Orientation Effects on Biphasic Liquid Flow in Mesoscale: Experiments and Analysis

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Abstract

Immiscible liquid-liquid co-flow is frequently encountered in a variety of industrial processes involving inter-phase transport. Miniaturization intensifies such processes by increasing the range of plug flow characterized by large surface to volume ratio. Accordingly several studies are reported on plug flow in microchannels (chapter 1). Mesoscale which retains the advantages of miniaturization without compromising on throughput, pressure drop and fabrication cost is less explored. The present study experimentally and analytically investigates immiscible liquid-liquid co-flow to understand biphasic flow physics in mesoscale where the body and surface forces are comparable.

Experimental studies are carried out in four co-flow orientations of a glass conduit of diameter 2.38mm and length 1m for both reacting and non-reacting systems. The methodology is detailed in chapter 2 and the experimental results are presented in chapter 3 which reveal a subtle role of orientation and fluid entry arrangement in non-reacting flow. A balance between surface, inertial, viscous and body forces results in either segmented flow where dispersed phase is distributed as plugs/droplets in the carrier phase, or thread flow where dispersed phase flows as a continuous thread through an annular film of the carrier phase. The relative ranges of existence of droplets and thread vary with conduit orientation. Plugs of varying characteristics are generated by different mechanisms in the same device by a mere change in conduit orientation.

The experimental observations are rationalised using a simplified analysis based on momentum and energy considerations with fluid properties, flow rates, conduit dimension and flow orientation as defining parameters (chapter 4). A mathematical analysis based on energy minimisation principle to predict the flow patterns for liquid-liquid co-flow in mesoscale is also presented (chapter 5).

The experimental results on reacting system to investigate inter-relationship between flow dynamics and reaction are presented in chapter 6. A mass transfer limited fast reaction is employed and segmented flow is found to give better reaction conversion than other patterns. Interfacial reaction induces changes in phase properties and alters the flow dynamics which in-turn influences the further reaction progress.

Keywords: Biphasic liquid co-flow, process intensification, mesoscale, squeezing, dripping, jetting, monodispersity, interfacial reaction, orientation effects.