Influence of Bubble Release Mechanism on the Rise Velocity and Deformation of Single Bubbles in Aqueous Ionic Liquid Solutions

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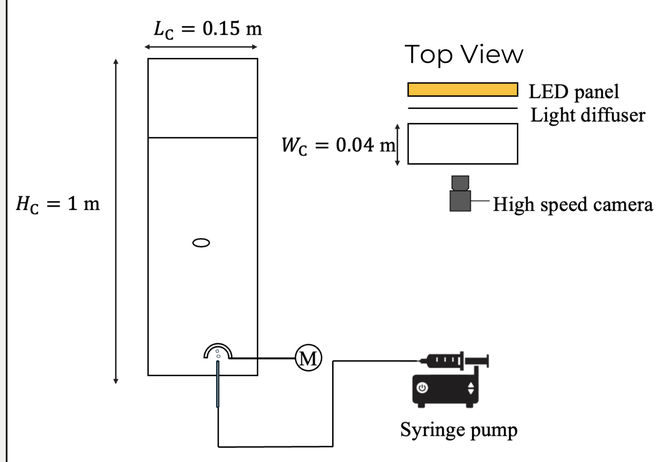
Research Gap

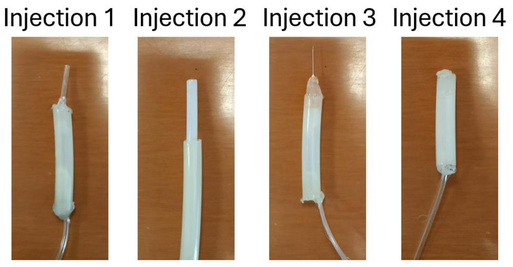
Bubble column performance depends on several factors, with single-bubble rise velocity, deformation, and trajectory stability as the most common entry point for understanding gas-phase fluid dynamics. Yet single-bubble studies rely on controlled release (Agrawal, A. (2021), Physics of Fluids.), and different generation methods (capillary injection vs. dumping-cup release) may impose different initial conditions — a variable rarely questioned. **Does the bubble release mechanism affect bubble dynamics?**

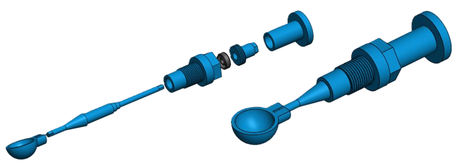
This work addresses that gap by comparing capillary injection and dumping-cup release, quantifying their effects on terminal rise velocity, aspect ratio, and trajectory in both distilled water and aqueous BMIM–BF_4 solutions — to establish whether generation method should itself be treated as a control parameter in bubble dynamics studies.

Experimental setup

Experiments were performed in a rectangular bubble column using air bubbles rising in distilled water and aqueous BMIM–BF_4 solutions under ambient conditions. Bubbles in the 3–10 mm diameter range were generated using two methods: rotating dumping-cup release and conventional capillary injection, enabling direct comparison of bubble behavior under different release conditions.



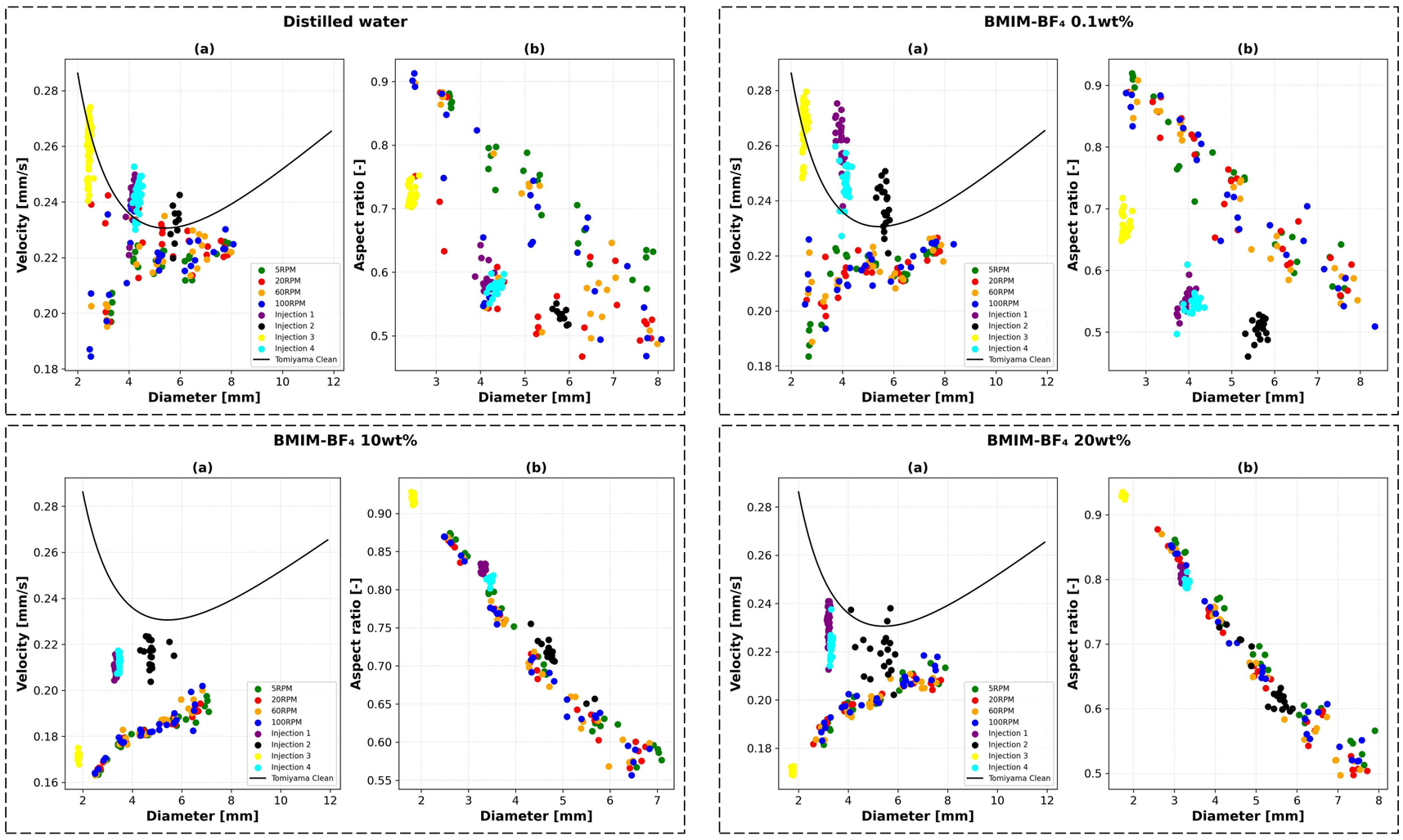




Fluid	Density $[kg/m^3]$	Viscosity $[\text{Pa s}] * 10^{-3}$	Surface tension $[N/m]$
Distilled water	998	0.89	0.072
BMIM-BF_4 $0.1\ wt\%$	998	0.89	0.072
BMIM-BF_4 $10\ wt\%$	1013.77	1.10	0.052
BMIM-BF_4 $20\ wt\%$	1030.49	1.33	0.048

Results and discussion "Terminal Velocity and Deformation Across Bubble Size"

$BMIM–BF_4$ concentration variations



Terminal Velocity

- Free injection → faster rise: 0.232–0.261 m/s
- Dumping-cup → slower rise: 0.164–0.224 m/s
- Release mechanism significantly affects bubble motion

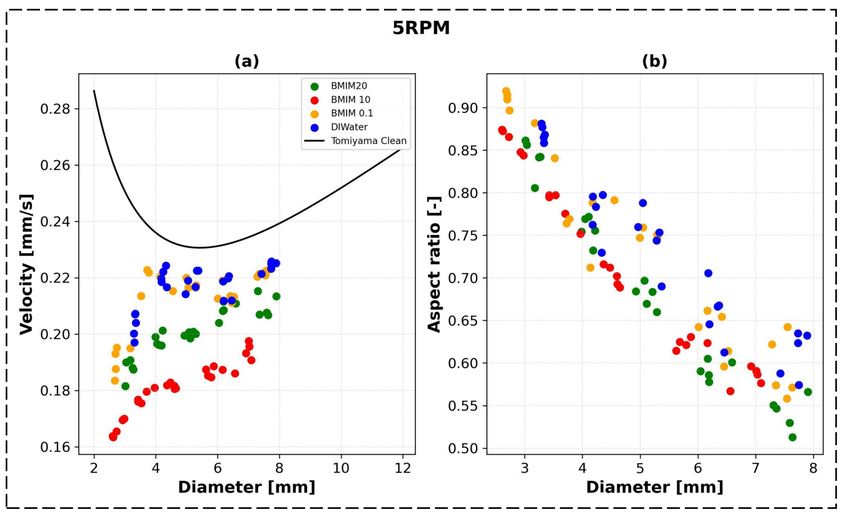
Bubble Deformation

- Free injection → more deformed (AR: 0.53–0.72)
- Dumping-cup → near-spherical (AR: 0.75–0.90)
- Reduced fluid dynamic resistance leads to faster rise, resulting in greater bubble deformation

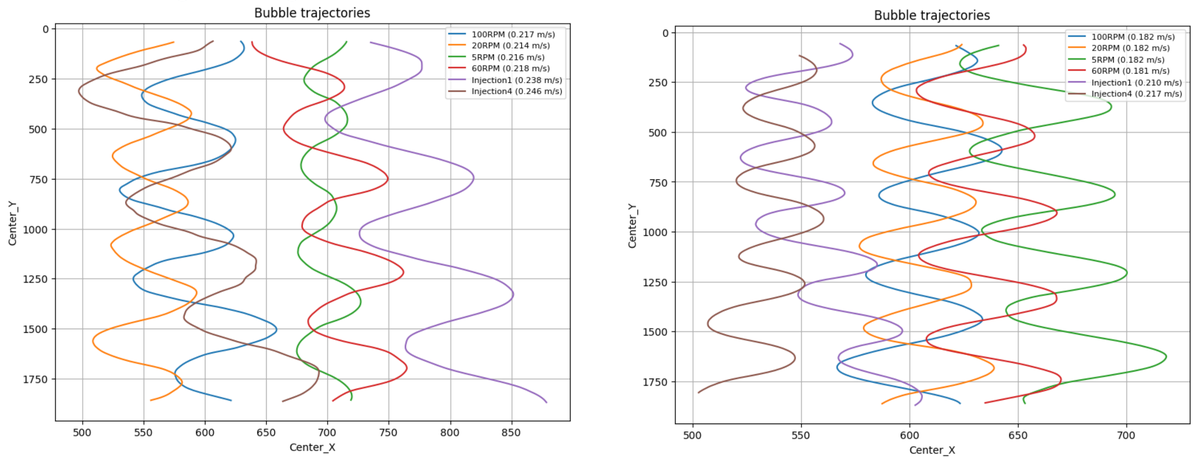
Effect of Ionic Liquid Concentration

- At **0.1 wt%,** bubbles exhibited **slightly higher terminal velocities** than in pure water.
- The effect of BMIM concentration on terminal velocity is **non-monotonic**: velocity does not decrease progressively with increasing concentration.
- The 10 wt% solution imposes the strongest reduction in rise velocity among all tested conditions.
- The **20 wt%** solution consistently yields **higher terminal velocities than the 10 wt%** solution.
- Rotational speed (5–100 rpm) had a **negligible effect** on terminal velocity and deformation trends.

Representative Rotation Speeds



Bubble Trajectory Behavior



(a) BMIM-BF_4 0.1 wt% **(b) BMIM-BF_4 10 wt%**

- Dumping-cup bubbles exhibit more pronounced oscillatory motion than freely injected bubbles.

Conclusions

- The **bubble release mechanism** significantly influences single-bubble fluid dynamics across the investigated diameter range (**0.0025–0.0083 m**) and operating speeds (**5–100 rpm**).
- **Freely injected bubbles** exhibited higher terminal velocities (**0.232–0.261 m/s**) than **dumping-cup bubbles** (**0.164–0.224 m/s**) under comparable conditions.
- Bubble shape differed between release methods: freely injected bubbles were more **deformed**, while dumping-cup bubbles remained closer to **spherical geometry**.
- Increasing **BMIM–BF_4 concentration** reduced variability in bubble shape and trajectory behavior.
- The results demonstrate that **controlled bubble release** is not reliable for single-bubble experiments.

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