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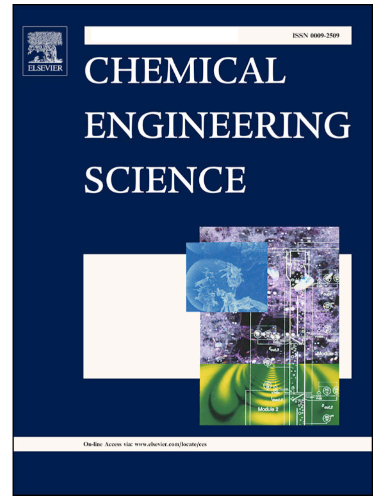

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Pressure drop of two-phase liquid-liquid slug flow in square microchannels

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Abstract

Networks of microdevices can be used to form, sort, split and recombine droplets by varying the fluidic resistance of the channels. To facilitate design of such systems we propose two models to calculate pressure drop of liquid-liquid slug flow in square microchannels. By approximating a droplet surrounded by liquid film as annular flow, the moving film model includes the velocity profile in the lubricating layer. In the no-film model, the presence of liquid film is neglected. Pressure drop measurements of water-toluene and water-silicone oil slug flow generated in glass/silicon devices of 200 and 400 μm width serve to validate these two models. We found that the droplet viscosity influences the applicability of the models. Good agreement is obtained for water-toluene slug flow, with the average error of 15-20 % between the measured and calculated values for both models, proving that the presence of the lubricating film may be neglected for flows with similar viscosities of both phases. On the contrary, both predictions agree poorly with experiments for silicon oil-water flow which we attribute to the lower than expected liquid film thickness around the silicon oil droplets. Therefore we use the moving film model to estimate the thickness of the lubricating layer which we find to lie between 0.5-0.75 % of the channel width, lower than the assumed 2 %. Finally we compare the performance of our models against two correlations adapted from literature. We thus demonstrate that our approach allows reliable pressure drop prediction for liquids with similar viscosities and delivers important information on flow hydrodynamics.

Keywords: slug flow; liquid-liquid; pressure drop; microfluidics; multiphase flow

1. Introduction

In large scale systems, information about pressure drop is usually necessary to dimension new devices, decide on the setup peripheries, such as pumps, valves etc. However for microdevices characterized by low reactor volumes, necessary pressure head is usually achieved by means of unexpensive components such as syringe pumps. More interestingly, differences in fluidic resistance in microchannels can be advantageously used to manipulate droplets of small volumes, e.g. for droplet merging/splitting [1–4] or phase separation.[5, 6] Systems relying on pressure difference between the channels include sample analysis where product stream needs to be separated from the continuous carrier phase, [7] introduction of phase separation unit into a microfluidic network to synthesise and directly react toxic intermediates [8] or high-throughput droplet production where the initial number of droplets can be exponentially increased via a tree of bifurcating channels. [4] In this context the ability to describe pressure losses induced by multiphase