Multiphase Transport Phenomena in Microfluidic Systems

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Microscale multiphase flows (gas-liquid and liquid-liquid) possess a number of unique properties and have applications ranging from use in microchemical synthesis systems to heat exchangers for IC chips and miniature fuel cells. Our work is focused on gas-liquid flows in microfabricated channels of rectangular or triangular cross section. We characterize the phase distribution and pressure drop of such flows and apply such information to a systematic design of gas-liquid microchemical reactors. The inherently transient nature of such multiphase flows provides a rich variety of flow regimes and dynamic flow properties. Characterization is done using pulsed-laser fluorescence microscopy and confocal microscopy (spinning disk and scanning), as well as by integrated flow regime sensors. Superficial gas and liquid velocities were varied between 0.01-100 m/s and 0.001-10 m/s, respectively.

Particular attention is given to segmented (slug or bubbly) flows in hydrophilic channels. Figure 1a illustrates the distribution of gas and liquid in the channel. Gas bubbles are surrounded by thin liquid films (thickness ~ 1 µm) at channel walls and liquid menisci in the corners. Such flows create a recirculation in the liquid segments (Figure 1b) and can, therefore, be used to efficiently mix two miscible liquids on the microscale within a length of only a few tens of the microchannel width [1,2]. We demonstrate that the transient nature of gas-liquid flows can be used to significantly improve mixing of miscible liquids compared with existing methods. After mixing is accomplished—Figure 2 (bottom) provides an illustration for mixing of two differently colored streams—the gas can be removed from the mixed liquid phase in a capillary phase separator for arbitrary velocities and flow patterns [1]. In addition to providing mixing enhancement, segmented flows narrow the distribution of residence times of fluid elements in the liquid phase, as compared to single-phase flows [1]. A narrower residence time distribution is particularly essential for particle synthesis on a chip.

![Figure 1: Segmented gas-liquid flow. (a) Gas-liquid phase distribution and (b) liquid phase velocity field obtained by microscopic particle image velocimetry (PIV). The mean velocity was subtracted from all velocity vectors to illustrate the recirculation motion in the liquid segment.](image1)

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![Figure 2: Illustration of enhanced liquid mixing in a microfluidic device by introducing a gas phase. Fluorescence micrographs show (a) the co-flowing liquid streams, L1 and L2, without the introduction of a gas phase, G, and (b) mixing in segmented gas-liquid flow and separation of the gas from the liquid in a single-stage microfluidic device.](image2)

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**REFERENCES:**

