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RESEARCH PAPER

Holdup characteristics of two-phase parallel microflows

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Abstract Two-phase parallel microflows, i.e., stratified flow and core-annular flow, have many applications in lab-on-chip devices. These include transport and reaction processes, such as liquid–liquid extraction and phase transfer catalysis. The phase holdup (fraction of the microchannel volume occupied by a specified phase) is a key parameter of these flow systems. In this work, mathematical models based on fundamental principles are used to predict the phase holdup in stratified flow and core-annular flow. For stratified flow, a two-dimensional model of flow in a rectangular channel of arbitrary aspect ratio is considered. A simpler one-dimensional model of stratified flow between infinite parallel plates is also analyzed. In the case of core-annular flow, axisymmetry is assumed in the model. The results of the models agree well with published experimental results. The dependence of phase holdup on the flow-rate fraction (the primary operating variable which can be controlled experimentally) is studied in detail. The nature of this relationship varies with the ratio of fluid viscosities and the channel's aspect ratio (in the case of stratified flow). In the literature, the holdup is sometimes erroneously assumed to be identical to the flow-rate fraction. It is shown that this is not possible in the case of core-annular flow, while in stratified flow it is true only for a unique *critical flow-rate*. This critical flow-rate is viscosity dependent. The aspect ratio of the channel is found to have a considerable influence on the holdup in stratified flow when the fluids have different viscosities. However, even in such cases, there exists a *point of geometric invariance* at which the holdup is independent of the aspect ratio. At this point, the simple one-dimensional model of stratified flow can predict the holdup with complete accuracy.

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List of symbols

- D Depth of channel
- H Width of channel
- h Interface position
- $\frac{dp}{dz}$ Constant pressure gradient in the direction of flow
- Q_i Volumetric flow-rate of ith phase
- v_i Velocity of ith phase

Greek letters

- α_{ca} Holdup of the core fluid in core-annular flow
- α_s Holdup of phase 1 in stratified flow
- α_s^* Holdup at the point of geometric invariance $\left(\approx \frac{1}{1+\mu}\right)$
- λ Aspect ratio $\left(= \frac{H}{D}\right)$
- μ_i Viscosity of ith phase
- μ Ratio of the viscosity of phase 1 (core fluid) to the viscosity of phase 2 (annular fluid) in stratified (core-annular) flow
- Φ_{ca} Flow-rate fraction of the core fluid in core-annular flow
- Φ_s Flow-rate fraction of phase 1 in stratified flow
- $\Phi_{crit,ca}$ Critical flow-rate fraction of the core fluid in core-annular flow (shown to be a physically unrealistic mathematical quantity)

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