Experimental Investigation of Flow Regime Transitions in a Rectangular Bubble Column Using Bed Expansion and MRI-Based Gas Holdup Measurements

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Bubble columns are widely employed as gas–liquid contactors in chemical and biochemical engineering due to their simple design and favorable mass and heat transfer characteristics. Their fluid dynamic behavior is governed by complex interactions between the dispersed gas and continuous liquid phases, with global flow regimes emerging from underlying local dynamics (Besagni, 2021). Accurate identification of these regimes and their transition points is therefore essential for reactor design, scale-up, and model validation (Kantarci et al., 2005). Gas holdup is a key parameter that reflects the volumetric fraction of gas within the gas–liquid mixture and provides valuable insight into multiphase flow dynamics (Shah, 1982).

The present work experimentally investigates flow regime transitions in a rectangular bubble column by combining global and local gas holdup measurements. Global gas holdup was determined using the bed expansion method, while local gas holdup distributions were obtained using phase-contrast magnetic resonance imaging (MRI). The integration of these measurement techniques enables multi-scale characterization of bubble column fluid dynamics without disturbing the flow field, allowing detailed spatial analysis of gas distribution within the column (Rennebaum et al., 2025; Rice, 2019).

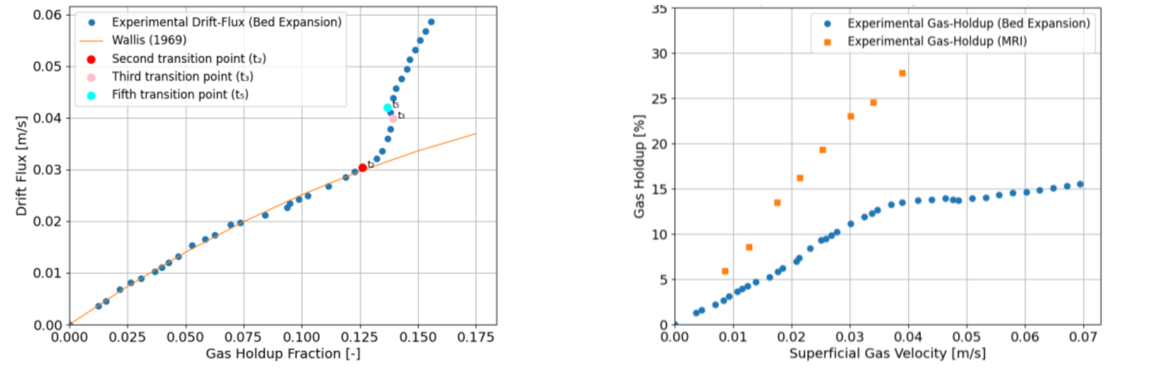
Experiments were conducted in a rectangular bubble column (15×4 cm) operated under ambient conditions using air as the gas phase and deionized water as the liquid phase. The bubble column was filled up to a liquid height equal to 63 cm (aspect ratio = 10). Gas was injected through a perforated plate sparger with 41 holes of 0.5 mm diameter, corresponding to an open area of approximately 0.13%. Superficial gas velocities ranged from 0.0037 to 0.0694 m/s, covering the investigated fluid dynamic operating range. The study adopts the theoretical and analytical framework proposed by Besagni (2021), in which flow regimes and flow-regime transition points are identified based on the relationship between global gas holdup and drift flux.

The experimental results illustrated in Figure 1(a) revealed the presence of four flow regimes and three transition points within the investigated operating range. Notably, the mono-dispersed homogeneous regime was not observed. Instead, the system exhibited poly-dispersed homogeneous behavior from the onset of operation, followed by a transition regime characterized by increasing bubble interactions and the formation of coalescence-induced structures. At higher drift flux values, a direct transition to the pure heterogeneous regime was observed, indicating rapid development of fluid dynamic instability once large-scale bubble structures formed.

Quantitative analysis showed that global gas holdup increased with superficial gas velocity for both measurement techniques. However, MRI-derived gas holdup values were consistently higher than those obtained from the bed expansion method, approximately twice as large across the entire operating range (see Figure 1 (a)). This systematic discrepancy may be attributed to magnetic susceptibility differences between the gas and liquid phases, which can induce local magnetic field distortions and affect signal interpretation.

Local measurements indicate that gas distribution within the column was not uniform along the vertical direction. The lower region exhibited greater gas accumulation compared to the upper region, demonstrating the existence of vertical gradients in the flow structure.

Overall, the results demonstrate the applicability of the drift-flux methodology for reliable identification of flow regime transitions in rectangular bubble columns. The combined use of global and local measurement techniques provides improved understanding of multiphase fluid dynamics and supports the development of more accurate predictive models for industrial gas–liquid reactors.



(a) (b)

Figure 1: (a) Drift flux Analysis. (b) Global gas holdup measured using MRI and bed expansion.

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