UIT **2026**

Preliminary assessment of the drag coefficient of single bubbles rising in a water–ionic liquid mixture

22/06/2026

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Outline

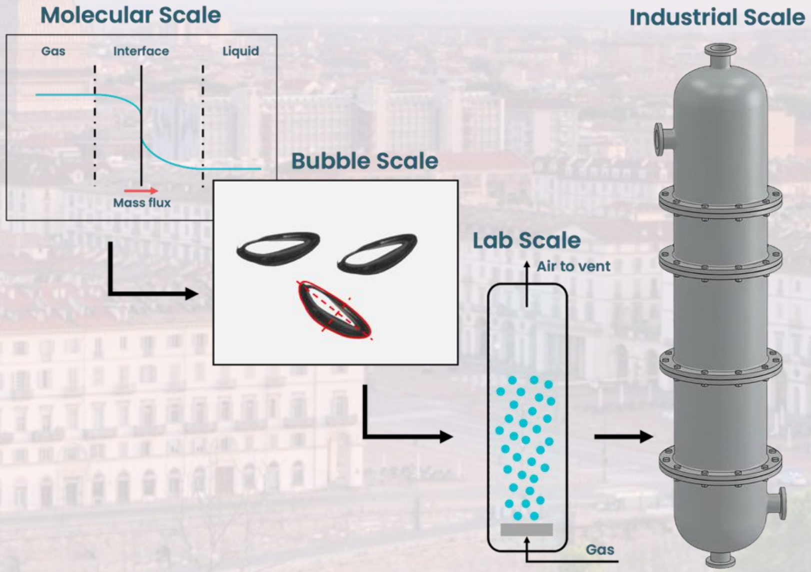
1. Motivations
2. Experimental facility layout and methods
3. Results
4. Conclusions

Motivations

Bubble columns
- Gas-liquid reactors
- Advantages
  - Excellent heat and mass transfer between the phases
  - Easy of operation
  - High durability
  - Solids can be handed without erosion or plugging problems
- Large scale gas-liquid processes are of great importance for our everyday life
  - Chemical & Biotec industry
  - CO_2 Absorption & Carbon capture
  - Pharmaceutical industry
- Mass transfer often limits reactor performance

Bubble scale
- Fluid properties (viscosity, surface tension, density) influence bubble shape, velocity...

Macroscopic scales
- Fluid dynamics control mixing and interfacial renewal determining the overall mass transfer rate

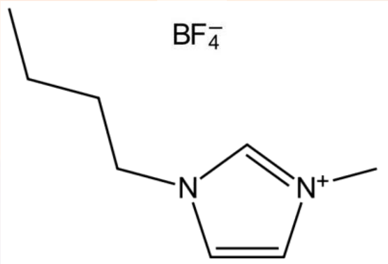


Motivations

- Negligible vapor pressure and high chemical and thermal stability
  - prevents **solvent evaporation and loss**
- Tunable physiochemical properties depending on cation-anion combination (about ~10^{14})
  - Physicochemical properties can be **systematically tailored**
  - Interesting for studying the influence on mass transfer

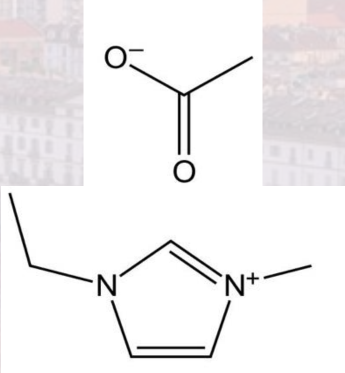
1-butyl-3-methylimidazolium tetrafluoroborate [BMIM][BF4]

- Physical absorption
- Relatively low viscosity
- Well-established benchmark system for CO_2 studies



1-ethyl-3-methylimidazolium acetate [EMIM][OAc]

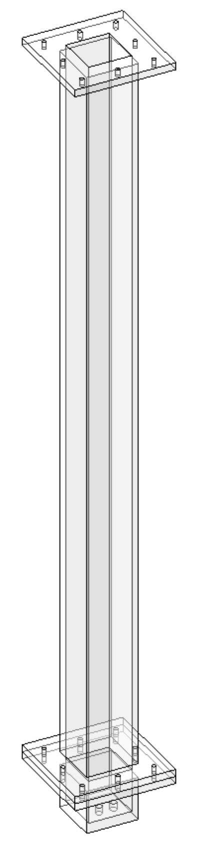
- Physical/chemical absorption
- High viscosity
- Stronger CO_2 affinity



liquid

Motivations

Small scale $D \approx 0.1$ m



Pilot scale $D \approx 0.4$m

Industrial scale $D \approx 3$ m

Understanding bubble-scale dynamics is key to developing reliable predictive models for industrial-scale reactor hydrodynamics

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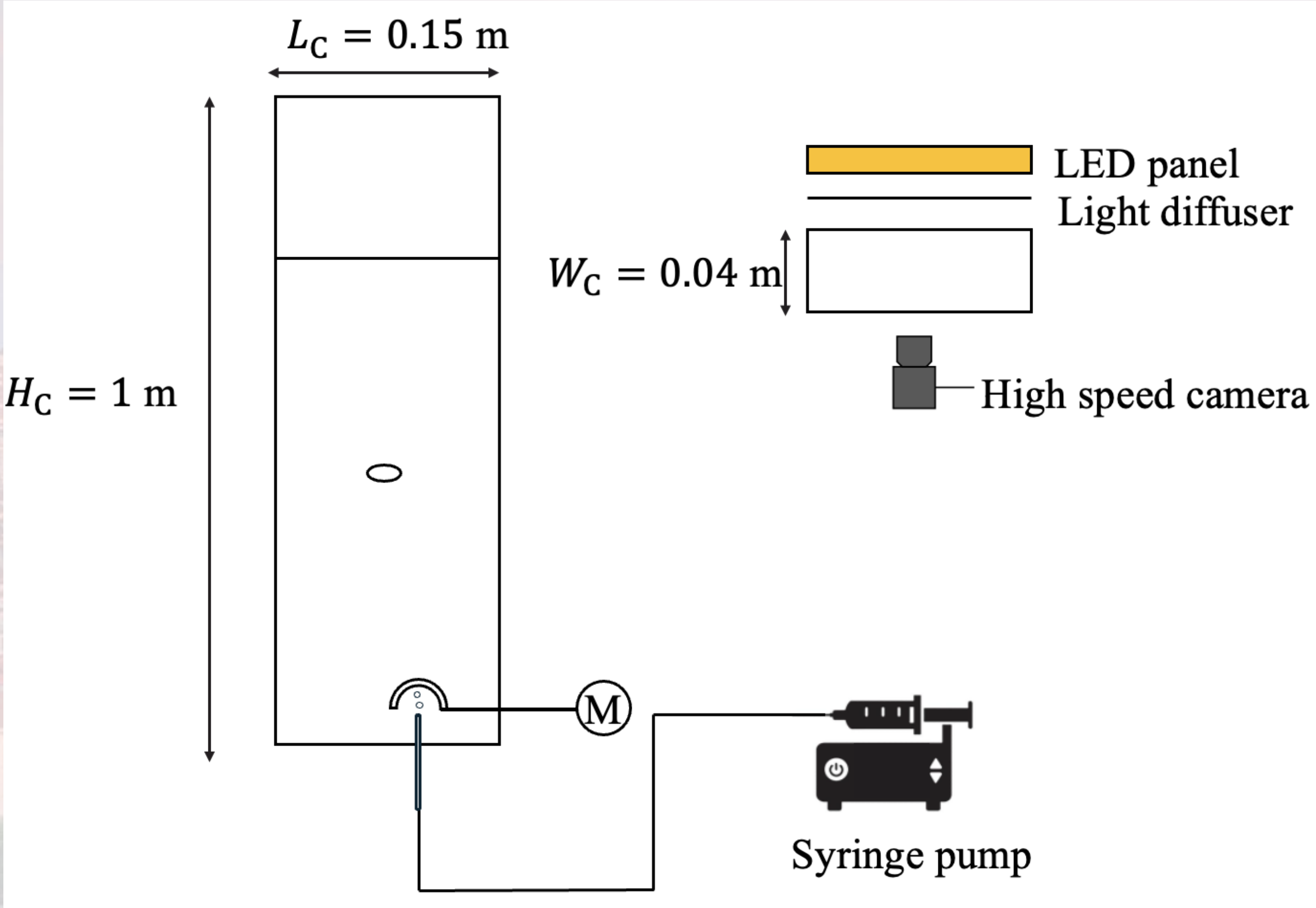
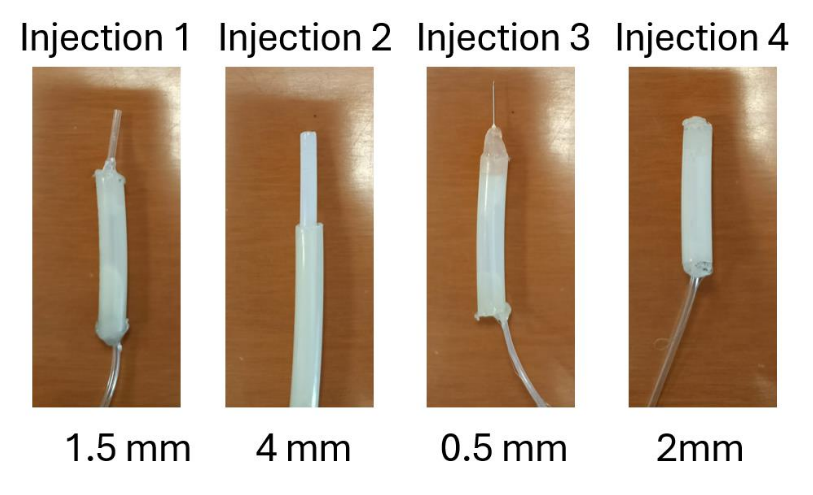
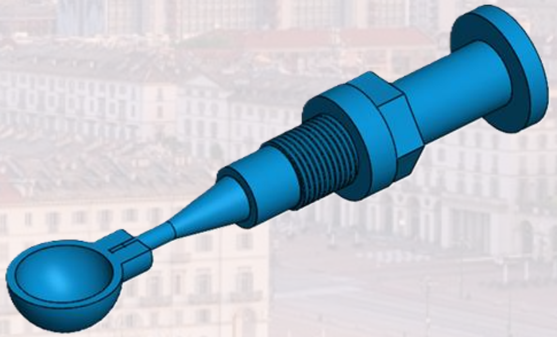
Experimental facility layout

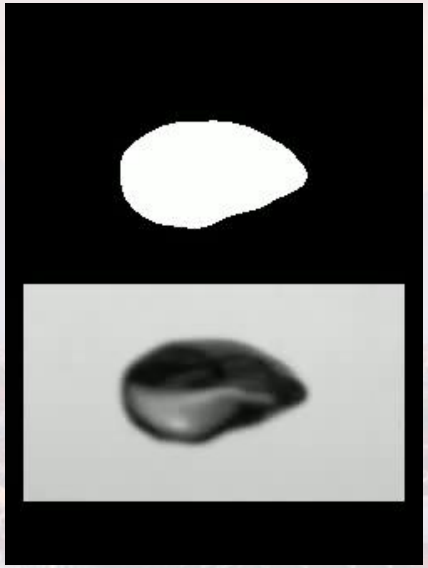


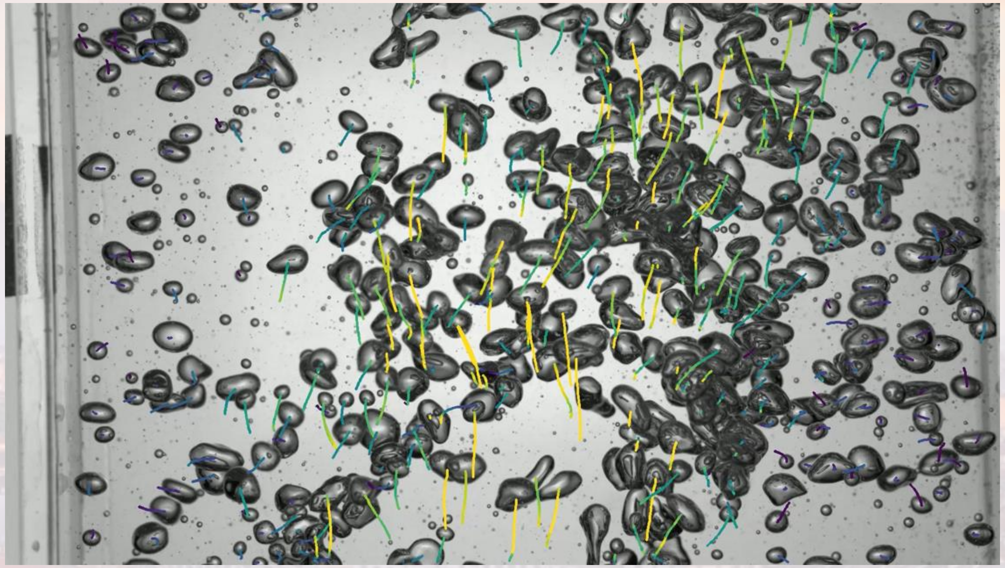




Experimental facility layout

- Record bubbles using high-speed camera
- Apply background subtraction
- Detect bubble contour by image thresholding
- Measure
  - Aspect ratio
  - Bubble position
- Track bubble motion to calculate
  - Rise velocity (also in bubble swarms)
  - Trajectory
- AI for optical multiphase flow
- The drag coefficient is obtained from the balance between buoyancy and drag forces





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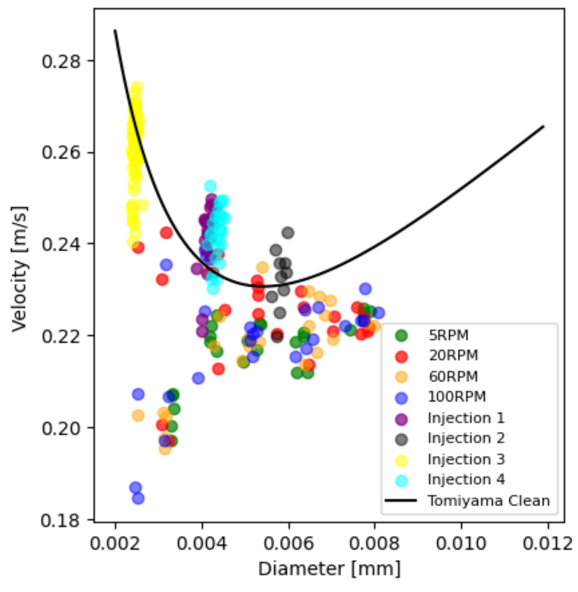
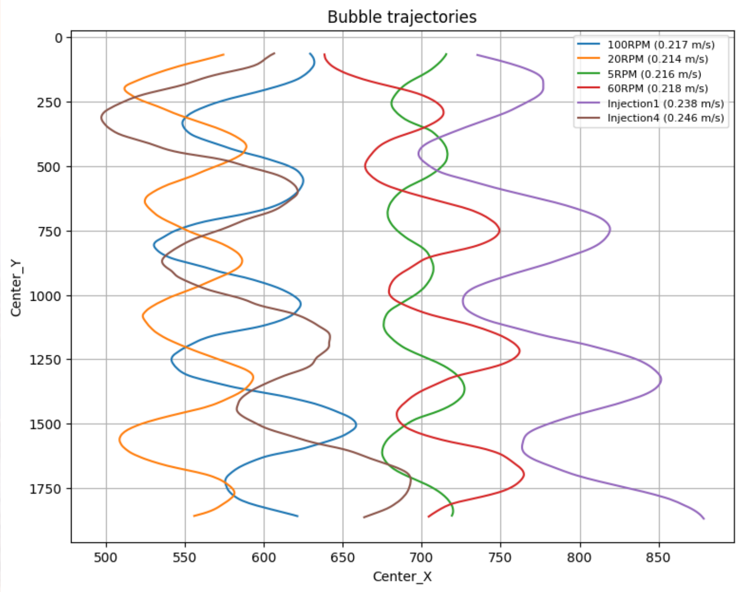
Results: influence of bubble release mechanism

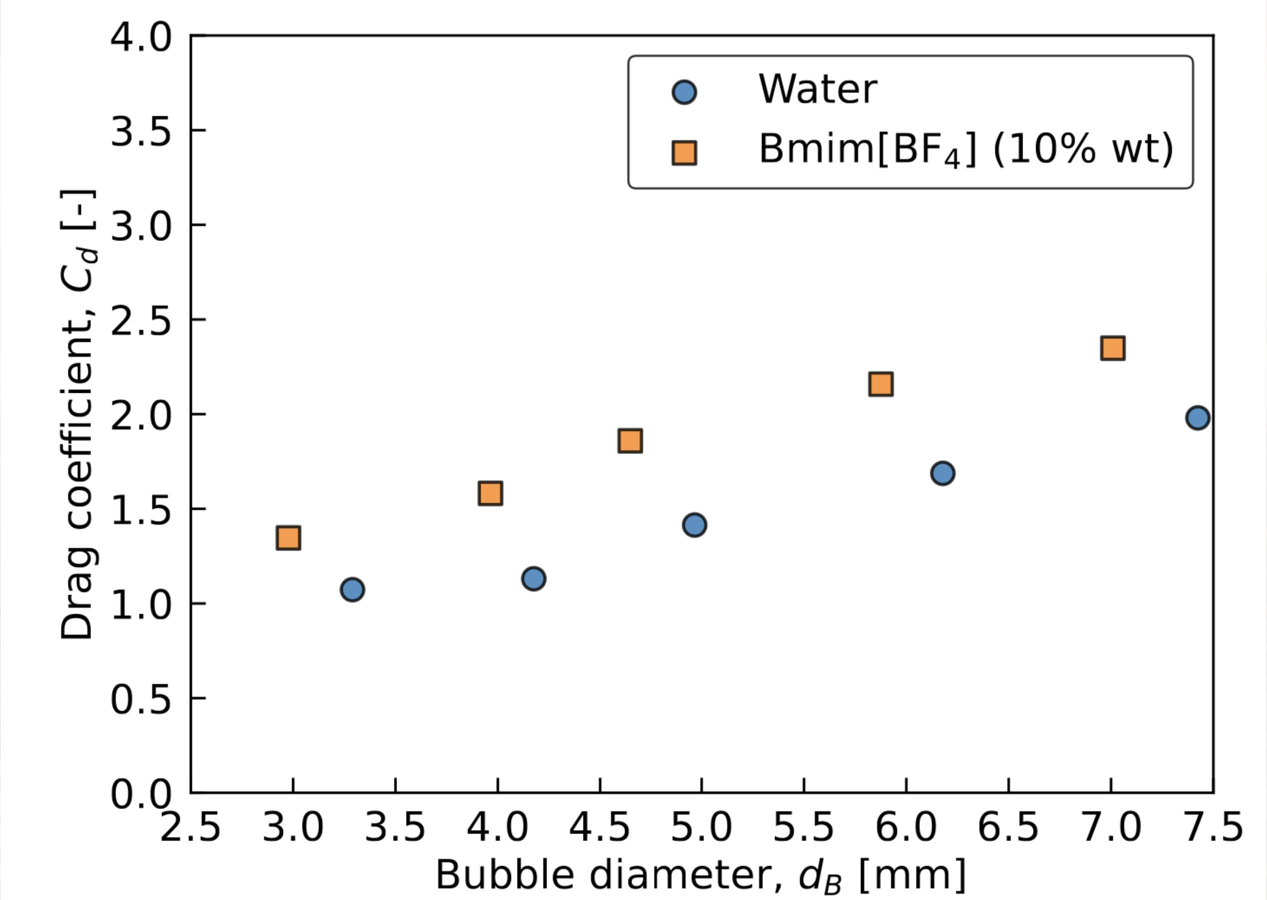
- Freely injected bubbles rise faster than dumping-cup bubbles
- Terminal velocity: 0.232–0.261 m/s (free injection) vs. 0.164–0.224 m/s (dumping cup)
- The effect is consistent across all investigated bubble diameters
- Bubble release conditions strongly influence subsequent bubble motion
- Free injection → fewer trajectory oscillations
- Dumping cup → more pronounced oscillatory motion
- Bubble motion stability depends on the release mechanism
- Initial conditions have a lasting impact on the bubble ascent trajectory





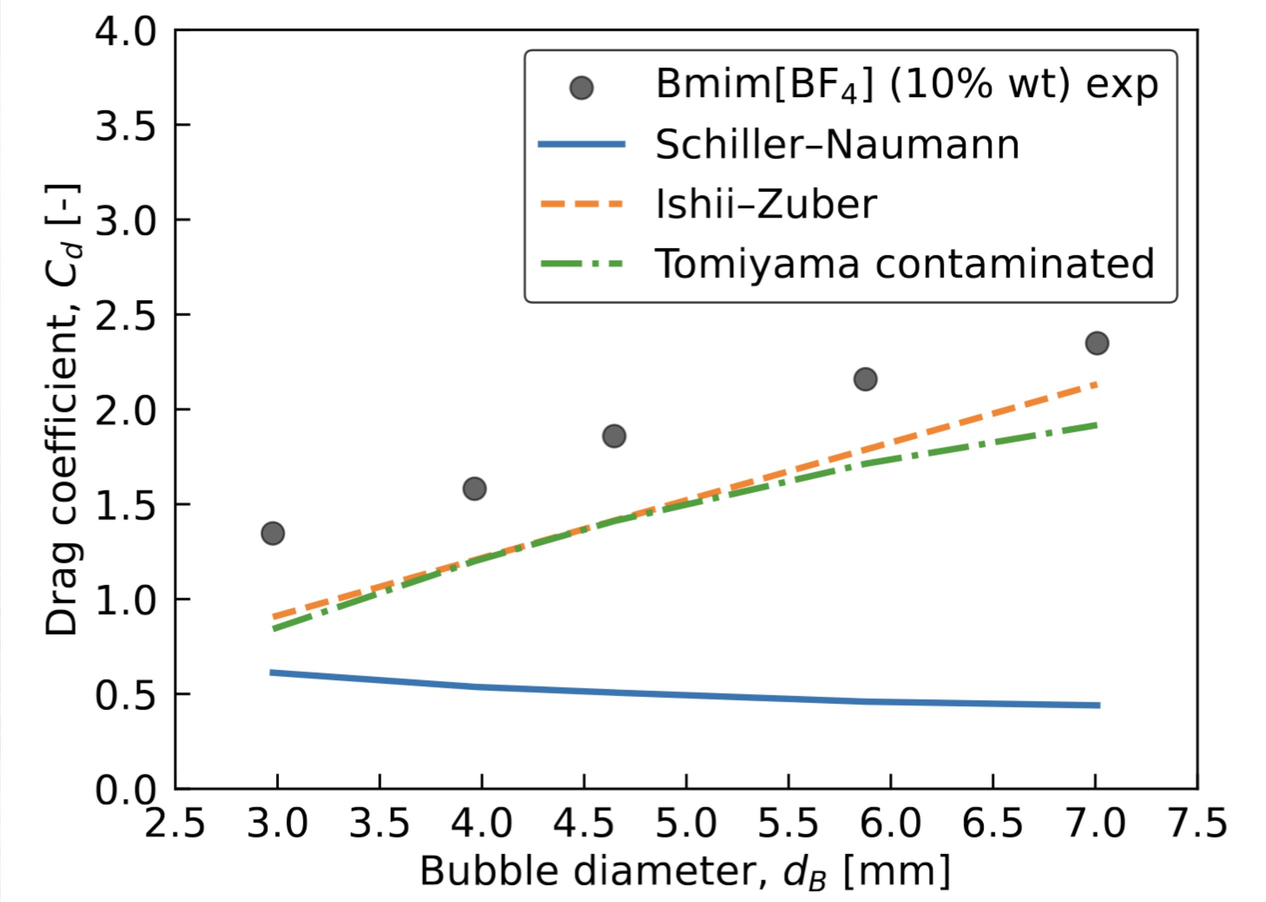
Results: influence of BMIM concentration on drag coefficient

- Bubble drag increases with increasing bubble diameter
- The ionic liquid mixture leads to higher drag coefficients over the entire diameter range
- Viscosity and surface tension play a key role in bubble hydrodynamics
- Experimental drag coefficients exceed model predictions over the entire diameter range
- Additional effects related to the ionic liquid are not captured by current correlations



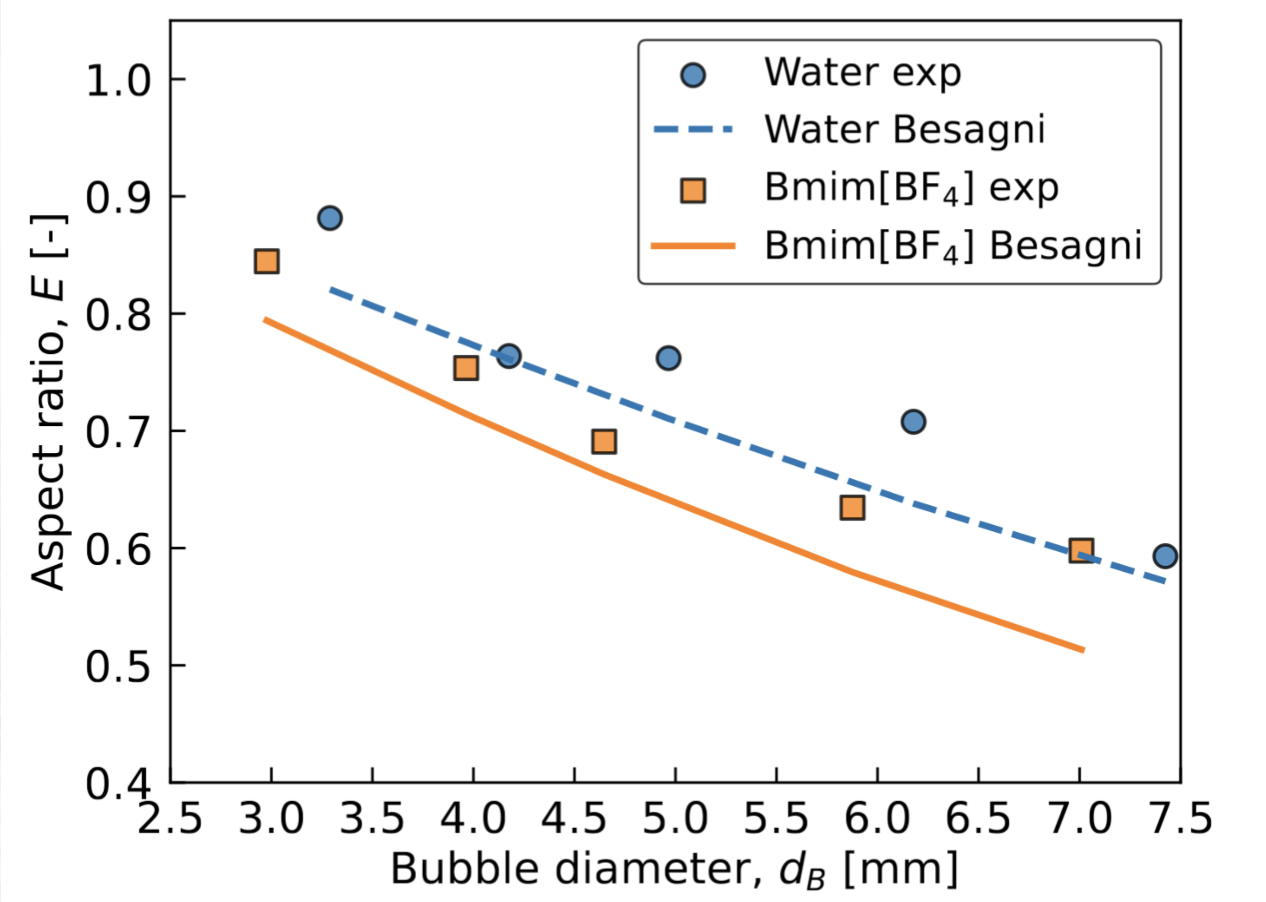
Results: influence of BMIM concentration on drag coefficient

- Bubble drag increases as bubble size and deformation increase
- The ionic liquid mixture leads to higher drag coefficients over the entire diameter range
- Viscosity and surface tension play a key role in bubble hydrodynamics
- Experimental drag coefficients exceed model predictions over the entire diameter range
- Interfacial contamination and ionic-liquid-specific effects are not fully captured by current correlations



Results: influence of BMIM concentration on drag coefficient

- Aspect ratio (E) is defined as the ratio between the bubble minor and major axes
- The aspect ratio decreases with increasing bubble diameter
- Bubbles in the water–Bmim[BF_4] (10 wt%) mixture exhibit slightly lower aspect ratios than in pure water.



Conclusions

- Bubble drag increases with bubble size and is consistently higher in the water–Bmim[BF_4] (10 wt%) mixture than in pure water
- The ionic liquid promotes greater bubble deformation, resulting in lower aspect ratios and non-spherical bubble shapes
- Current drag correlations underestimate the experimental data, indicating that ionic-liquid-specific effects are not fully captured
- Understanding single-bubble dynamics is essential for developing reliable closure relations and predictive models for industrial-scale bubble columns

Thank you for the attention!

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This work has been financed by the Italian Ministry of University and Research (Ministero dell'Universit. e della Ricerca) within the FIS2 call. In particular, this work has been conducted within the AURIGA ("Unveiling the RIddles of GAs liquid fluid dynamics: towards novel carbon dioxide absorption systems") project. Project number FIS-2023-00204, CUP D53C25000730001, funded within the FIS2 call (Decreto Direttoriale n. 1236 del 1-08-2023).