FLOW PATTERN: FRIEND OR FOE?

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Two generic approaches may be recognised in the prediction of multiphase flows:

(1) The *empirical* approach in which data are collected and fitted by more or less arbitrary correlations which are then used for interpolation or (less securely) for extrapolation to predict practical cases.

(2) The *phenomenological* approach in which the physical nature of the flow (namely the *flow pattern*) is recognised and models are generated based on this recognition. The *multifluid models* can be regarded as a special case of the general class of the phenomenological models. A common feature of all this class of models is the need for *closure laws.* Such closure relationships have often to be based on experimental observations and this places a severe limit on their generality.

Though, for over 40 years, I have been a protagonist of the phenomenological approach, recent experiences have caused me to look again and to review the situation as I see it. It certainly does not follow that the phenomenological method will always give the best results and I will illustrate this point with some examples for steady state flows. For transient flows, the only viable approaches are to use the homogeneous model or the multifluid (phenomenological) model. But is it correct to use, within these multifluid transient models, closure laws that are (almost invariably) derived for the steady state? I fear not, as recent work at Imperial College has shown.

The first step in applying the phenomenological modelling approach is to identify the flow pattern. How good are we at this? Not very good, I am afraid! I will illustrate this by some examples, again from recent work at Imperial College. In the most widely investigated case of gas-liquid flows, the models currently used fail to predict effectively the effects of system variables such as pressure and viscosity. For liquid-liquid flows, there is a very significant effect of the channel wall material. Most experiments are done with transparent tubes (for the very good reason that it is always useful to see what is going on in the tube!). However, flow patterns in liquid-liquid flow can be significantly different in transparent plastic tubes to those in steel tubes. For the technically important case of three-phase gas-liquid-liquid flows, the flow patterns are extremely complex. The system behaviour is strongly affected by which of the two liquid phases is continuous. We are a long way from predicting such cases with any generality.

Mixing of the liquid phases in liquid-liquid and gas-liquid-liquid flows is of great significance in governing *in-situ* phase fraction (holdup) and pressure gradient. A crucial factor is *phase inversion* i.e. the transition from one liquid phase being continuous to the other being continuous. In an oil-water flow, at high enough velocity to cause inter-dispersion of the phases, the effective viscosity rises rapidly as the phase inversion point is approached on increasing the water fraction (water cut). This causes corresponding peaks in the liquid holdup and pressure gradient. A similar phenomenon occurs in three-phase flow. I shall illustrate these effects from recent Imperial College work including isokinetic probe studies of the mixing between oil and water phases in gas-liquid-liquid three phase stratified flows. The correct prediction of the mixing processes is essential in predicting system parameters. This presents a formidable challenge!

Most experimental work on two-phase gas-liquid flows is done at near-atmospheric conditions. The flows are complex and interesting enough without incurring the added cost of high-pressure loops and instrumentation. The models developed are often validated against near-atmospheric pressure data, though the models themselves may contain factors that would be influenced by pressure. Perhaps the most important effect of pressure is that on flow pattern transitions. I will present data for both horizontal and vertical flows that illustrate this pressure effect on the transitions. The results may sometimes be surprising! The effect of pressure on design parameters such as pressure drop is also illuminating. At constant phase superficial velocities, we find that the effect of pressure (i.e. gas density) on pressure gradient in slug flow is negligible over a very wide range of pressure. This would not be the case were the flow to be stratified. At low pressure, transition from stratified to slug flow gives a large increase in pressure gradient. This may not be the case at high pressure!

In the light of the existing uncertainties, where do we go from here? Of course, fundamental studies are of interest and importance but they are not likely to produce acceptable prediction methods in the foreseeable future. Perhaps a good way forward would be to be honest about the uncertainties and try to predict *worst case scenarios.* Thus, if the highest pressure drop occurs in a particular flow regime, then this should be used in the design rather than a lower one based on the *predicted* flow regime. This could produce less economic designs but the implemented systems would have better chance of success. Another way forward might be to set up *standard problems* relating various situations. These would form a benchmark for modelling. However, this approach should be followed cautiously. Models often turn out to be strangely flexible when faced with the challenge of predicting a given set of data!