Ministero dell'Università e della Ricerca

FIS

POLITECNICO MILANO 1863 | DEPARTMENT OF ENERGY

AURIGA "Unveiling the Riddles of Gas-Liquid Fluid Dynamics: Towards Novel Carbone Dioxide Absorption Systems" project: current status and perspectives

11.05.2026 I Prof. Giorgio Besagni, PhD I 55th European Two-Phase Flow Group Meeting

Outline

1. AURIGA project
2. Theoretical activity
3. IL selection and characterization
4. Bubble-scale activity
5. Large-scale-scale activity
6. Way forward

AURIGA project

01

AURIGA project – The goals

AURIGA - Unveiling the RIddles of GAs-liquid fluid dynamics: towards novel carbon dioxide absorption systems

General Goals

“In this proposal, I will formulate a novel theory to unveil some of the riddles (e.g., multi-scale connections) of gas-liquid fluid dynamics and, subsequently, I will apply the acquired perspective to develop a novel ionic-liquid reactor to absorb carbon dioxide from sour gas streams.”

Specific Goals

A. developing a physical-based approach to describe a-priori the flow patterns in bubble columns, including the relationships between local and global flow properties;

B. building and set-up experimental facilities (small-scale and large-scale) to study the influence of ionic liquids on the local and the global fluid dynamics and to study the mass transfer in CO_2-*IL* systems;

C. scaling-up towards the industrial scale.

AURIGA project – The Team

Principal Investigator

- Prof. Giorgio Besagni, PhD

Post Docs

- Nicolò Varallo (*fluid dynamics and mass transfer exp. and numerical research*)
- TBD – Selection ongoing (*impact assessment research*)
- TBD – Selection ongoing (*system analysis and forecasting research*)

PhD Students

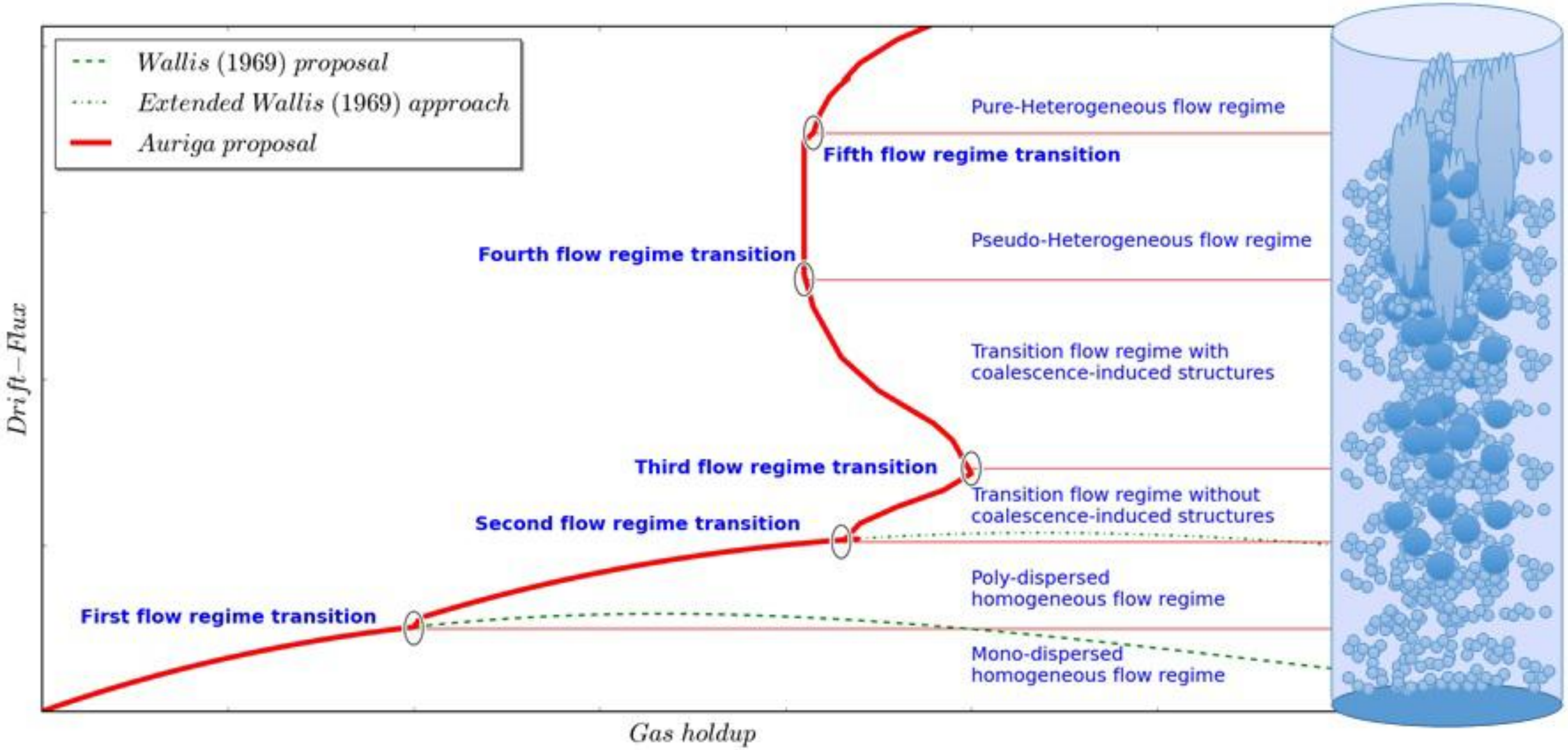
- Andrea Ferrario (*coalescence research*)
- Alberto Arici (*mass transfer and scaling-up research*)
- Djamel Eiddine Aissaoui (*bubble-scale research*)
- Francesco Pierini (*large-scale research*)
- Vitor Augusto Regert Dos Santos (*theoretical research*)

Research assistances positions still to be opened

Theoretical activity

02

Theoretical framework



Besagni, Giorgio. "Bubble column fluid dynamics: A novel perspective for flow regimes and comprehensive experimental investigations." International Journal of Multiphase Flow 135 (2021): 103510.

Database

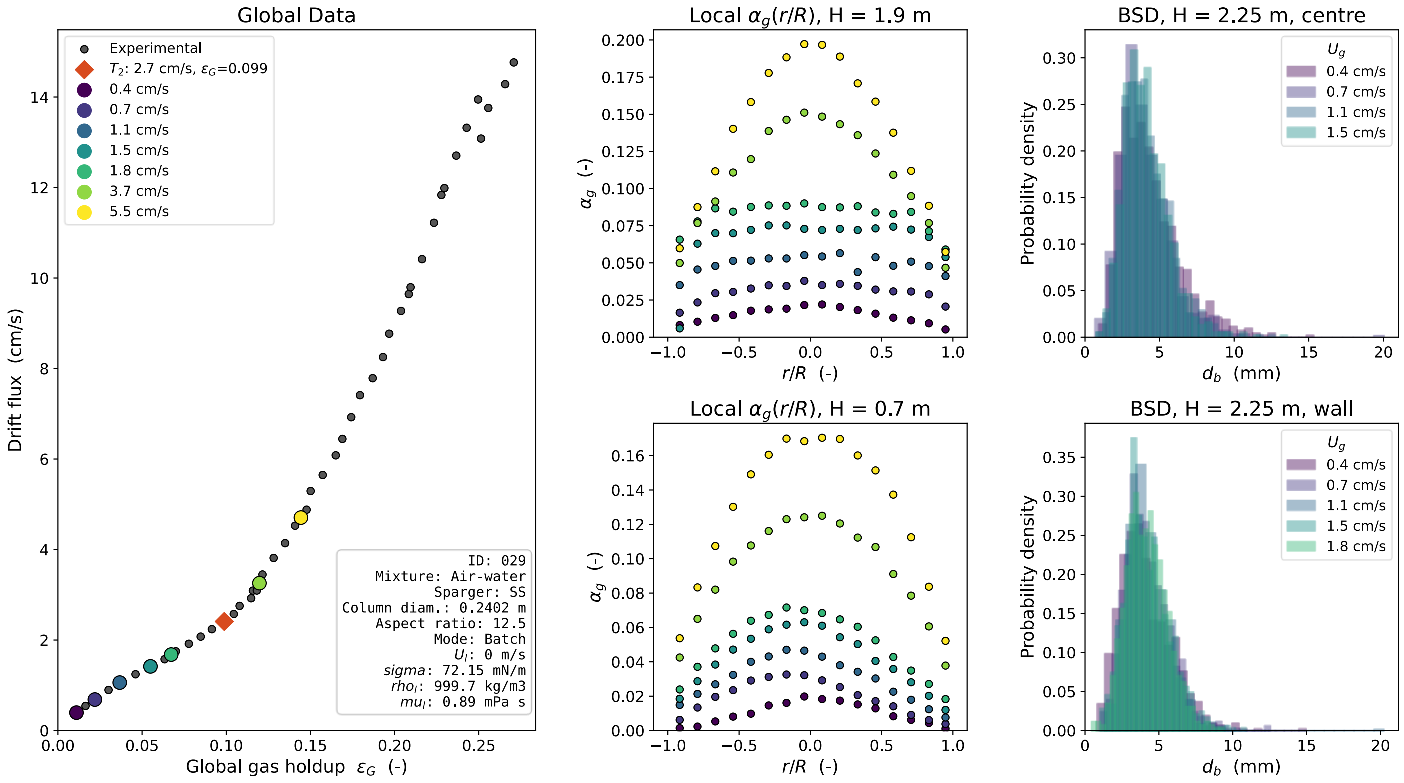
Framework

- structured database extracted from literature;
- local and global data linked;
- wide range of operating conditions, fluid properties, sparger and column geometries;

Outcomes and Outlooks

- 216 experiments;
- 216 gas holdup curves analyzed;
- 35 experiments with local data;
- 26 experiments with mass transfer data;
- 37 sources from literature.

Processing of all our previous images



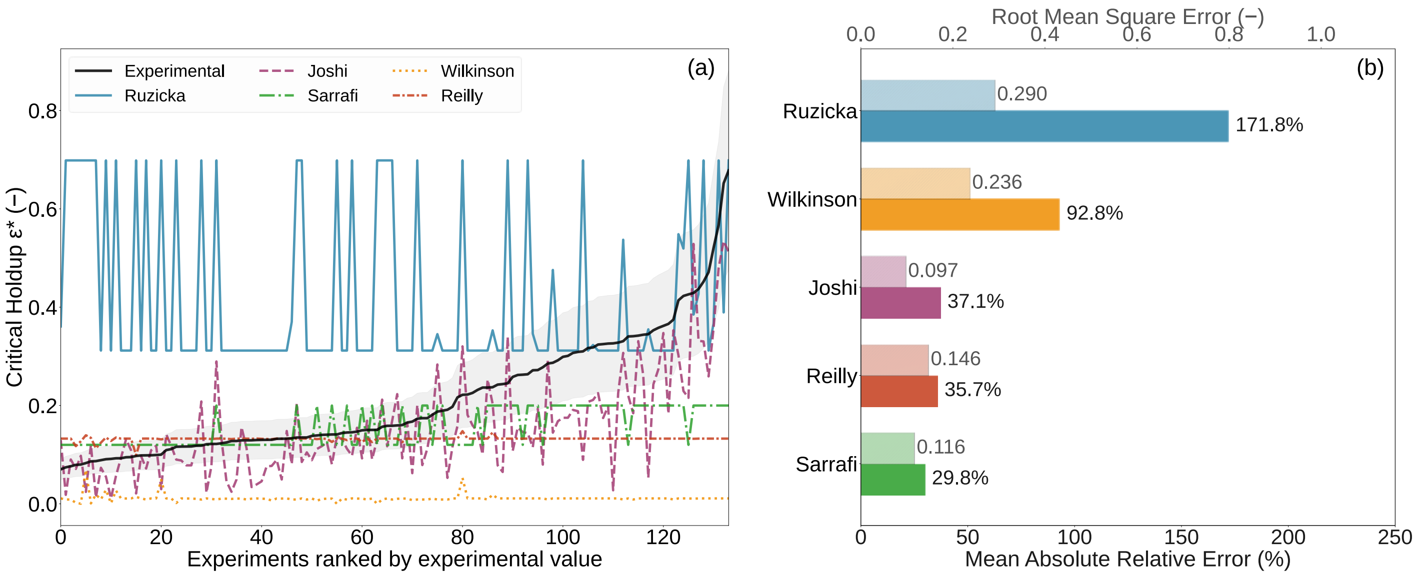
Flow regime transition modeling

Framework

- Compared existing models for predicting the end of the homogeneous regime;
- used terminal rise velocity from Wallis-plot fitting when required;
- calibrated fitting parameters using the full database to avoid case-specific tuning;
- applied all closures as originally proposed.

Outcomes and outlooks

- Joshi's model follows the experimental trend of critical gas holdup;
- propose an improved transition criterion able to predict the transition coordinates for all five flow-regime transitions.



IL selection and characterization

03

Selection of ILs

Framework

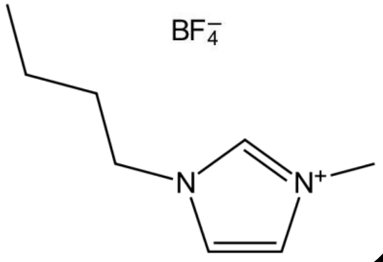
Why ILs? Negligible vapor pressure and high chemical and thermal stability. Prevents solvent evaporation and loss.
Tunable and wide physico-chemical properties depending on cation-anion combination (about ~10^{14}). Physico-chemical properties can be systematically tailored. Interesting to study influence on mass transfer.

Outcomes and outlooks

- Two ILs have been selected and acquired

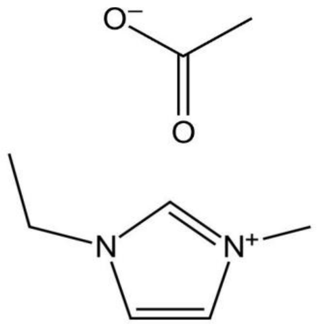
1-butyl-3-methylimidazolium tetrafluoroborate
[BMIM][BF4]

- Physical absorption
- Relatively low viscosity
- Well studied benchmark for CO_2 study



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

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



Cooperation with Institute of Multiphase Flows, TUHH

TUHH ims Institute of Multiphase Flows

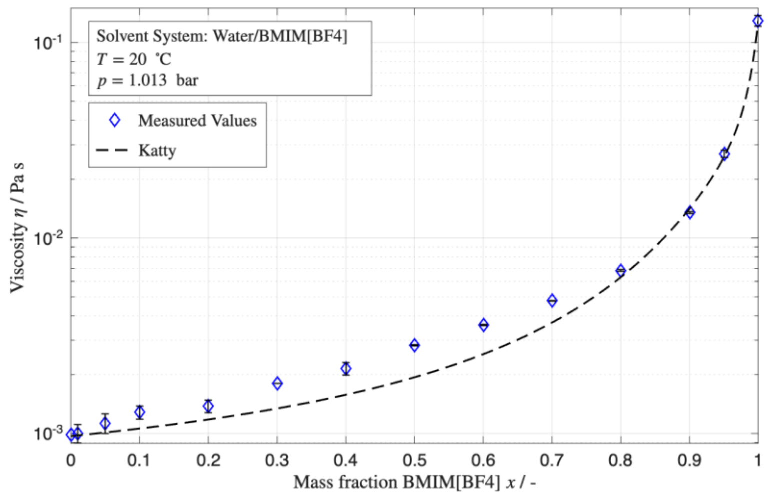
Characterization of ILs

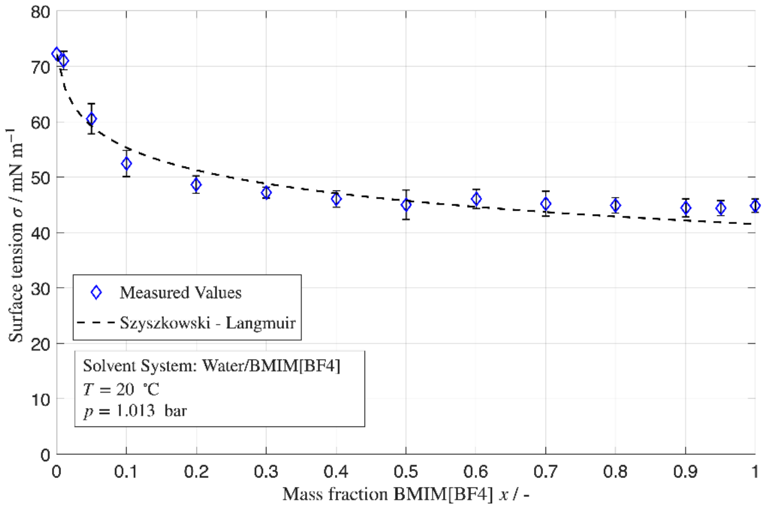
Framework

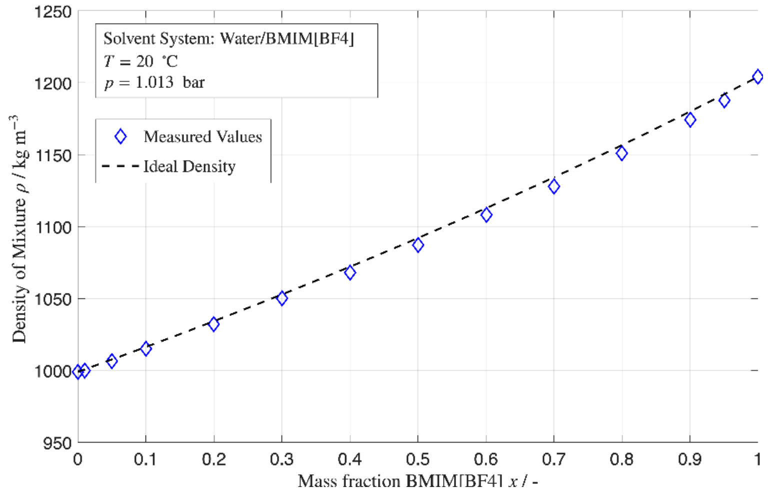
Physico-chemical properties measurement of ILs-water mixtures.

Outcomes and outlooks

- density, viscosity and surface tension have been measured for **14 Binary mixtures of ILs and water;**
- on-going solubility measurements.







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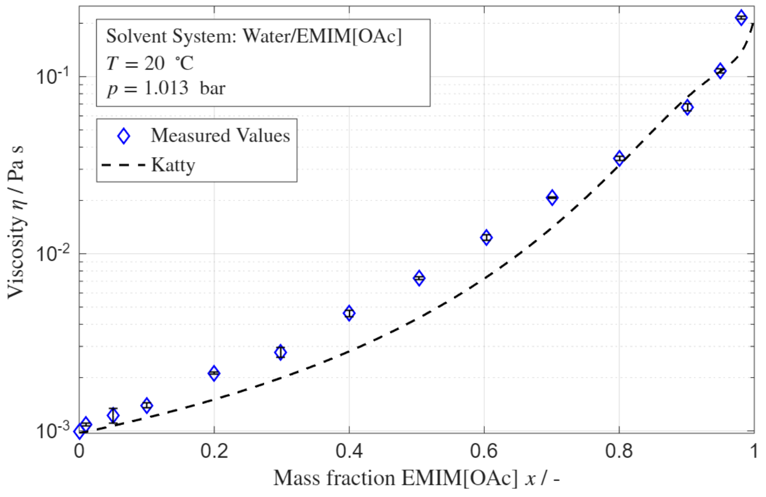

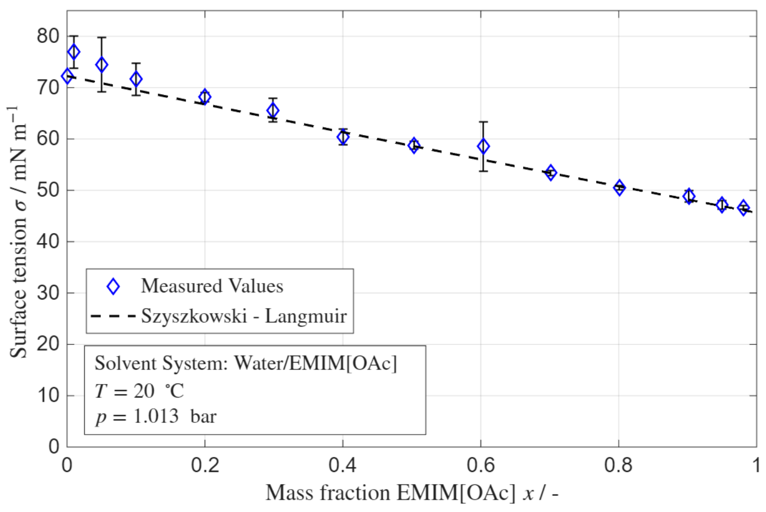

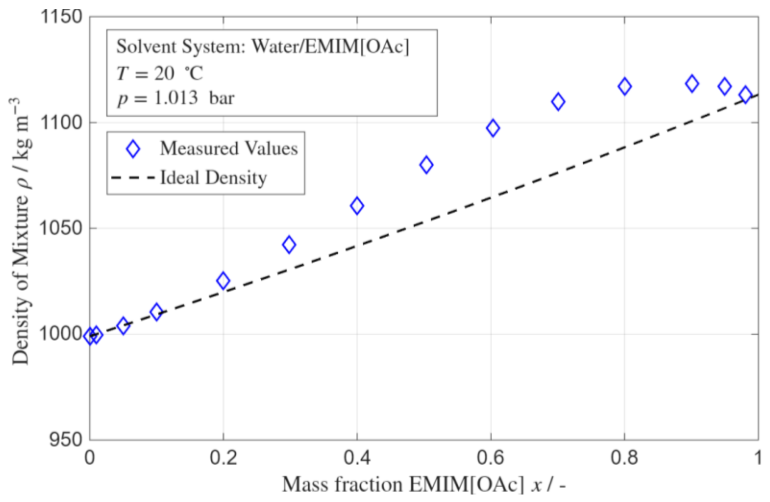

Bubble-scale activity

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Cooperation with Complex Fluids and Flows Unit, OIST

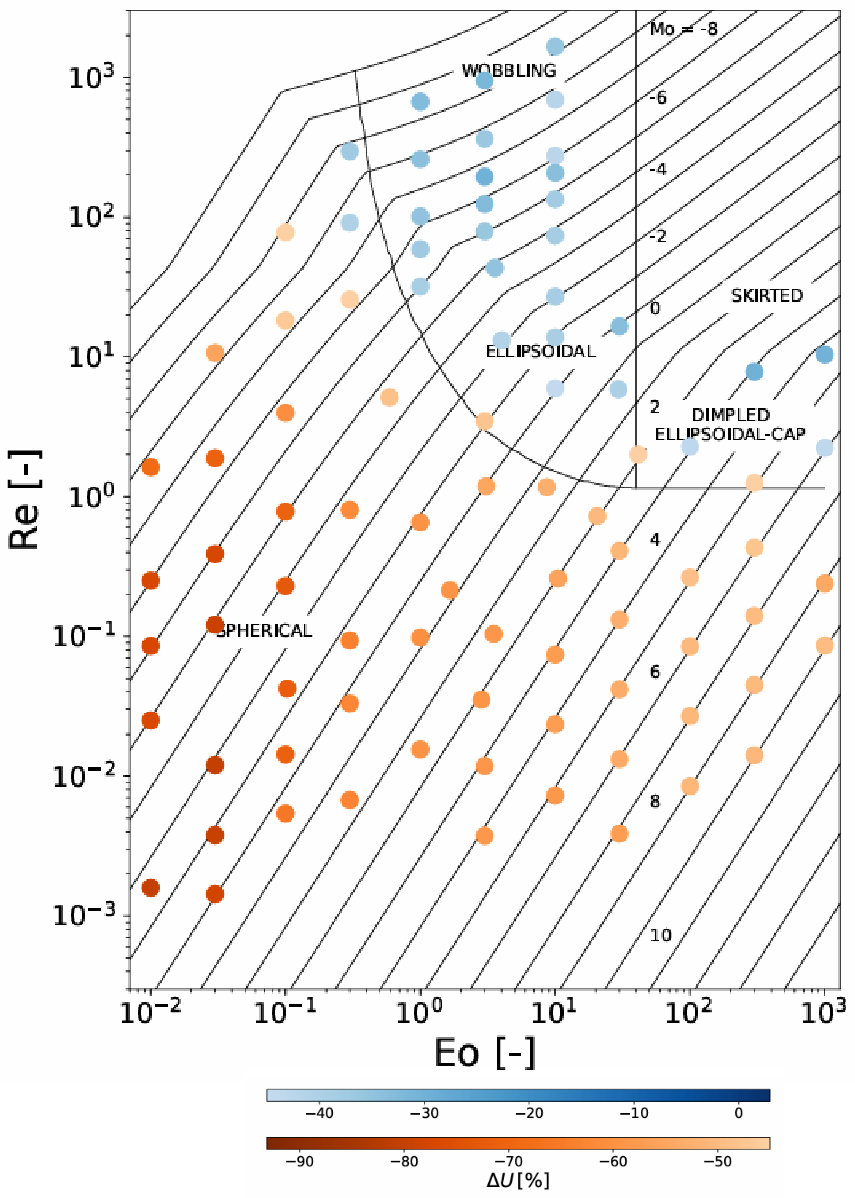
Numerical research

Framework

DNS simulation of rising bubbles in confined and non-confined domains to obtain general correlations to relate the bubble shape and size;

Outcomes and outlooks

- terminal velocity measurement;
- influence of liquid properties on bubble shape;
- mapping of bubble shape as function of Eo, Re and Mo.

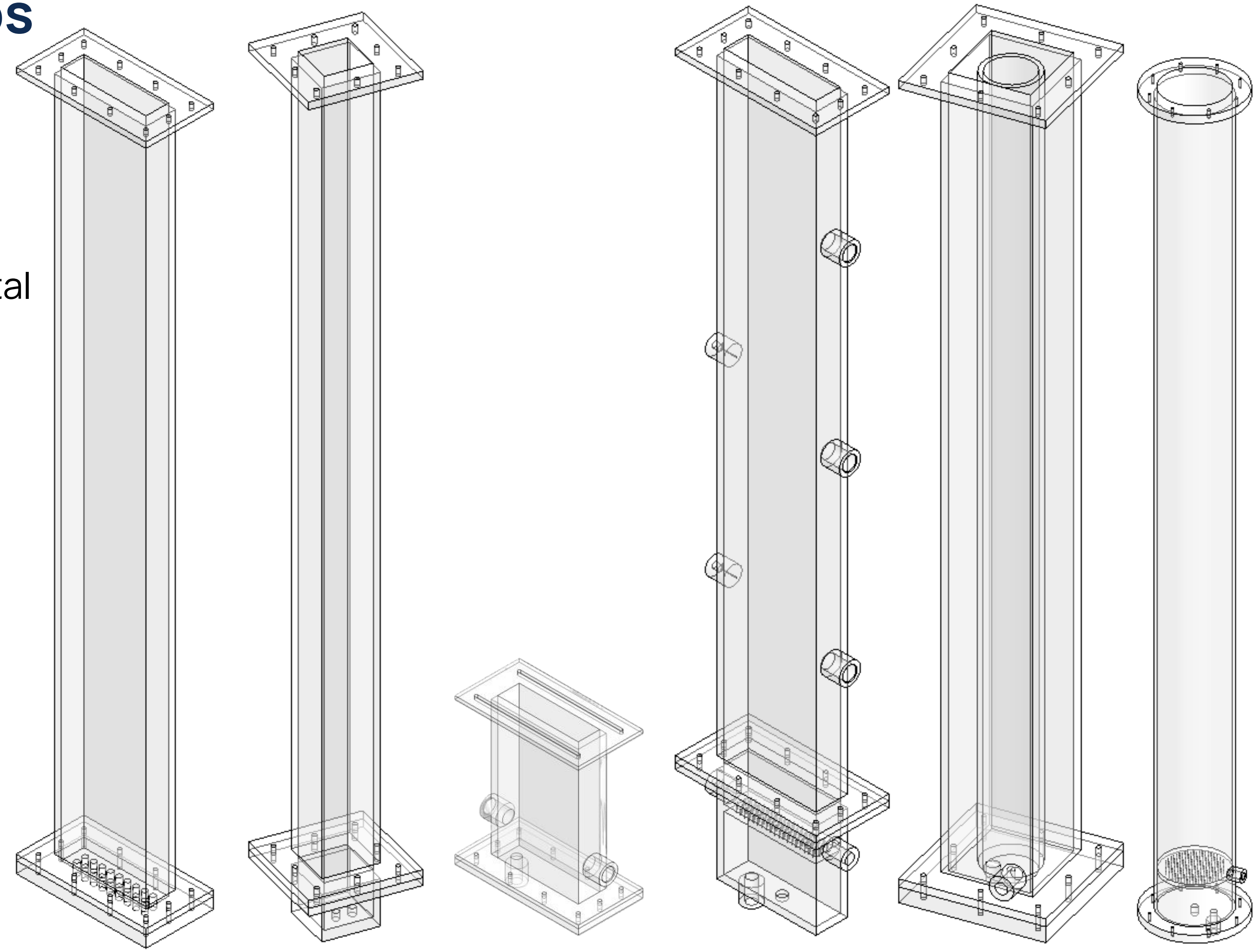


Small-scale experimental setups

Framework

After preliminary tests, a new set of experimental facilities have been identified:

- facility for CFD-grade data (a)
- facility for single-bubble fluid dynamics (b)
- facility for bubble coalescence (c)
- facility for bubble swarm (d)
- facility for mass transfer studies (e)
- facility for scaling-up studies (f)



(a) (b) (c) (d) (e) (f)

Cooperation with Computational fluid dynamic Department, HZDR

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

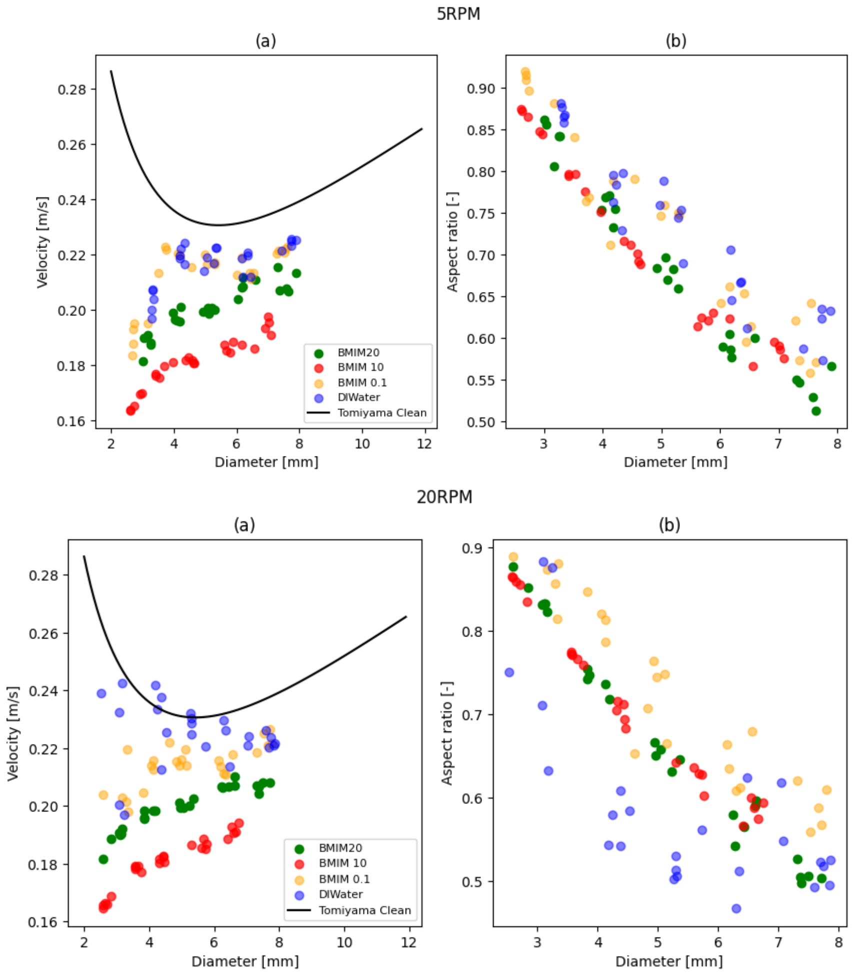
Single bubble experiments

Framework

Single-bubble experiments in a rectangular bubble column using dumping-cup and capillary injection methods. Air bubbles (2.5–8.3 mm) were studied in water and BMIM-BF_4 solutions using high-speed imaging.

Outcomes and outlooks

- free injection produced higher rise velocities than dumping-cup release;
- increasing BMIM concentration stabilized bubble shape and trajectory behavior;
- bubble release conditions strongly affected bubble dynamics.



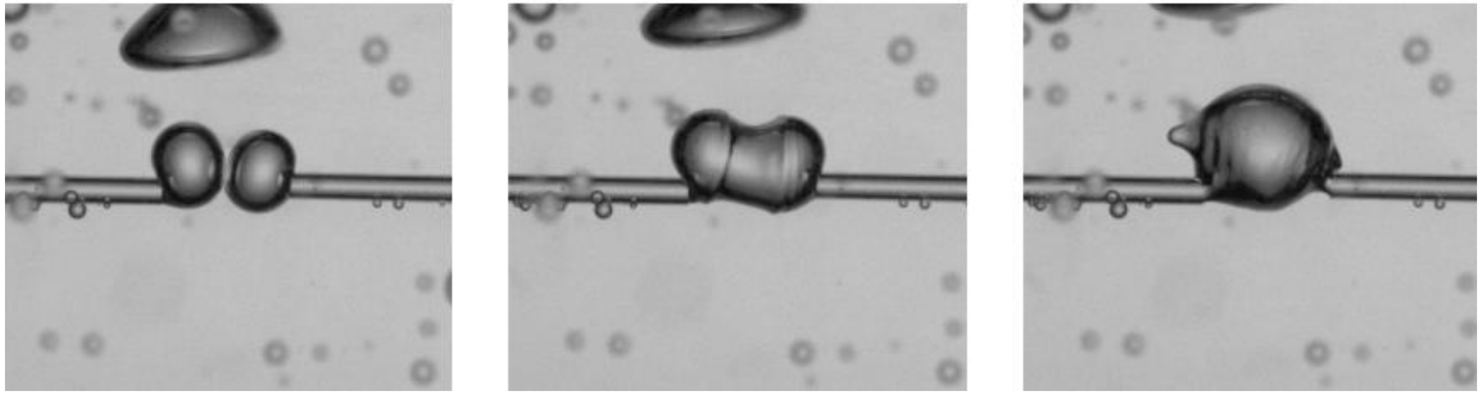
Coalescence experiments

Framework

Coalescence of bubble pairs to investigate time and efficiency. Injection through opposed capillaries with different orifice dimension, distance and bubble approach velocity. Image acquisition trough high speed camera.

Outcomes and outlooks

- Identification of the coalescence transition in water-ILs mixtures;
- coalescence time an efficiency measurements;
- comparison of experimental results with theoretical film drainage models.



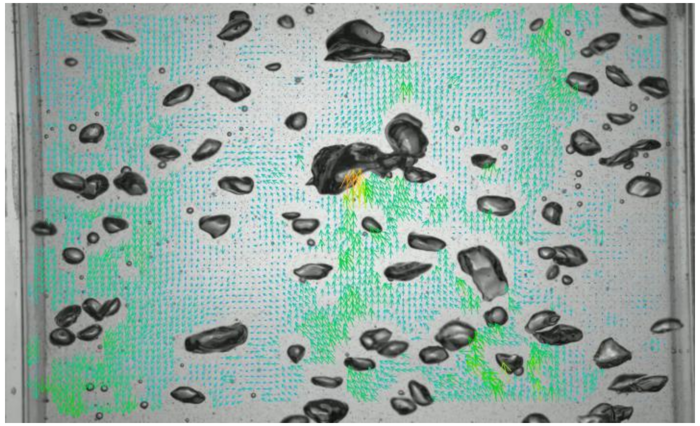
Institute of Process Imaging

HZDR HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

Swarm of bubble experiments

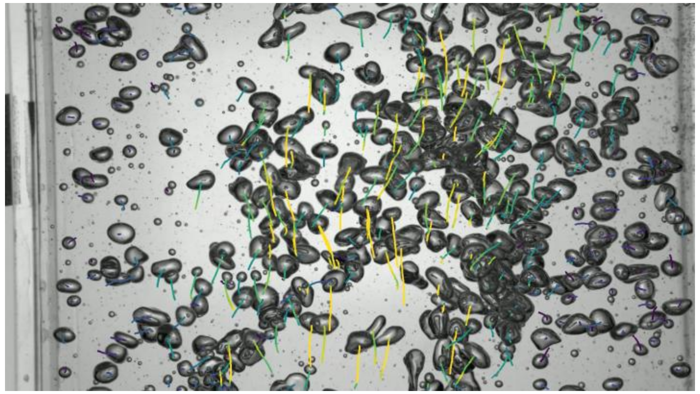
Framework

Flow regime transitions investigated in a rectangular bubble column using drift-flux analysis and optical flow visualization. A PSIV setup was developed using 100 μm polyamide particles as tracers. MRI-based measurements used to obtain local gas holdup distributions.



Outcomes and outlooks

- flow regimes and transition points identified;
- microbubbles proved effective as tracers under specific operating conditions.
- MRI enabled non-intrusive spatial characterization of bubble column fluid dynamics.



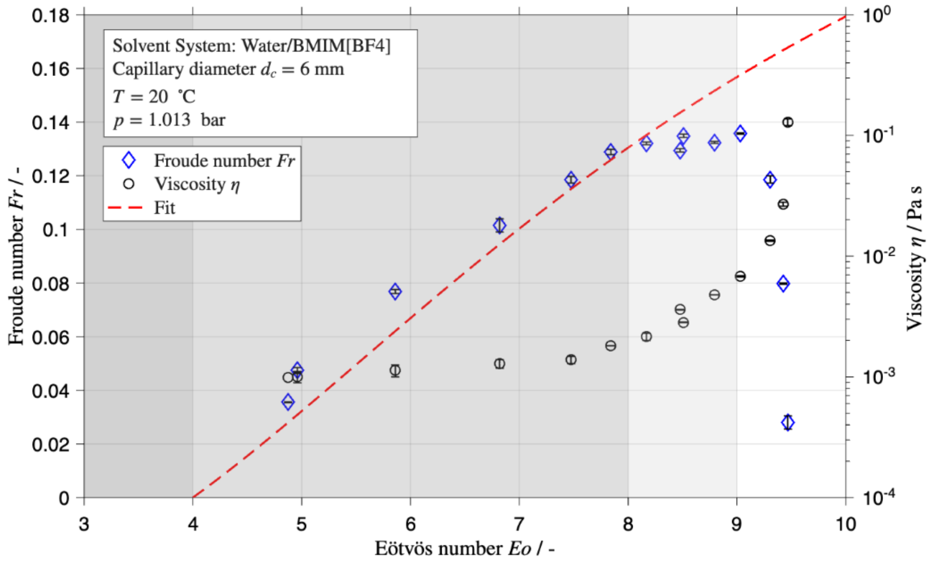
Mass transfer experiments

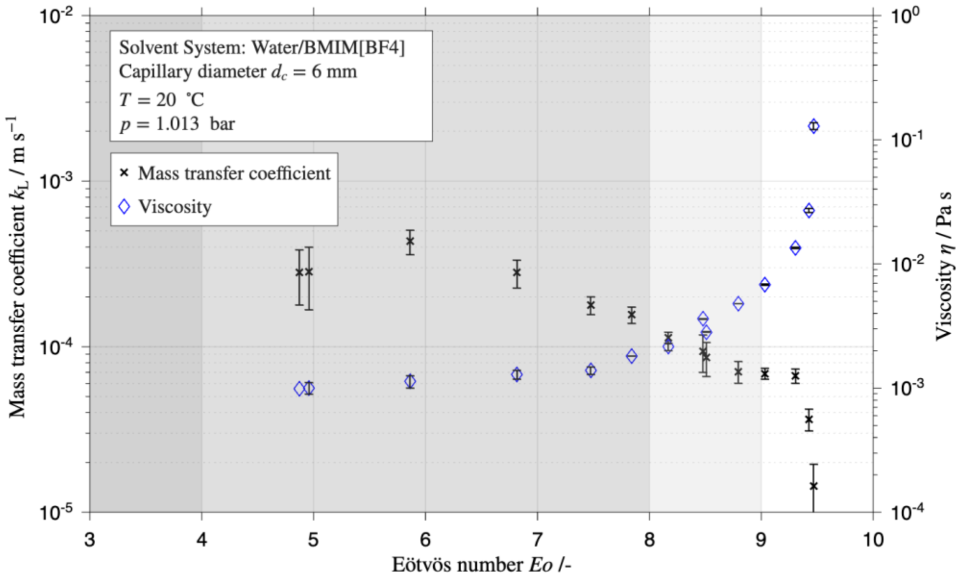
Framework

14 Binary mixtures of [BMIM][BF4] and water and 14 of [EMIM][Oac] and water. Taylor bubbles are injected in vertical capillars $(d = 6, 7, 8\ mm)$ at atmospheric pressure & ambient temperature. Terminal rise velocity is evaluated from vertical shift of centroid in stagnant IL/water mixtures. Mass transfer coefficient k_L is evaluated from bubble volume decrease.

Outcomes and outlooks

- [BMIM][BF4]: after an initial increase due to larger rising velocities, k_L values decrease accordingly to the increase of viscosity;
- [EMIM][OAc]: larger viscosity lead to an initial decrease of values, while for high concentration chemical absorption lead to larger values.





Large-scale activity

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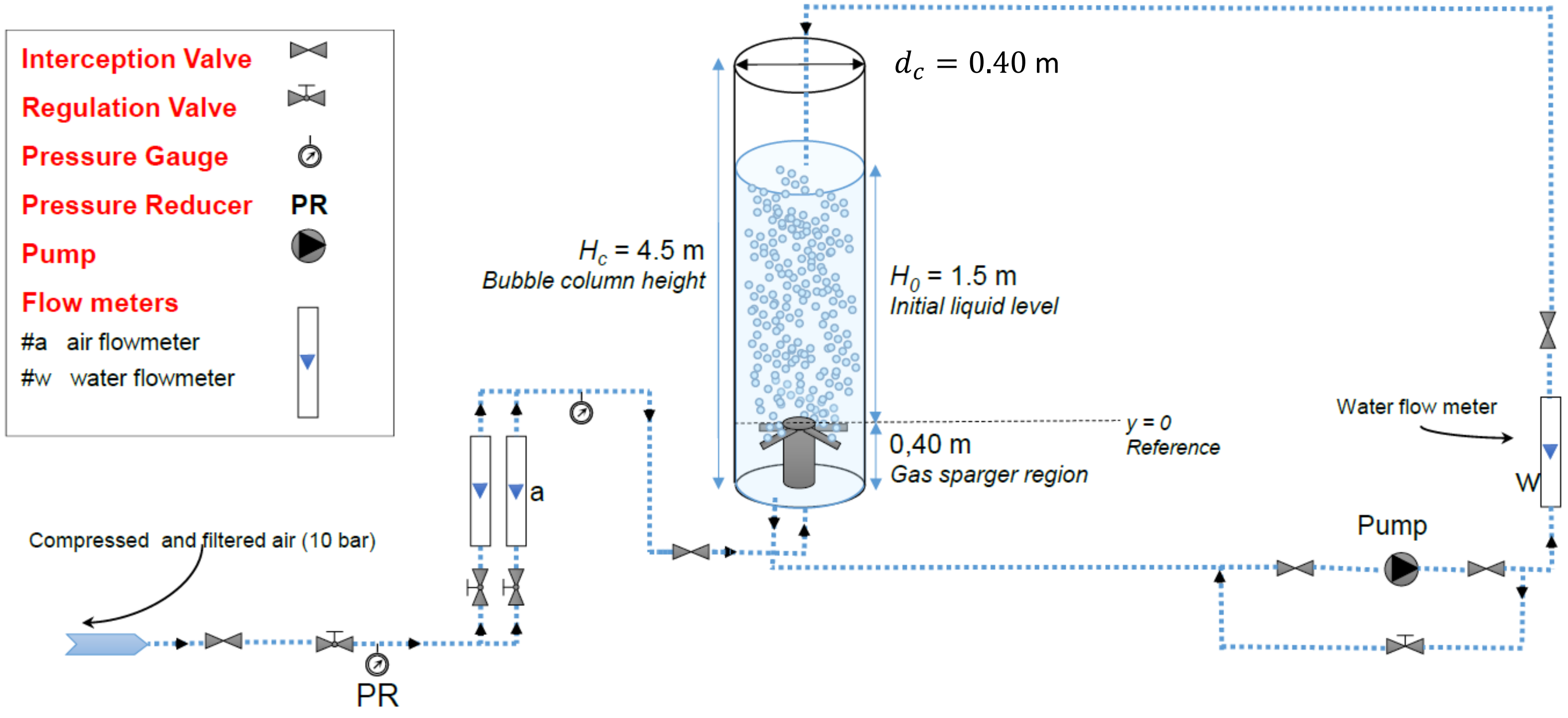
Large-scale experimental setup

Framework

Large-scale facility under construction. It will be equipped with PH, conductivity probes for mass transfer evaluation. Optical probes, doppler probes and wire mesh for local fluid dynamic measurements.



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Numerical activity (i)

Framework

Euler–Euler Morphology-Adaptive simulations of bubble columns and pipe flows.

Outcomes and outlooks

- validation of the MultiMorph CFD-PBM framework for bubble columns and pipe flow simulations;
- prediction of flow regime transitions in gas–liquid vertical flows;
- advanced numerical simulations in complex geometrical configurations

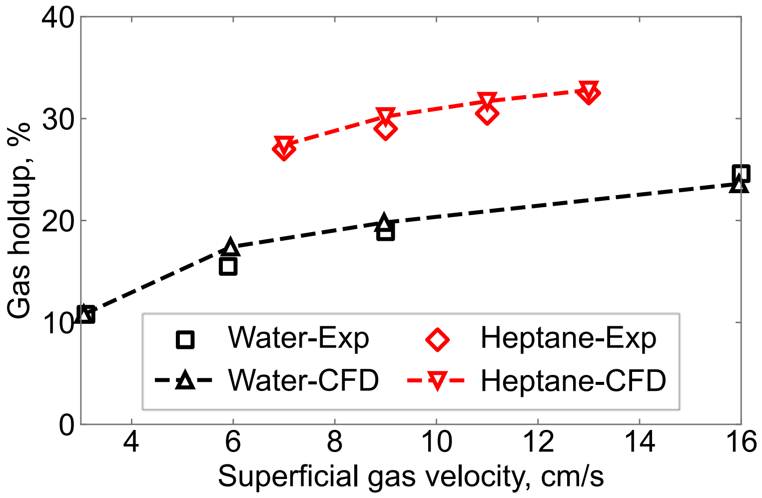
Numerical activity (ii)

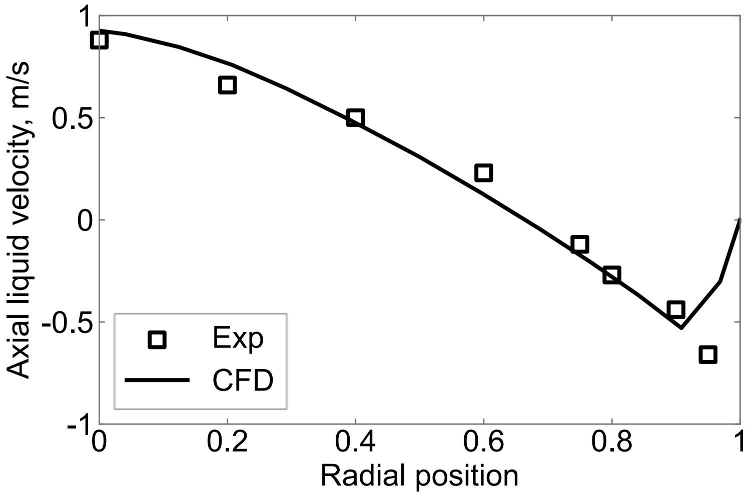
Framework

Euler–Euler simulations of industrial-scale reactors, considering different liquid phases and operating conditions.

Outcomes and outlooks

- development of a validated CFD framework for industrial-scale applications;
- study influence of liquid-phase properties on bubble column fluid dynamics;
- scale-up analysis of gas–liquid reactors under industrial operating





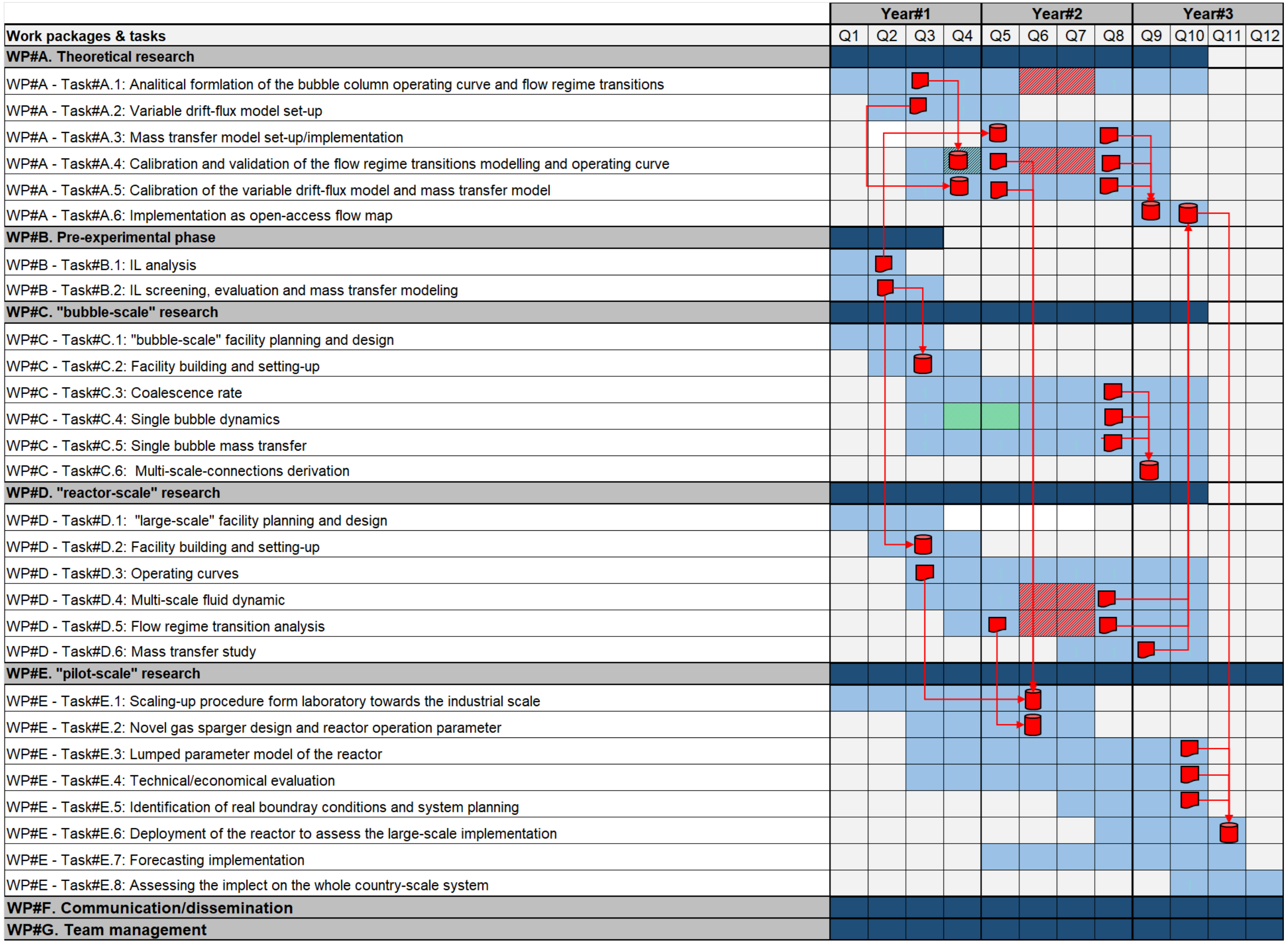
Way forward

03

Outlooks …

Scale-up the laboratory results towards the country-scale, looking towards the decarbonisation goals. Based on the theoretical and experimental research, a scaling-up method will be implemented to design industrial-scale reactors.

The observations will be used to develop a technical/economical lumped parameter model of the reactor, which will be applied to study and assess the proposed technology’s impact on the country-scale energy system in both the present-day case and future energy system scenarios.



Thank you for the attention!

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Contatti

Via Lambruschini 4, 20156, Milan, Italy
02 2399 8431
giorgio.besagni@polimi.it
www.polimi.it