Examples of Flow-determined Bubble Size

An example of the use of the above relations can be found in the important area of two-phase pump flows and we quote here data from studies of the pumping of bubbly liquids. The issue here is the determination of the volume fraction at which the pump performance is seriously degraded by the presence of the bubbles. It transpires that, in most practical pumping situations, the turbulence and shear at inlet and around the leading edges of the blades of the pump (or other turbomachine) tend to fission the bubbles and thus determine the size of the bubbles in the blade passages. An illustration is included in figure 1 which shows an air/water mixture progressing through an axial flow impeller; the bubble size downstream of the inlet plane is much smaller that that approaching the impeller.

The size of the bubbles within the blade passages is important because it is the migration and coalescence of these bubbles that appear to cause degradation in the performance. Since the velocity of the relative motion depends on the bubble size, it follows that the larger the bubbles the more likely it is that large voids will form within the blade passage due to migration of the bubbles toward regions of lower pressure (Furuya 1985, Furuya and Maekawa 1985). As Patel and Runstadler (1978) observed during experiments on centrifugal pumps and rotating passages, regions of low pressure occur not only on the suction sides of the blades but also under the shroud of a centrifugal pump. These large voids or gas-filled wakes can cause substantial changes in the deviation angle of the flow leaving the impeller and hence lead to substantial degradation in the pump performance.

The key is therefore the size of the bubbles in the blade passages and some valuable data on this has been compiled by Murakami and Minemura (1977, 1978) for both axial and centrifugal pumps. This is summarized in figure 2 where the ratio of the observed bubble size, R_m, to the blade spacing, h, is plotted against the Weber number, $We = \rho_C U^2 h/S$ (U is the blade tip velocity). Rearranging the first version of equation (Njh1), estimating that the inlet shear is proportional to U/h and adding a proportionality constant, C, since the analysis is qualitative, we would expect that $R_m = C/We^{\frac{1}{3}}$. The dashed lines in

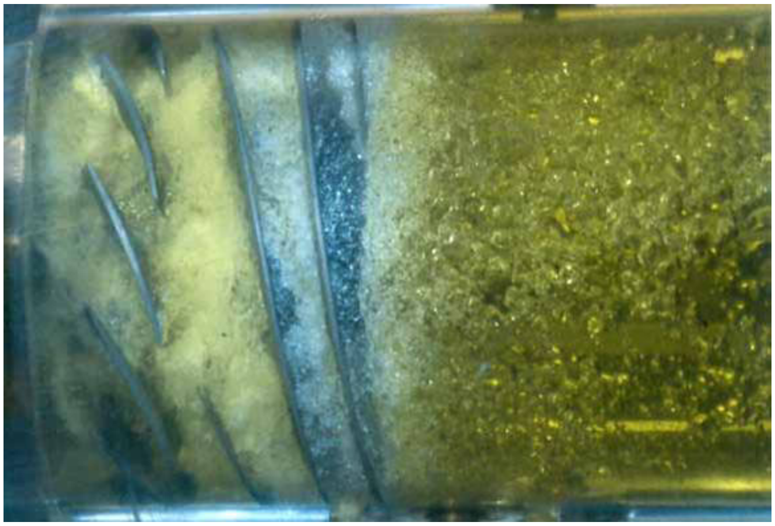

Figure 1: A bubbly air/water mixture (volume fraction about 4%) entering an axial flow impeller (a 10.2cm diameter scale model of the SSME low pressure liquid oxygen impeller) from the right. The inlet plane is roughly in the center of the photograph and the tips of the blades can be seen to the left of the inlet plane.

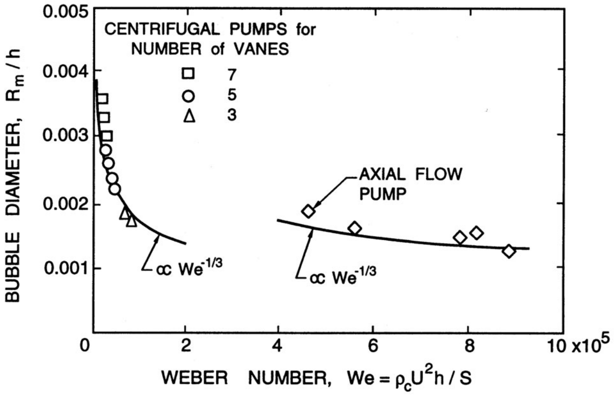

Figure 2: The bubble sizes, R_m, observed in the blade passages of centrifugal and axial flow pumps as a function of Weber number where h is the blade spacing (adapted from Murakami and Minemura 1978).

Figure 3: Traveling bubble cavitation on the surface of a NACA 4412 hydrofoil at zero incidence angle, a speed of 13.7 m/s and a cavitation number of 0.3. The flow is from left to right, the leading edge of the foil is just to the left of the white glare patch on the surface, and the chord is 7.6cm (Kermeen 1956).

figure 2 are examples of this prediction and exhibit behavior very similar to the experimental data. In the case of the axial pumps, the effective value of the coefficient, $C = 0.15$.

A different example is provided by cavitating flows in which the highest shear rates occur during the collapse of the cavitation bubbles. As discussed in section (Nhd), these high shear rates cause individual cavitation bubbles to fission into many smaller fragments so that the bubble size emerging from the region of cavitation bubble collapse is much smaller than the size of the bubbles entering that region. The phenomenon is exemplified by figure 3 which shows the growth of the cavitating bubbles on the suction surface of the foil, the collapse region near the trailing edge and the much smaller bubbles emerging from the collapse region. Some analysis of the fission due to cavitation bubble collapse is contained in Brennen (2002).