Concentration Waves

There is one phenomenon that is sometimes listed in discussions of multiphase flow instabilities even though it is not, strictly speaking, an instability. We refer to the phenomenon of concentration wave oscillations and it is valuable to include mention of the phenomenon here before proceeding to more complex matters.

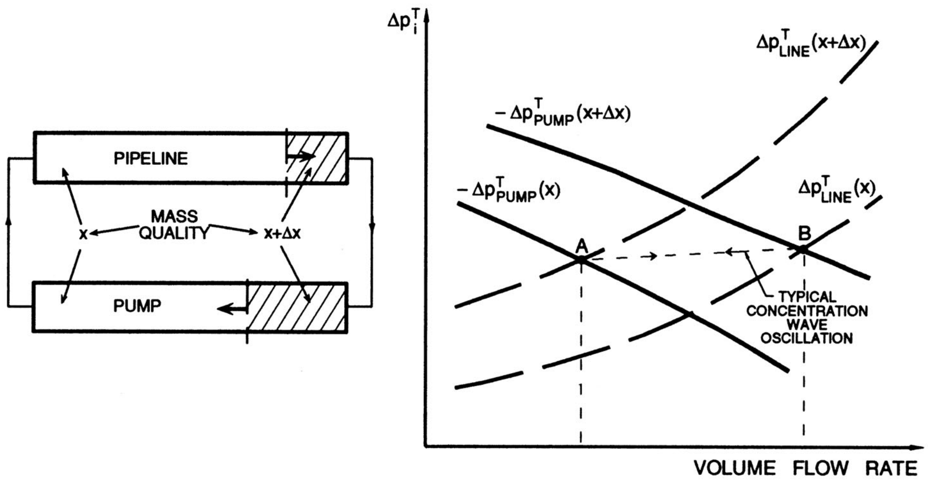

Figure 1: Sketch illustrating a concentration wave (density wave) oscillation.

Often in multiphase flow processes, one encounters a circumstance in which one part of the circuit contains a mixture with a concentration that is somewhat different from that in the rest of the system. Such an inhomogeneity may be created during start-up or during an excursion from the normal operating point. It is depicted in figure 1, in which the closed loop has been arbitrarily divided into a *pipeline* component and a *pump* component. As indicated, a portion of the flow has a mass quality that is larger by $\Delta\mathcal{X}$ than the mass quality in the rest of the system. Such a perturbation could be termed a concentration wave though it is also called a density wave or a continuity wave; more generally, it is known as a kinematic wave (see sections (Ns)). Clearly, the perturbation will move round the circuit at a speed that is close to the mean mixture velocity though small departures can occur in vertical sections in which there is significant relative motion between the phases. The mixing processes that would tend to homogenize the fluid in the circuit are often quite slow so that the perturbation may persist for an extended period.

It is also clear that the pressures and flow rates may vary depending on the location of the perturbation within the system. These fluctuations in the flow variables are termed concentration wave oscillations and they arise from the inhomogeneity of the fluid rather than from any instability in the flow. The characteristic frequency of the oscillations is simply related to the time taken for the flow to complete one circuit of the loop (or some multiple if the number of perturbed fluid pockets is greater than unity). This frequency is usually small and its calculation often allows identification of the phenomenon.

One way in which concentration oscillations can be incorporated in the graphical presentation we have used in this chapter is to identify the component characteristics for both the mass quality, $\mathcal{X}$, and the perturbed quality, $\mathcal{X}+\Delta\mathcal{X}$, and to plot them using the volume flow rate rather than the mass flow rate as the abscissa. We do this because, if we neglect the compressibility of the individual phases, then the volume flow rate is constant around the circuit at any moment in time, whereas the mass flow rate differs according to the mass quality. Such a presentation is shown in figure 1. Then, if the perturbed body of fluid were wholly in the pipeline section, the operating point would be close to the point A. On the other hand, if the perturbed body of fluid were wholly in the pump, the operating point would be close to the point B. Thus we can see that the operating point will vary along a trajectory such as that shown by the dotted line and that this will result in oscillations in the pressure and flow rate.

In closing, we should note that concentration waves also play an important role in other more complex unsteady flow phenomena and instabilities.