Microbubble Beam (MBB), A Potential Dispersion Mechanism for Multiphase Gas-Liquid Microreactor Systems

George N. Doku¹, Willem W. Verboom¹, David N. Reinhoudt¹ and Albert van den Berg¹

¹MESA+ Research Institute, University of Twente, P.O. Box 217, 7500 AE Enschede, Netherlands.

Abstract

We studied the use of micropipettes integrated in miniaturized channels for online introduction (perpendicularly) and dispersion of gas as microbubbles in liquid flows. Multiple-line microbubble trains (microbubble beams, MBB) were produced, as a gas-liquid dispersion mechanism for multiphase microreactor systems. The bubble size and quantity generated were dependent on the physical and flow properties of the liquid, the gas and the pipette. The bubble sizes obtained were far smaller, the bubble quantities were far higher, and specific interfacial contact areas estimated were about 2-10 times higher than those reported in the literature.

Keywords: Gas-liquid dispersion; microreactors, micropipette; microbubble beam.

1. Introduction

The complexity of forcing immiscible-phase reactants to mix, diffuse, and react makes multiphase microreactor systems, operated continuously, critical. Gas-liquid dispersion methods such as the single line segmented microbubble-train, [1] bubble slugs [2] and annular flow configurations [3] have been reported, citing specific interfacial contact areas of 9000 – 50000 m²/m³ with decreasing channel dimensions and bubble diameters down to 50 μm. This paper reports on online generation of further smaller size, and multiple-line segmented microbubble columns (dubbed, microbubble beams (MBB)) within a moving liquid using micropipette tips, employing a principle akin to the process of aspiration/nebulization employed in analytical instrumentation.

2. Experimental

Systems consisting of single and multiple micropipette tips mounted in a channel (Figure 1) for the generation of microbubble beams (MBB, as a gas-liquid dispersion mechanism) in moving liquids were constructed in stainless steel housing, with Pyrex windows on both sides of the housing for imaging. The liquid velocity, gas supply pressure, pipette hole size, the
liquid temperature, liquid viscosity, pipette-liquid hydrophilicity, and multiple-pipette configurations, were monitored in separate experiments to verify their effects on the bubble generation and the bubble size, quantity and speed. Glass pipette and liquid water were the hydrophilic entities, whilst surface-silanized pipette and 50% nitrobenzene-25% ethanol-25% ethyl acetate were the hydrophobic entities employed in the study. A low-magnification microscope/low-speed camera system was used to view the behaviour of the whole bubble beam produced, whilst the bubble sizes were determined with a high-magnification microscope/high-speed camera and a microscale mounted under the microscope.

3. Results and Discussion

Whilst high liquid velocity (Figures 2 and 3a), small pipette holes (Figure 3), low gas supply pressures (Figure 3b), low liquid temperatures, medium liquid viscosities and liquid hydrophobicity (Figure 4) are conditions for effective microbubble formation (i.e., decreasing the bubble size and increasing the bubble quantity), gas supply pressure requirements increase with decreasing pipette hole size, increasing liquid surface tension and similar pipette-liquid hydrophilicity. Specific interfacial contact areas estimated (based on the bubble sizes and quantities for the dense regions of the MMB) for the hydrophilic liquid were as large as $8 \times 10^4 \text{m}^2/\text{m}^3 \pm 10\%$ corresponding to bubbles as small as 30 $\mu$m, whilst the hydrophobic liquid gave contact areas between $20 - 40 \times 10^4 \text{m}^2/\text{m}^3 \pm 10\%$ corresponding to bubbles 12 - 5 $\mu$m in

![Figure 1. Schematic diagrams and exploded views of the experimental chip set-ups of (a) single-pipette system, and (b) multiple-pipette system.](image-url)

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diameters. Multiple-micropipette configuration, rather than one large pipette hole, is the recommended means of increasing gas quantity requirements.

![Figure 2. Microbubble beams captured with a low-magnification microscope/low-speed camera, from different pipette hole sizes at a liquid velocity of 80 cm/s; and from a 0.5 μm id pipette for different liquid velocities.](image)

![Figure 3. Bubble size dependence on (a) liquid velocity/pipette hole id, and (b) gas pressure/pipette id.](image)
Figure 4: (a) Microbubbles captured with a high-magnification microscope/high-speed camera, from hydrophilic and hydrophobic liquids, for different liquid velocities; (b) plots of bubble diameter versus liquid velocity for hydrophilic and hydrophobic liquids.

4. Conclusions
The in-channel-integrated micropipette technique gives smaller bubble sizes, larger bubble quantities and high interfacial contact areas, than those reported in the literature. The most important operational conditions for effective microbubble generation are small pipette id, high liquid speed, reverse pipette-liquid hydrophilicity, and liquid hydrophobicity.

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References