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Effect of Inlet Mixers on Flow Uniformity in Parallel Microchannels

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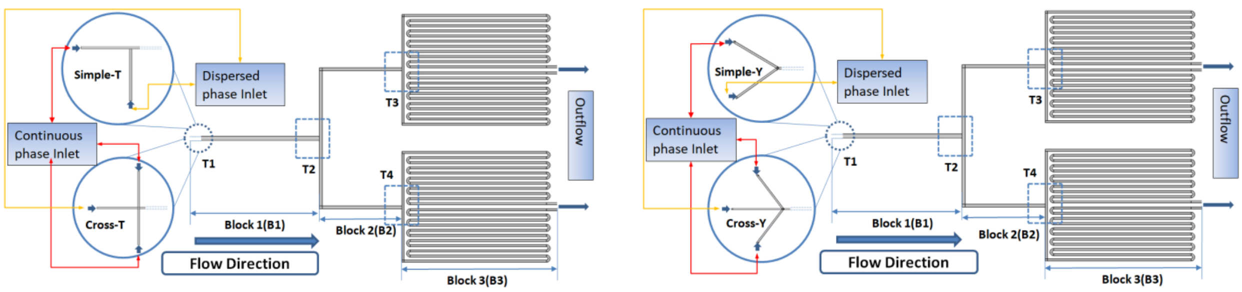
1. Introduction

Microreactors are characterised by a high surface to volume ratio and sub-millimetres dimension channels, which offers a significant increase in heat and mass transfer rates over conventional reactors. Micro-reaction technology, therefore, provides several benefits over conventional chemical processes, such as substantial improvements in product quality, yield, and selectivity. However, to increase the throughput it's important to have parallel micro channels which is done by numbering up approach. Typically, two approaches have been considered for numbering-up, i.e. internal and external numbering-up. These approaches have major limitations of increasing pumping cost in case of external approach and flow maldistribution in case of internal approach. To overcome these challenges, in our previous work [1], a splitting distributor was designed with four successive T-junctions (T_1, T_2, T_3 and T_4) with four parallel micro channels. The design strategy of the splitting distributor was adopted from Hoang et al. [2], Adamson et al. [3], and modified as reported [1] to ensure the flow uniformity in terms of constant relative length of bubbles/slugs in all the blocks. In the present work, the design of splitting distributor reported in our previous work [1] was used with different inlet mixers (Simple T, Y and Cross T, Y) at Block-I and 44 parallel meandering micro channels (0.5 mm) at Block – III (see Fig. 1). The present work aims to investigate the effect of inlet mixers on formation and splitting dynamics of bubbles/slugs, relative lengths of bubbles/slugs ($L_{bubble/slug}/W_{channel}$), volume of bubbles/slugs and flow uniformity in parallel micro-channels. In addition, correlation was also developed to predict the relative lengths of bubbles/slugs in the parallel micro-channels.

2. Methods

PMMA sheets were used to fabricate the microchannel devices (1 x 0.6 mm^2 at Block-I) (see Fig. 1) using vertical milling machine (VMC). Water + SDS (0.17 Wt/Wt %) and air was used as test fluids. OB1 controller (Elveflow) was used to control the liquid (water + SDS) flow rates (3-20 ml/min) and mass flow controller (Alicat, USA) was used to control the air flow rates (3 -12 ml/min). High speed camera (Fastec, USA) was used to visualize and record the multiphase flows at 1000 fps. The recorded images were processed using in-house MATLAB code to measure the lengths of bubble/slugs in all the blocks. However, to ensure the reproducibility of the results the all experiments were repeated at least twice.



(a) (b)

Figure 1. Schematic diagram of parallel micro channels used in the present work (a) Simple-T and Cross-T, (b) Simple-Y and Cross-Y

3. Results and discussion

Experimental investigations were performed at different liquid flow rates ($Q_{water+sds}$ =3-20 ml/min) and air flow rates (Q_{air}=3-12 ml/min) to investigate the effect of inlet mixers on the formation and splitting dynamics of bubbles/slugs and their corresponding relative lengths, and flow uniformity in parallel micro-channels. Fig. 2 shows the three types of bubble splitting mechanisms observed at T2-junction (as shown in Fig. 1) namely, obstructed, partially obstructed and unobstructed respectively. In the obstructed mechanism, slug splitting process was mainly controlled by the augmented pressure in the obstructed continuous phase and by the surface tension force at the final pinch-off. Whereas, in partially obstructed mechanism, the shear force exerted by the continuous phase in the normal direction at T1 and the augmented pressure, controls the bubble splitting mechanism. However, in unobstructed mechanism (a gap between the channel walls and slug remains throughout the splitting process) high magnitude of shear force dominates the splitting mechanism compared to surface tension force. Fig. 3 shows the flow uniformity of bubbles/slugs in Block –III (cross Y-inlet mixer) parallel micro-channels (only four channels out of 44 showed here) at different Ca at fixed We.

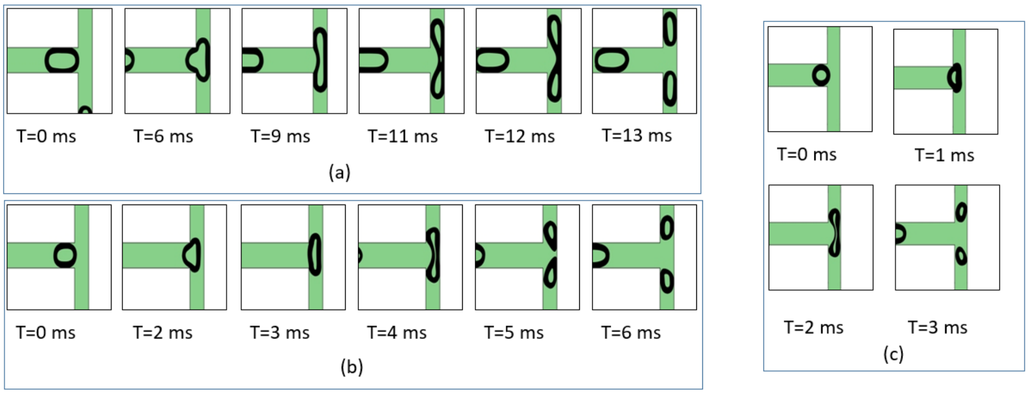


Figure 2. Splitting dynamics of bubble/slug at 2nd T-junction of Cross Y-type inlet mixer (a) obstructed splitting (b) partially obstructed splitting (c) unobstructed splitting.

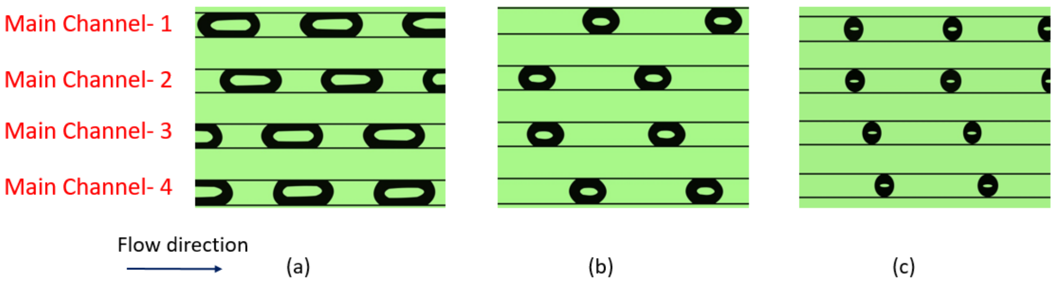


Figure 3. Flow uniformity in four parallel channels (Cross-Y) in Block-III at fixed $We_{Block-I}$ (= 1.6e-04) (a) $Ca_{Block-III}$ = 0.001; (b) $Ca_{Block-III}$ = 0.00332; (c) $Ca_{Block-III}$ = 0.00596.

4. Conclusions

In the present work, splitting distributor was used with different inlet mixers to obtain the flow uniformity in the parallel micro-channels. Various bubble splitting mechanisms were observed at all T-junctions namely, obstructed, partially obstructed and unobstructed. Flow uniformity was found for wide range of $Q_{water+sds}$ = (5-18 ml/min) in cross Y inlet mixer as compared to other inlet types. Correlation was also developed to predict the relative lengths of bubbles in the parallel micro-channels with 12.98 % as mean standard deviation. The detailed investigations of effect of inlet mixers and their comparison on the flow uniformity in parallel micro channels will be presented in the full length manuscript.

References

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