Ministero dell'Università e della Ricerca

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

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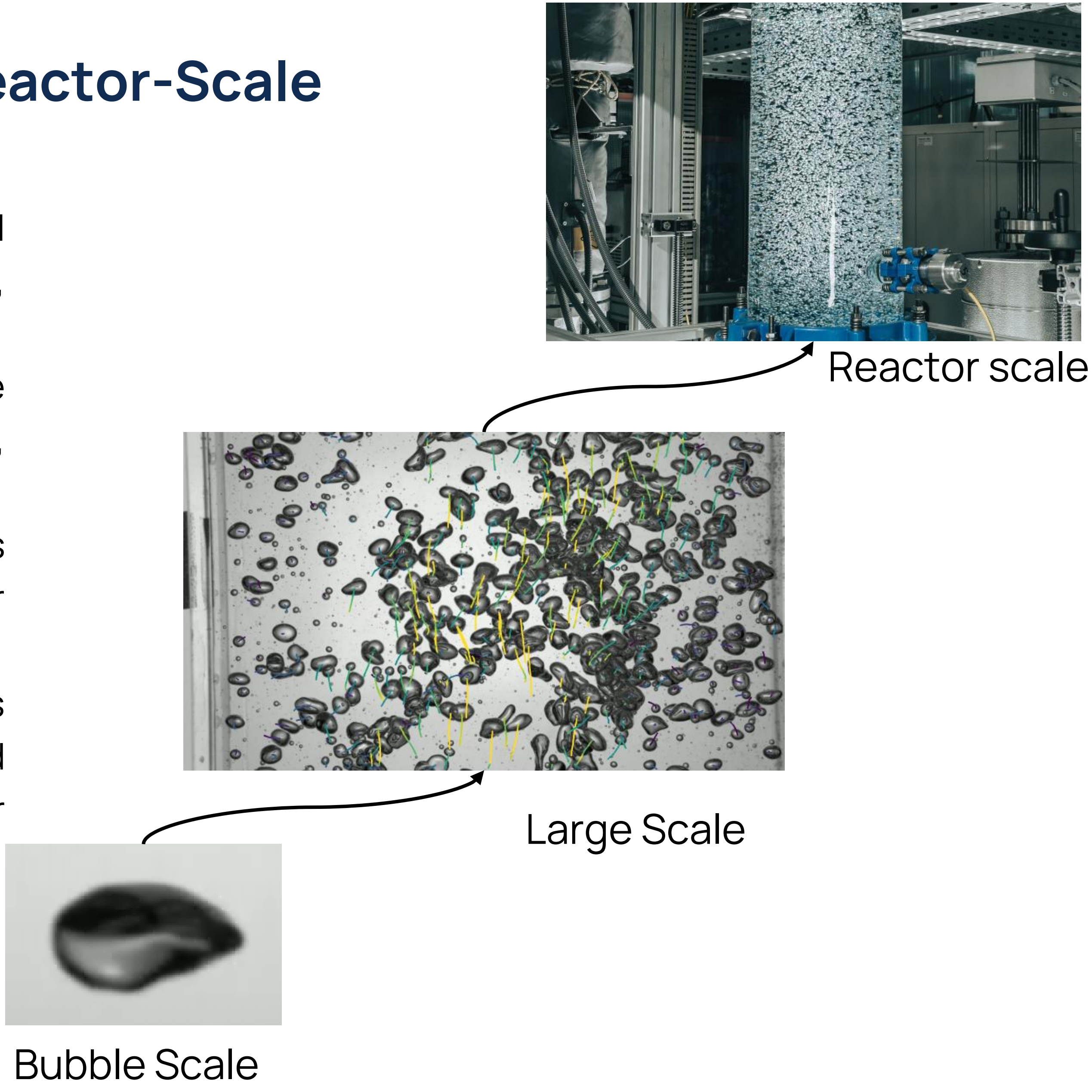
Outline

Motivation: From Bubble-Scale to Reactor-Scale

- Bubble columns are widely used industrial gas–liquid contactors for their simple design, efficient mixing, high mass transfer area.
- Reactor performance depends on bubble-scale phenomena: bubble size, velocity, deformation, interactions
- ➞ These microscopic behaviors determine gas holdup, flow regime, mixing, and overall reactor efficiency
- Flow regimes are the observable signature of this bubble-to-reactor coupling — identifying them and their transition points accurately is essential for reactor design, scale-up, and model validation



Motivation: Why MRI? Global, Local, and Non-Intrusive

- Bed expansion gives a global gas holdup value, but only a single bulk number — no spatial information
- MRI can provide both: global gas holdup (via spatial averaging of local measurements) and local gas holdup distributions — enabling direct comparison against bed expansion
- Fully non-intrusive — doesn't disturb the flow field, unlike probes inserted into the column
- Not limited by optical access — makes it especially valuable for dense, opaque, or high-holdup columns where camera-based methods fail
- Potential to also resolve bubble size distributions, extending its usefulness beyond holdup alone

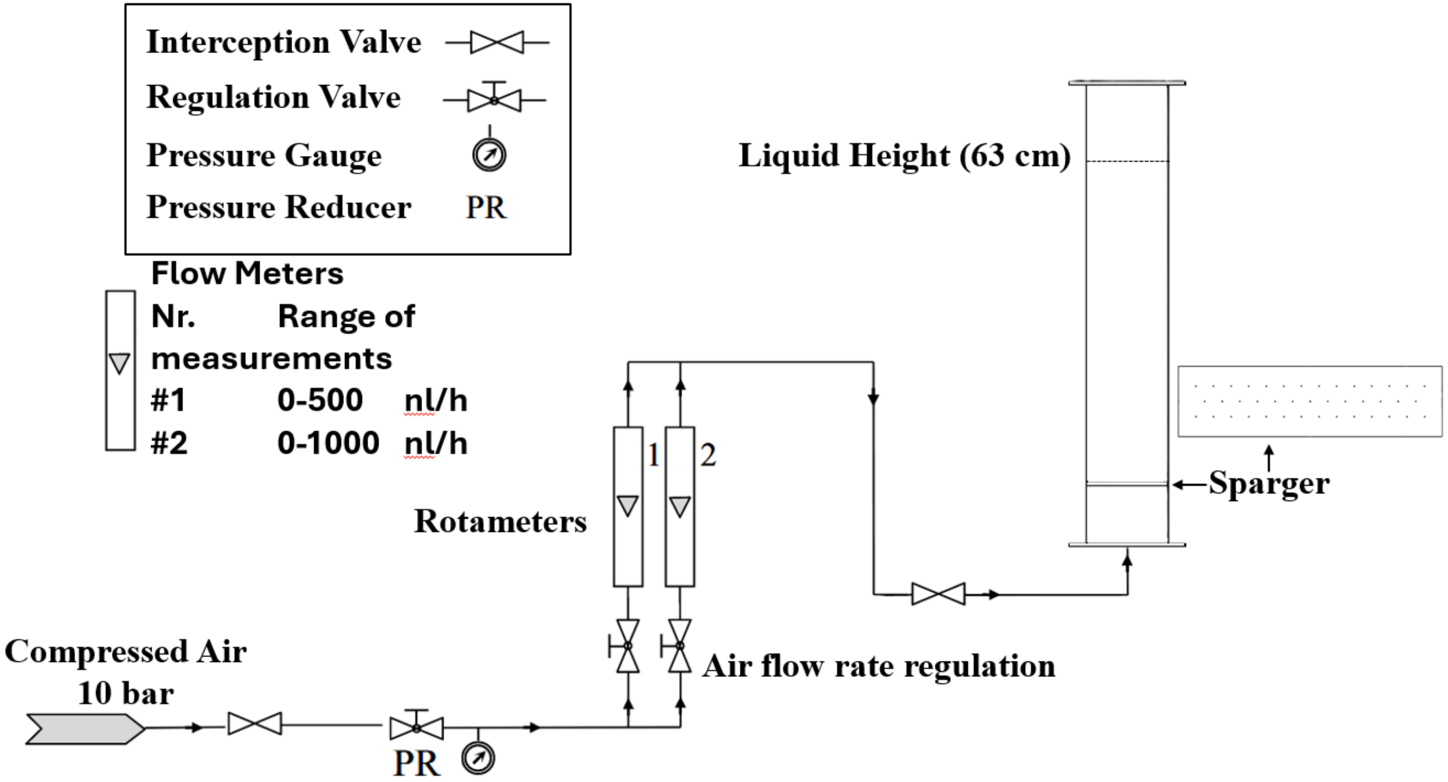
	Bed Expansion	MRI
Global holdup	✓	✓
Local holdup	×	✓
Non-intrusive	✓	✓
Opaque / Dense columns	×	✓

TUHH Hamburg University of Technology

Institute of Process Imaging

Experimental Setup

- Rectangular Plexiglas bubble column: 15 × 4 cm cross-section
- Filled to 63 cm liquid height (aspect ratio = 10)
- Perforated plate sparger: 41 holes, 0.5 mm diameter (~0.13% open area)
- Air–water system, ambient conditions
- Superficial gas velocity: 0.0037 – 0.0694 m/s
- Same column characterized two ways: bed expansion (global holdup) and MRI (global + local holdup), performed at the Institute of Process Imaging (IPI), TUHH Hamburg



Method: Flow Regime Framework (Besagni, 2021)

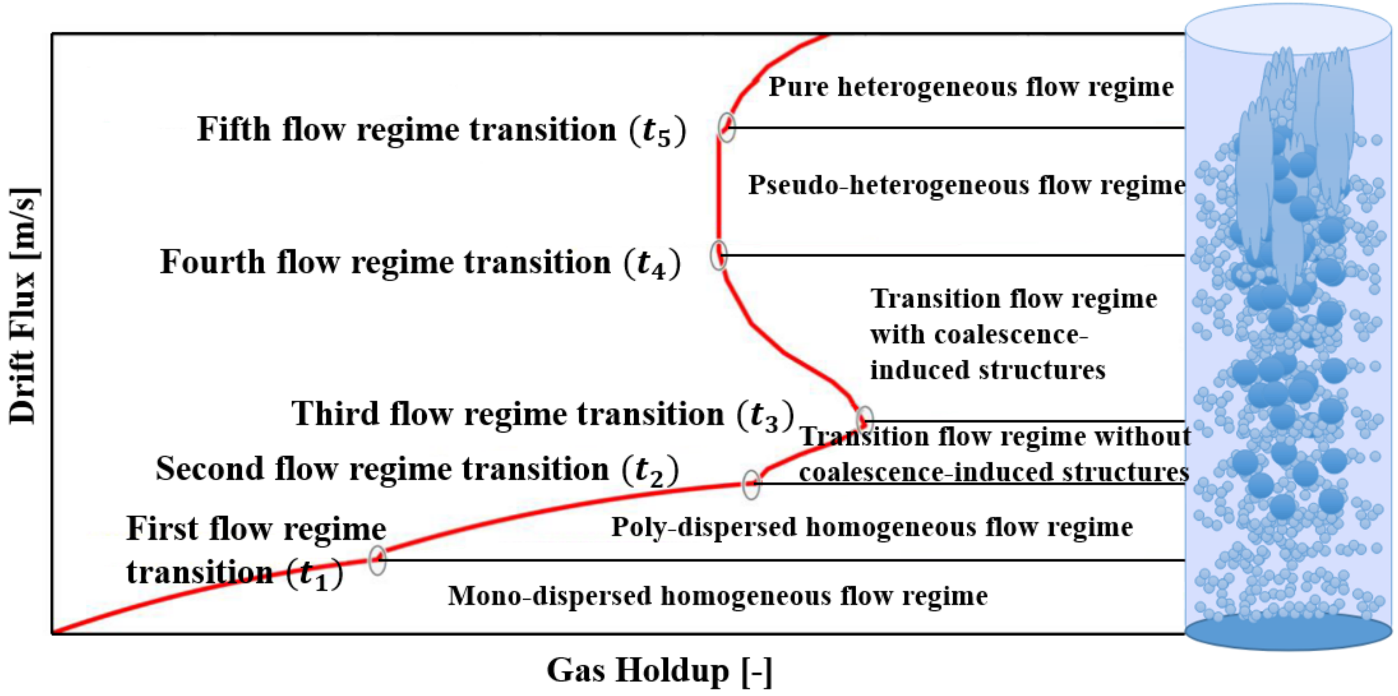
- Superficial gas velocity U_G
- Gas holdup ε_G
- Drift flux

$$J_T = U_G\,(1-\varepsilon_G) \pm U_G\varepsilon_G$$

- Ω curve: ε_G vs J_T describes regime evolution
- t1: (Wallis Method) Compare experimental J_T vs theoretical J_E

$$J_E = v_b\,(1-\varepsilon_G), J_T \neq J_E$$

- t2: Re-apply Wallis shift
- t3: Maximum of JT vs εG
- t4: εG plateau region
- t5: End of plateau (structural change)



Method: MRI Acquisition

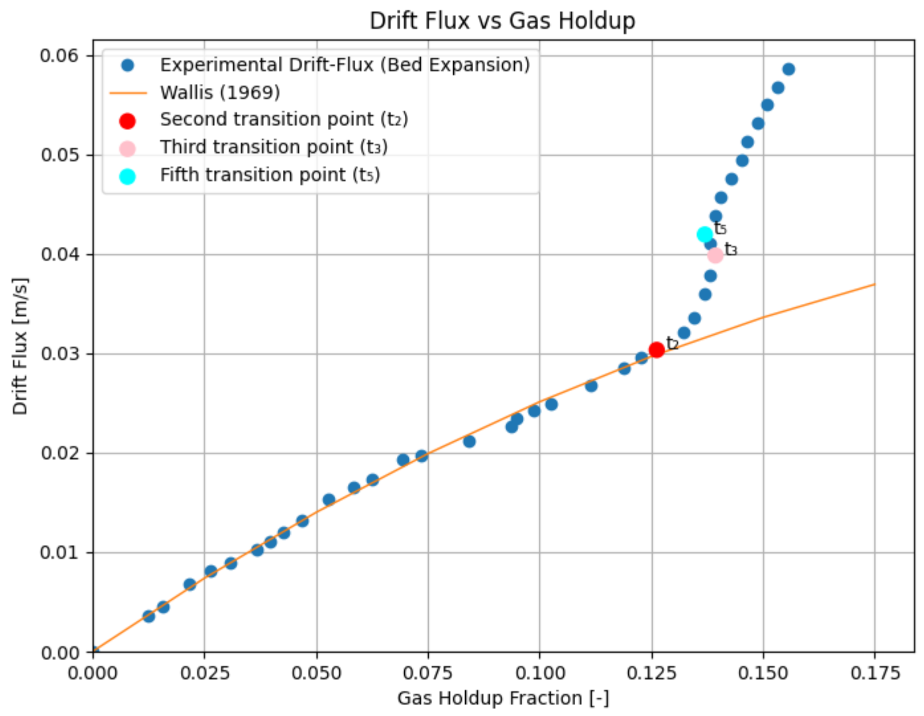
System:
- 3 T vertical MRI system (Tesla Engineering Ltd., UK)
- High-performance gradient coil (same manufacturer)
- Birdcage RF coil (Tesla Dynamic Coils, Netherlands) — transmission
- 32-channel RF receive array — signal reception
- Philips Medical Systems (Netherlands) backend

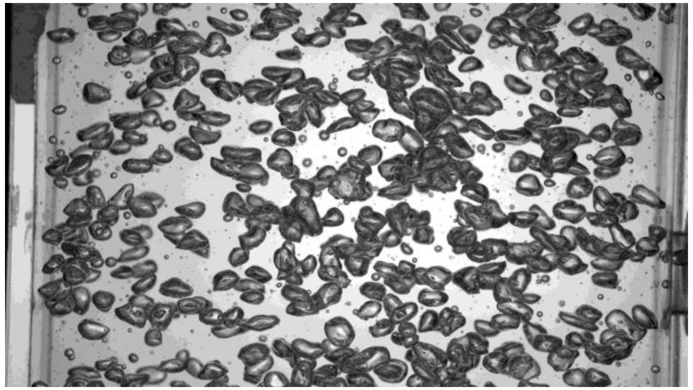
Sequence — gas holdup measurement:
- Fast Field Echo (FFE) sequence
- Horizontal slices, perpendicular to column height
- Voxel size: $2.6 \times 2.6 \times 10$ mm^3
- Flip angle 15°, TE 1.54 ms, TR 100 ms
- Frames averaged per slice for a stable, time-averaged holdup value

MRI Data Evaluation:
- **Threshold** — classify each voxel as gas or liquid based on local signal intensity
- **Denoise** — discard small isolated clusters (fewer than ~10 voxels) as noise, not real bubbles
- **Normalize** — compute local holdup from signal loss relative to a no-flow reference; cap negative values at zero (not physically meaningful)
- **Average** — combine local values spatially to get one global gas holdup, directly comparable to bed expansion

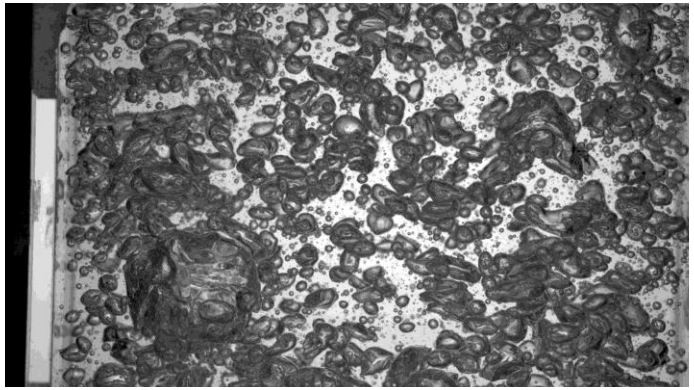
Result: Four Regimes, Three Transitions

- 4 flow regimes and 3 transition points identified
- No mono-dispersed homogeneous regime — poly-dispersed from the onset (t1 collapses at the origin)
- Direct transition from coalescence-structure regime to pure-heterogeneous (t4/t5 collapse)
- Confirmed visually: coexisting bubble size classes at low UG; fully developed coalescence structures at high UG

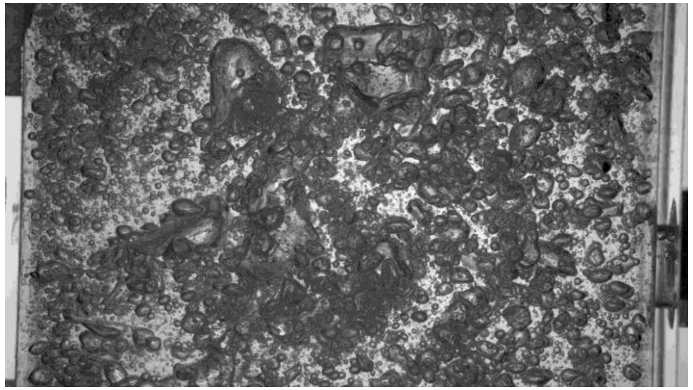




(a) $U_G = 0.01852\ m/s$



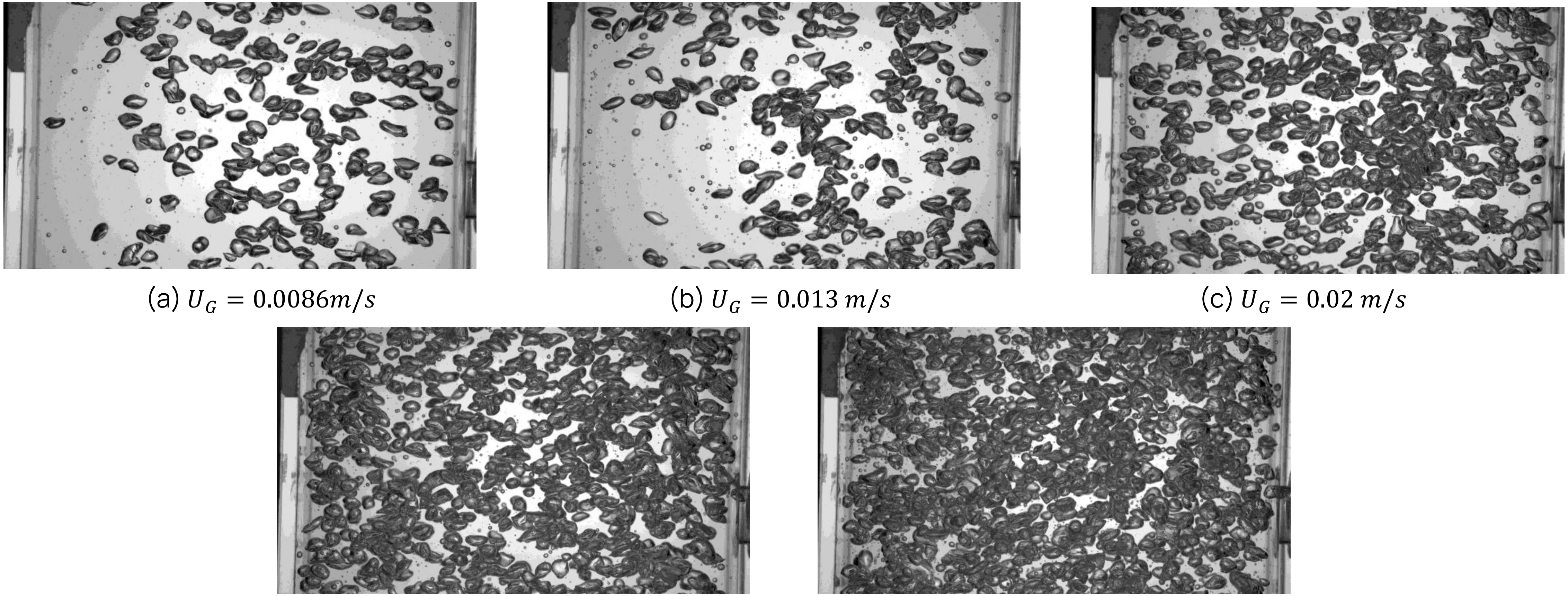
(b) $U_G = 0.04861\ m/s$



(c) $U_G = 0.05787\ m/s$

Result: Confirming the Regime Across the MRI Range

- Five representative operating points spanning the full MRI measurement range (U_G = 0.0086 – 0.039 m/s)
- Flow visualization confirms the regime remained consistently poly-dispersed across all conditions — no coalescence-induced structures appear



(a) $U_G = 0.0086 m/s$

(b) $U_G = 0.013\ m/s$

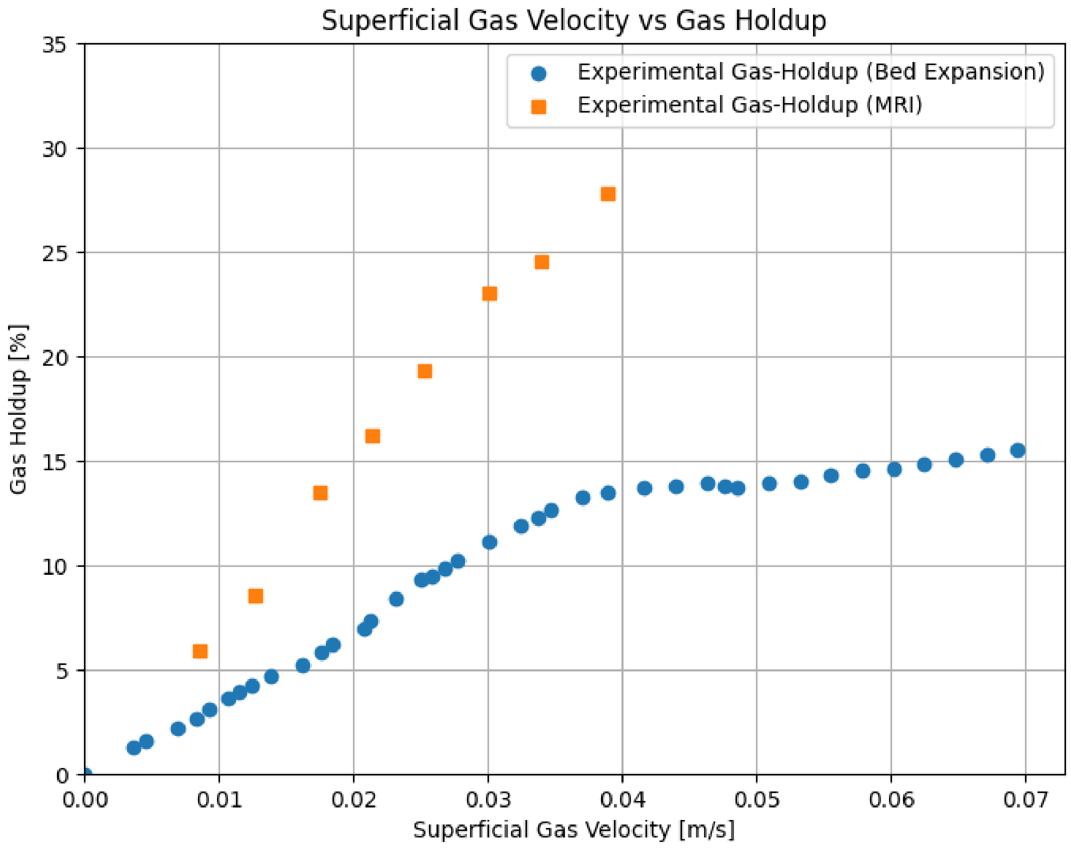
(c) $U_G = 0.02\ m/s$

(d) $U_G = 0.03\ m/s$

(e) $U_G = 0.039\ m/s$

Result: MRI vs. Bed Expansion

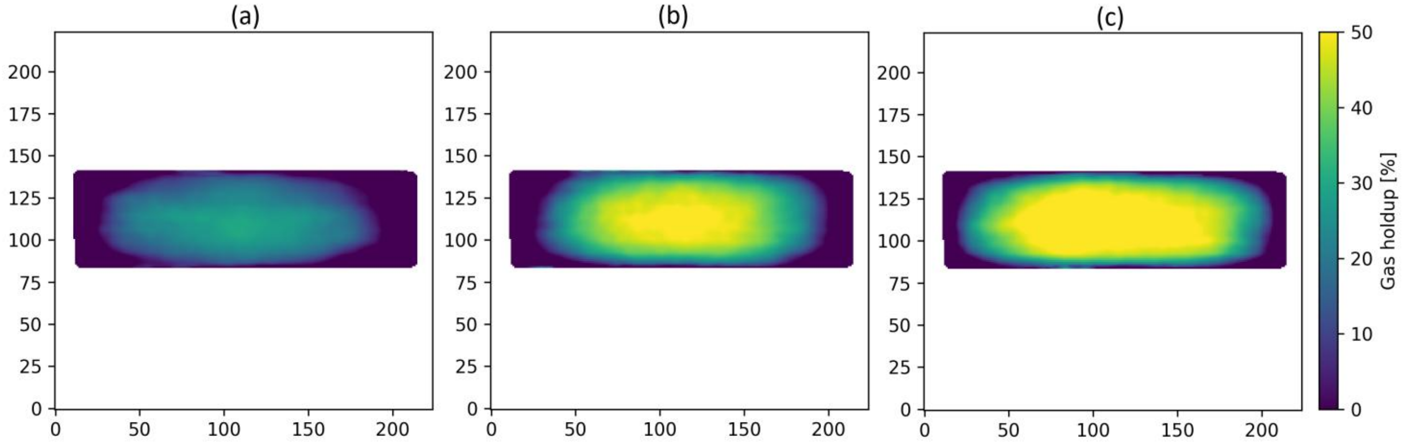
- Both methods show gas holdup increasing with superficial gas velocity — consistent trend
- MRI-derived values are systematically ~2× higher than bed expansion across the entire range
- Leading hypothesis: magnetic susceptibility mismatch between gas and liquid distorts the local field near bubbles, biasing the MR signal
- Further investigation ongoing (IPI group, Hamburg) to confirm the mechanism



Result: Local Gas Holdup Distribution

- Local holdup measured at three vertical regions: bottom (0–25 cm), middle (25–50 cm), top (50 cm–liquid level)
- Radial pattern: higher gas holdup in the column center, lower near the walls
- As U_G increases, spatial variation becomes more pronounced, especially toward the center
- ***Note:*** reported local values carry the same systematic MRI overestimation discussed earlier — the pattern is reliable, the absolute magnitude should be read with that caveat in mind

superficial gas velocity [m/s]	0.009	0.013	0.017	0.021	0.025	0.03	0.034	0.039
Bottom	10.8	12.4	18	20.8	24.3	29.4	30.5	34.6
Middle	6.6	12	16.9	19.9	21.2	25.6	27.43	30.1
Top	0.32	1.32	5.6	7.8	12.5	14.2	15.7	18.55



Time-averaged local gas holdup contours in the middle plane at different superficial gas velocities:
(a) $U_G = 0.0086\ m/s$ (b) $U_G = 0.02525\ m/s$ (c) $U_G = 0.03886\ m/s$.

Conclusion

- Four flow regimes, three transition points identified — mono-dispersed regime absent, first transition collapses at origin, direct jump from coalescence structures to pure-heterogeneous
- Global gas holdup increased with U_G in both methods; MRI consistently ~2× bed expansion across the full range
- Supports the applicability of the drift-flux methodology (Besagni, 2021) for regime identification in rectangular geometry.
- Demonstrates the value of non-intrusive diagnostics (MRI) for resolving spatial fluid dynamic behavior that global methods alone cannot capture

Thank you for your time and your attention.

Acknowledgment

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