Gas-liquid slug flow study in single pellet string microreactors

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Highlights

- Pressure drop was recorded for gas-liquid slug flow in single pellet string microreactors.
- Liquid retention was observed in the packed bed.
- Pressure drop gradient increases with increasing gas and liquid flow rates.

1. Introduction

Heterogeneously catalysed reaction accounts for 80-90% of industrial catalytic chemical processes, making packed bed reactors commonly used in the industry. Micro-packed beds (μPBs) combine the advantages of packed bed and microreactor technology, which can achieve significant process intensification. Understanding the dynamics of gas-liquid two-phase flow within μPBs is essential for such microreactor design and process optimization in catalytic reactions. The single pellet string microreactor (SPSM) is characterized by a reactor-to-particle diameter ratio (D/d) ranging between 1 and 1.867. In contrast to conventional μPBs, the SPSM allows for easy observation of the flow regime and exhibits relatively simple flow regimes, due to its regular packing configuration [1]. The less complicated flow within the SPSM makes it more appealing for reaction applications, which often require that the catalysts retained should be (highly) active. In addition, the small D/d ratio in the SPSM can lead to the improved radial heat transfer performance in the bed. As a result, SPSM proves to be an advantageous starting point for delving into the hydrodynamic aspects of μPBs.

2. Methods

To obtain dry slug flow, hydrophobic material polytetrafluoroethylene (diameter: D=0.8 mm) and perfluoro alkoxy (D=1.6 mm) capillaries were applied. The packed particles are glass beads of different sizes (d). Two SPSMs (D=0.8 mm, d=0.53 mm; D=1.6 mm, d=1.24 mm) of different lengths were investigated. An HPLC pump was utilized to deliver water to one inlet of the Y-junction mixer, while nitrogen (N_2) from a pressurized gas cylinder was introduced into another inlet using a mass flow controller. The Y-junction mixer facilitated the merging of gas and liquid phases, which then progressed to the SPSM. Throughout the experiments, pressure data were recorded while gradually increasing the liquid/gas flowrate, maintaining a constant gas/liquid volumetric flow ratio. A high-speed camera was positioned in the middle of the microreactor to capture the flow regime.

3. Results and discussion

Inside the SPSM, both gas and liquid phases presented themselves as dispersed slugs, alternating as they traversed the SPSM in a manner consistent with the distinctive attributes of dry slug flow, as shown in Figure 1. This dry slug flow pattern is also discernible in the empty capillary sections upstream and downstream the SPSM, albeit with some irregularities and variations in slug length observed downstream. Consequently, the packing configuration within the SPSM exerts influence on the flow regime, as evidenced by occurrences of gas/liquid slug breakage and coalescence among neighboring slugs within the reactor [2].

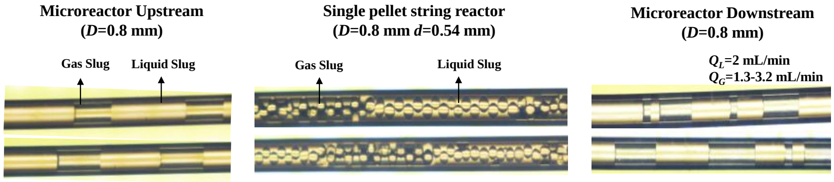

Figure 1. Transition of gas-liquid slug flow regime as the fluid progresses from the upstream empty microreactor to the SPSM and then to the downstream.

The slug flow in the SPSM shows unique features compared to an empty microreactor. In the empty microreactor, gas and liquid phases coexist independently without liquid films on the microreactor inner wall. In the SPSM, besides existing in the form of liquid slugs, liquid droplets are also dispersed within the gas slugs, a result of liquid retention between the inner wall and the packed glass beads. The strong capillary forces, influenced by the small pore size between the wall and packing in the SPSM, keep the liquid in place against gravitational and inertial forces. As a result, the liquid phase stays confined in the contact region rather than the space between particles and the wall, as shown in Figure 2.

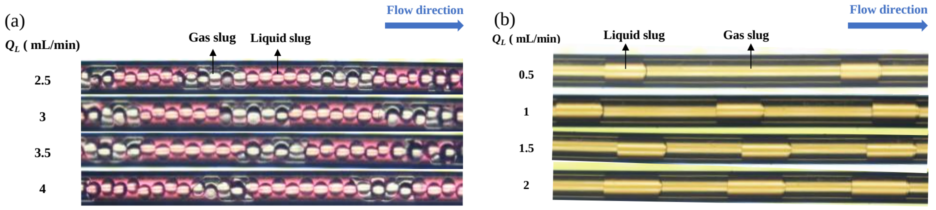

Figure 2. The flow pattern changes of water-N_2 dry slug flow in (a) PFA SPSM (D=1.6 mm, d=1.24 mm) with increasing Q_L under Q_G =2.59 mL/min, (b) PTFE microreactor (D=0.8 mm) with increasing Q_L under Q_G =2.59 mL/min.

The pressure drop gradient of slug flow in the SPSM (D=0.8 mm and d=0.53 mm) with changing liquid and gas volumetric flow rates (Q_L and Q_G) was depicted in Figure 3. Similar to dry slug flow in an empty microreactor, changes in Q_L exert a more pronounced influence on the pressure drop gradient than Q_G. Furthermore, it was observed that the impact of changes in Q_G also relies on the value of Q_L.

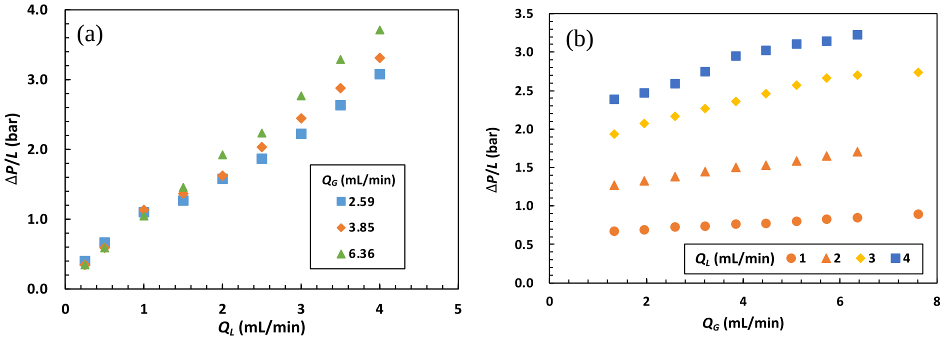

Figure 3. The variation of pressure drop with respect to (a) liquid flow rate under different gas flow rates (b) gas flow rate under different liquid flow rates in the SPSM with D=0.8 mm and d=0.53 mm.

4. Conclusions

Packed bed microreactors offer a number of opportunities for the effective and sustainable chemical synthesis, making hydrodynamic research (flow mechanism and relevant transport characteristics) necessary for further process optimization. Gas-liquid slug flow regime and pressure drop were studied in the SPSM in this work. The dry slug flow in the SPSM was found different from that in an empty microreactor, due to the liquid retention caused by the capillary force. Pressure drop gradient within the SPSM increases with increasing Q_L and Q_G, while changes in Q_L exert a more pronounced influence. The experimental data on hydrodynamic study of the SPSM will provide insights on the pressure drop model improvement.

References

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[2] O. Tonomura, N. Arai, and S. Hasebe, J. Taiwan Inst. Chem. Eng. 130 (2022) 103908

Keywords
dry slug flow; hydrodynamic; microreactor; packed bed; pressure drop