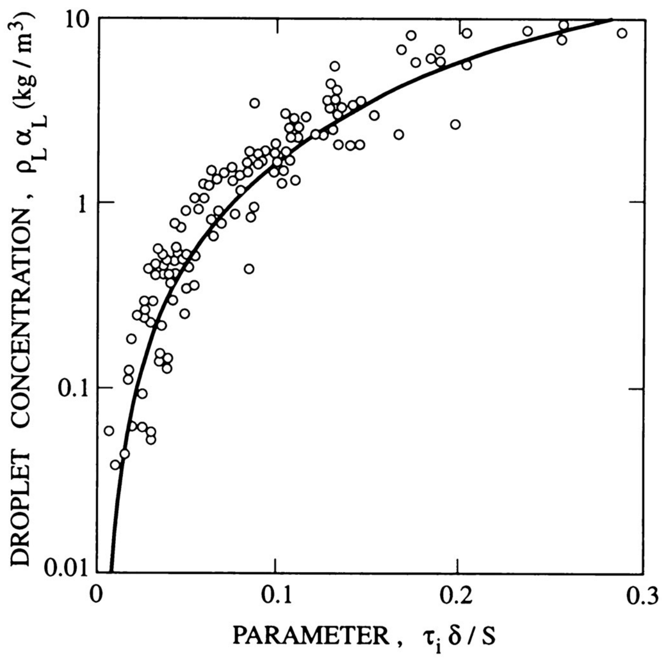

Figure 3: The mass concentration of liquid droplets in the gas core of an annular flow, $\rho_L \alpha_L$, plotted against $\tau_i \delta / S$. From Hutchinson and Whalley (1973).

lation is shown in figure 4 and, for a given u^*, can also be considered as a graph with the resulting droplet size, D (or rather its square), plotted horizontally; typical droplet sizes are shown in the figure.

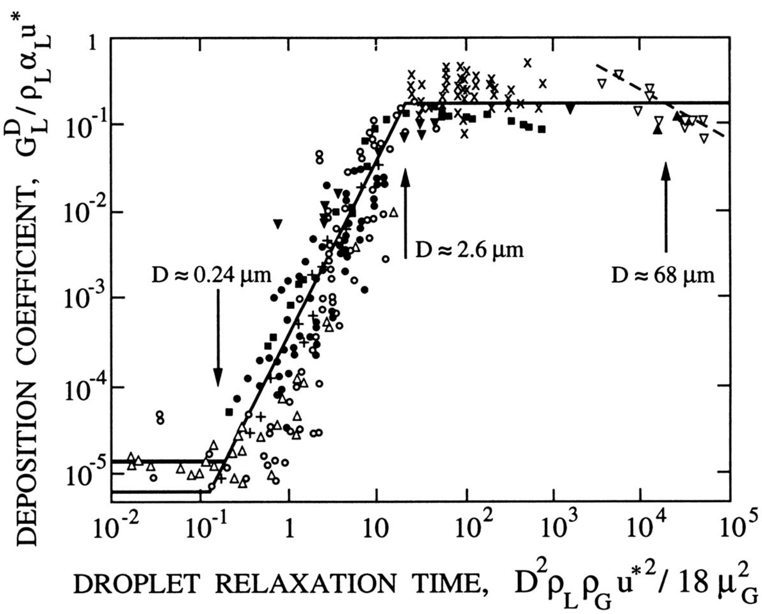

Figure 4: The dimensionless deposition mass transfer coefficient, $G_L^D/\rho_L \alpha_L u^*$, for vertical annular flow plotted against a dimensionless relaxation time for the droplets in the core, $D^2 \rho_L \rho_G u^{*2}/18\mu_G^2$. A summary of experimental data compiled by McCoy and Hanratty (1977).