OBJECTIVE CLASSIFICATION OF TWO-PHASE FLOW REGIMES

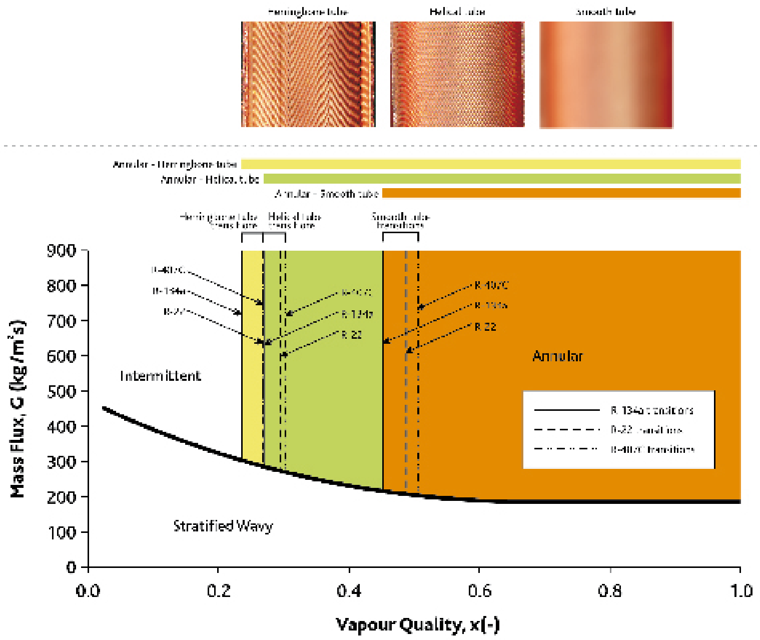
by Leon Liebenberg and Josua P Meyer

Vapour and liquid phases flow in horizontal tubes according to several topological configurations, called flow patterns or flow regimes that are determined by the interfacial structure between the two phases. The existence of a particular flow regime depends on a variety of parameters, including the thermophysical properties of the fluid, the tube diameter, orientation and geometry, force field, mass flux, heat flux and vapour quality.

Several researchers have shown that flow regimes influence the heat and momentum transfer processes during two-phase flow, inferring that any accurate prediction of heat transfer and pressure drop during condensation should be based on an analysis of the prevailing flow pattern. In addition, identification and modelling of the flow regime can enhance the overall performance and safety in two-phase flow systems.

Although a reliable, objective and quantitative instrumentation-based indicator of flow regime is desirable, definitions of flow regimes are usually based on visual (photographs or graphic illustrations) and linguistic descriptions, with a corresponding element of subjectivity.

The complex nature of two-phase flow, characterised by turbulence, deformable phase interface, phase interaction, phase slip and compressibility of the gas phase, makes it difficult to obtain reliable flow models. The drawback of previous techniques for flow regime identification is their lack of generality, as their ability to detect transitions depends on the specific heat exchanger and fluid used.



→ New flow regime map for refrigerants condensing inside smooth and micro-fin tubes. The map shows clearly how enhanced tubes delay the onset of intermittent flow, thus enhancing heat transfer compared to a smooth tube counterpart.

Flow regime identification can be performed either by visual inspection of the flow in a transparent section of the evaporator or condenser (which is inaccurate) or by measuring and quantifying the fluctuations of the flow parameters such as chordal void fraction or dynamic pressure (which is more accurate), reflecting the flow structure. The dynamic pressure signal is the more attractive option, as the measuring technique is simple, robust and relatively cheap. However, the main problem is that dynamic pressure is an energetic parameter, whose relation with the flow structure is not direct, since it results from numerous phenomena such as bubble passage.

By analysing the probability density function (PDF) or the power spectral density (PSD) function of the time-trace signal, the flow pattern recognition from the signal fluctuations can be performed. During such analyses, flow regimes are usually validated by means of high-speed photography or videography. The PSD technique reveals the energy distribution of the pressure signal in the frequency domain in a manner that is elegant and easy to interpret. The resonant frequency and PSD amplitude are interpretable in terms of hydrodynamic phenomena, such as rising, coalescence and exploding of gas bubbles, or the compression/expansion of vapour due to the dynamically changing vapour-liquid interface.

Some researchers have used fractal dimensions to analyse flow patterns, while others have shown the potential of applying artificial neural networks (ANNs) to avoid subjective judgements. The structure of ANNs enables them to model multiple complex non-linear problems that are poorly understood and/or too complex for accurate physical modelling. Other techniques include parametric modelling of time series, chaotic dynamics diagnosis and time-frequency analysis.

Despite these numerous attempts to unravel flow regime characteristics from the selected signal, firmly established, reliable and efficient criteria for flow regime discrimination are not yet available. This suggests the need for detailed two-phase flow modelling and experimentation, so that accurate and easy-to-use flow regime-based correlations of heat transfer coefficients and pressure drop will result.

__Prof. Leon Liebenberg and Prof. Josua P Meyer__ are associated with the University of Pretoria's Department of Mechanical and Aeronautical Engineering. Prof. Meyer is the Chair of the University's School of Engineering, and Head of the Department of Mechanical and Aeronautical Engineering.
lieb@up.ac.za