Vertical Pipe Flow

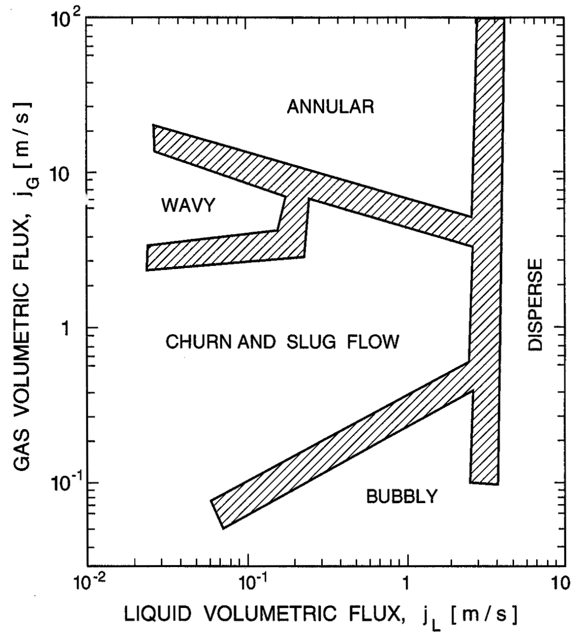

Figure 1: A flow regime map for the flow of an air/water mixture in a vertical, $2.5cm$ diameter pipe showing the experimentally observed transition regions hatched; the flow regimes are sketched in figure 2. Adapted from Weisman (1983).

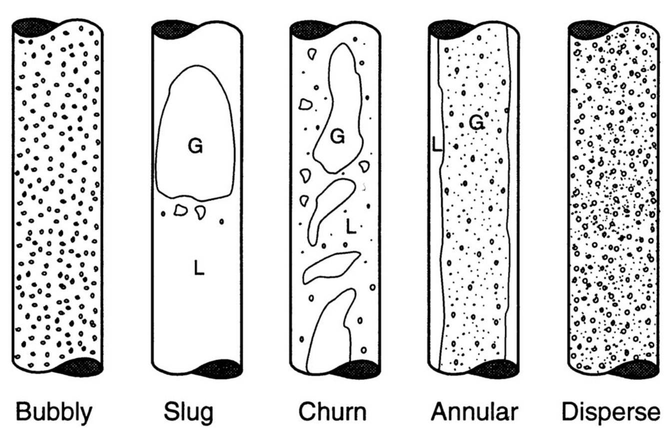

Figure 2: Sketches of flow regimes for two-phase flow in a vertical pipe. Adapted from Weisman (1983).

When the pipe is oriented vertically, the regimes of gas/liquid flow are a little different as illustrated in figures 1 and 2 (see, for example, Hewitt and Hall Taylor 1970, Butterworth and Hewitt 1977, Hewitt 1982, Whalley 1987). Another vertical flow regime map is shown in figure 3, this one using momentum flux axes rather than volumetric or mass fluxes. Note the wide range of flow rates in Hewitt and Roberts (1969) flow regime map and the fact that they correlated both air/water data at atmospheric pressure and steam/water flow at high pressure.

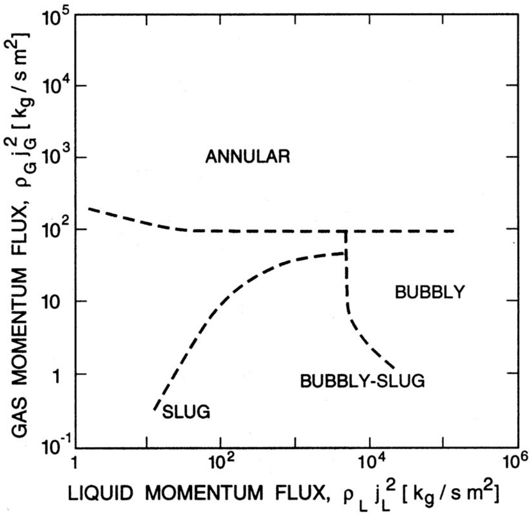

Figure 3: The vertical flow regime map of Hewitt and Roberts (1969) for flow in a 3.2cm diameter tube, validated for both air/water flow at atmospheric pressure and steam/water flow at high pressure.

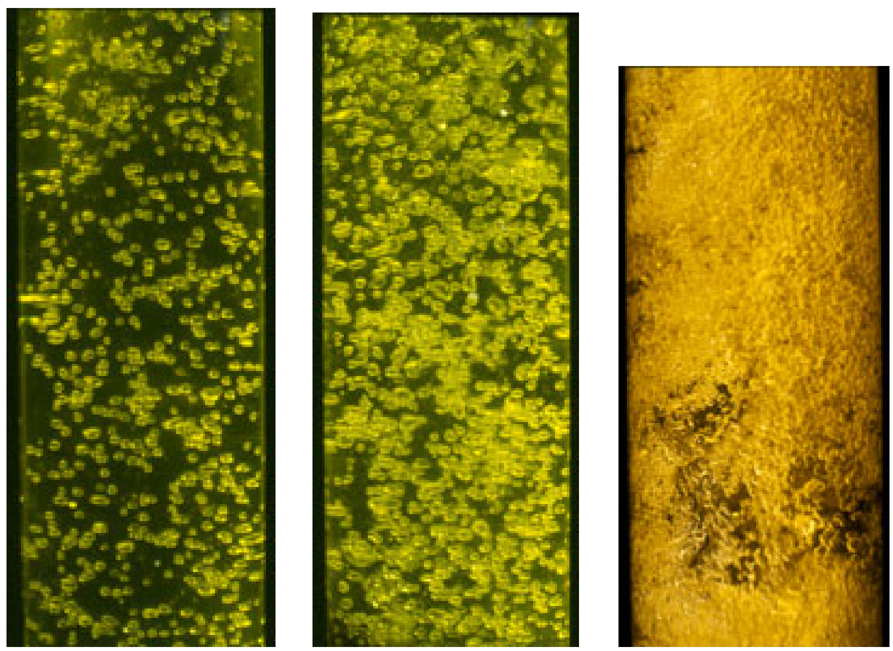

Figure 4: Photographs of air/water flow in a 10.2cm diameter vertical pipe (Kytömaa 1987). Left: 1% air; middle: 4.5% air; right: $> 15\%$ air.

Typical photographs of vertical gas/liquid flow regimes are shown in figure 4. At low gas volume fractions of the order of a few percent, the flow is an amalgam of individual ascending bubbles (left photograph). Note that the visual appearance is deceptive; most people would judge the volume fraction to be significantly larger than 1%. As the volume fraction is increased (the middle photograph has $\alpha = 4.5\%$), the flow becomes unstable at some critical volume fraction which in the case illustrated is about 15%. This instability produces large scale mixing motions that dominate the flow and have a scale comparable to the pipe diameter. At still larger volume fractions, large unsteady gas volumes accumulate within these mixing motions and produce the flow regime known as churn-turbulent flow (right photograph).

It should be added that flow regime information such as that presented in figure 1 appears to be valid both for flows that are not evolving with axial distance along the pipe and for flows, such as those in boiler

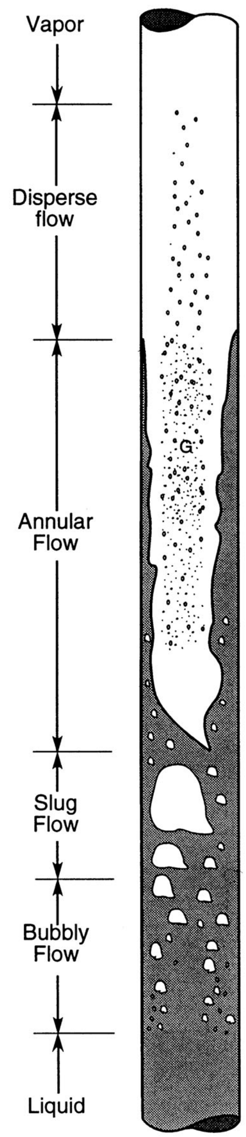

Figure 5: The evolution of the steam/water flow in a vertical boiler tube.

tubes, in which the volume fraction is increasing with axial position. Figure 5 provides a sketch of the kind of evolution one might expect in a vertical boiler tube based on the flow regime maps given above. It is interesting to compare and contrast this flow pattern evolution with the inverted case of convective boiling surrounding a heated rod in section (Nif).