

## Vertical Flow Friction

As indicated by the flow regimes of section (Njb), vertically-oriented pipe flow can experience partially separated flows in which large relative velocities develop due to buoyancy and the difference in the densities of the two-phases or components. These large relative velocities complicate the problem of evaluating the pressure gradient. In the next section we describe the traditional approach used for separated flows in which it is assumed that the phases or components flow in separate but communicating streams. However, even when the multiphase flow has a solid particulate phase or an incompletely separated gas/liquid mixture, partial separation leads to friction factors that exhibit much larger values than would be experienced in a homogeneous flow. One example of that in horizontal flow was described in section (Nkb). Here we provide an example from vertical pipe flows. Figure 1 contains friction factors (based on the total volumetric flux and the liquid density) plotted against Reynolds number for the flow of air bubbles and water in a 10.2cm vertical pipe for three ranges of void fraction. Note that these are all much larger than the single phase friction factor. Figure 2 presents further details from the same experiments, plotting the ratio of the frictional pressure gradient in the multiphase flow to that in a single phase flow of the same liquid volumetric flux against the volume quality for several ranges of Reynolds number. The data shows that for small volume qualities the friction factor can be as much as an order of magnitude larger than the single phase value. This substantial effect decreases as the Reynolds number increases and also decreases at higher volume fractions. To emphasize the importance of this phenomenon in partially separated flows, a line representing the Lockhart-Martinelli correlation for fully separated flow (see section (Nkf)) is also included in figure 2. As in the case of partially separated horizontal flows discussed in section (Nkb), there is, as yet, no convincing explanation of the high values of the friction at lower Reynolds numbers. But the effect seems to be related to the large unsteady motions caused by the presence of a disperse phase of different density and the effective stresses (similar to Reynolds stresses) that result from the inertia of these unsteady motions.

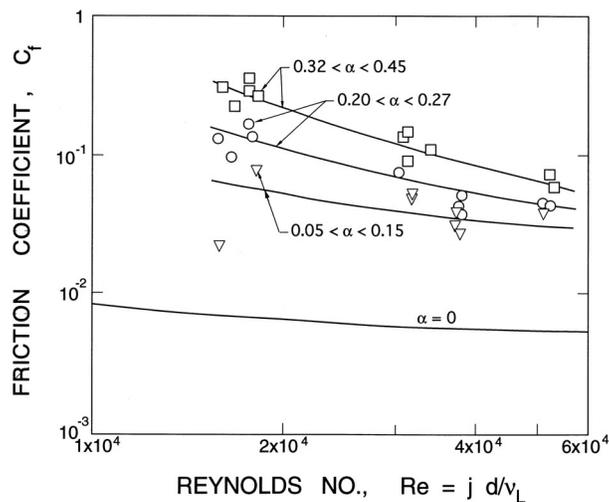


Figure 1: Typical friction coefficients (based on total volumetric flux and the liquid density) plotted against Reynolds number (based on the total volumetric flux and the liquid viscosity) for the flow of air bubbles and water in a 10.2cm vertical pipe flow for three ranges of air volume fraction,  $\alpha$ , as shown (Kytömaa 1987).

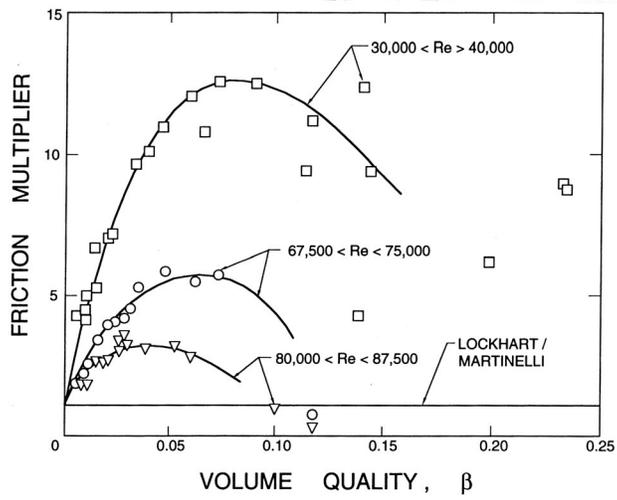


Figure 2: Typical friction multiplier data (defined as the ratio of the actual frictional pressure gradient to the frictional pressure gradient that would occur for a single phase flow of the same liquid volume flux) for the flow of air bubbles and water in a 10.2cm vertical pipe plotted against the volume quality,  $\beta$ , for three ranges of Reynolds number as shown (Kytömaa 1987).