17th International Conference on Gas-Liquid and Gas-Liquid-Solid Reactor Engineering (GLS-17)
December 7-10, 2026, Goa, India

Experimental Investigation of CO_2 Capture in Ionic Liquid–Water Mixtures: Thermophysical properties, Solubility, and Taylor bubble Mass Transfer

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Keywords: Taylor bubbles; CO_2 mass transfer; ionic liquids; carbon capture

Introduction. Ionic liquid (*ILs*) have emerged as promising solvent systems for CO_2 capture owing to their tunable physicochemical properties, negligible vapor pressure, and favorable absorption characteristics [1]. However, their high viscosity and elevated cost remain one of the principal limitations to large-scale industrial deployment [2]. One approach to mitigate these drawbacks is the addition of a cosolvent [3]. This strategy, though, intensifies the complex molecular interactions and strong coupling among physicochemical properties, fluid dynamics, and gas-liquid mass transfer that are not yet fully understood. Grasping these interdependencies across scales is essential for the rational design of next-generation gas-liquid contactors. This work presents a comprehensive experimental investigation of CO_2 absorption in aqueous mixtures of 1-ethyl-3-methylimidazolium acetate ([EMIM][OAc]) and 1-butyl-3-methylimidazolium tetrafluoroborate ([BMIM][BF_4]), two hydrophilic *ILs* that have attracted considerable attention for CO_2 capture applications.

Experimental Methods. The experimental campaign is organized into three interconnected parts. First, a comprehensive dataset of density, viscosity, and surface tension was collected across the full composition range, from pure water to neat ionic liquid, for both [EMIM][OAc] and [BMIM][BF_4]. All measurements were performed at three different temperatures (293.15 K, 298.15 K, 303.15 K) in triplicate using standard rheometric, tensiometric and densimetric techniques. Second, CO_2 solubility in the *IL*–water mixtures was measured gravimetrically at ambient temperature and pressure.

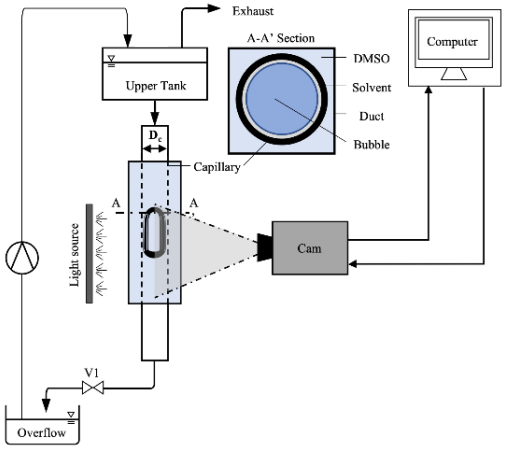


Figure 1: Scheme of the stationary Taylor bubble experimental set-up.

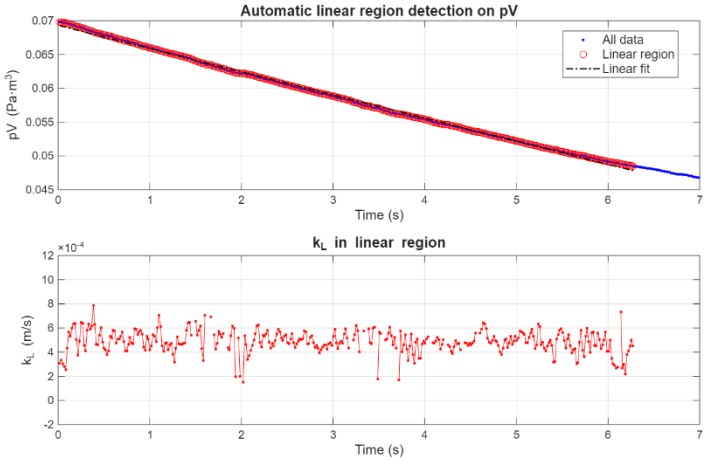


Figure 2: Representative time evolution of p·V (up) and derived liquid-side mass transfer coefficient (down).

Equilibrium was identified as the state at which no further mass increase was detected within the resolution of the balance. Third, CO_2 Taylor bubble experiments were conducted in vertical circular capillaries with three inner diameters (6, 7, and 8 mm) in the facility shown in Fig. 1. Single CO_2 bubbles were held stationary by a counter-current liquid flow, and imaging was used to capture the temporal evolution of the bubble volume during absorption. From the bubble shrinkage, liquid-side mass transfer coefficients (k_L) were calculated following established methodologies [4–6] with an exemplary result shown in Fig. 2. Finally, Taylor bubble rise velocities were measured across all solvent compositions and capillary sizes to characterize the fluid dynamic behavior of the system.

Results and Discussion. The physicochemical measurements confirm strong composition-dependent trends: increasing the *IL* content leads to substantially higher viscosity and lower surface tension. CO_2 solubility measurements reveal a clear dependence on *ILs* concentration and type. [EMIM][OAc] mixtures exhibit higher CO_2 uptake, consistent with the known chemical affinity of the acetate anion for CO_2, while [BMIM][BF_4] mixtures show predominantly physical absorption. Taylor bubble experiments show, for [BMIM][BF_4], that increasing *IL* concentration reduces k_L values, consistently driven by the increase in viscosity and the associated decrease in molecular diffusivity. For [EMIM][OAc], however, after an initial decrease, kL values increase at high IL concentration, due to the effect of chemical absorption. The effect of capillary diameter is also significant: larger capillary dameters yields larger k_L values for equivalent solvent compositions, consistent with the higher bubble rise velocity in larger capillaries promoting enhanced interfacial surface renewal. Rise velocity measurements further reveal the effect of physicochemical properties on wall effect providing additional evidence of the strong coupling between solvent rheology and hydrodynamics. The combined analysis across three capillary sizes enables the separation of geometric and physicochemical contributions to mass transfer performance and highlights the limitations of correlations derived for simple aqueous systems when applied to *IL*-based solvents.

Conclusions. This work presents an integrated experimental framework for characterizing CO_2 absorption in *IL*–water mixtures across physicochemical and fluid dynamic scales. The results demonstrate that solvent composition governs not only CO_2 solubility and physicochemical properties, but also bubble fluid dynamics and interfacial mass transfer. The systematic use of three capillary diameters enables a geometry-resolved analysis of k_L and rise velocity, providing a richer dataset for model validation and scale-up. These insights support the rational formulation of IL-based solvents for energy-efficient carbon capture in gas–liquid contactors.

Acknowledgments

This work has been financed by the Italian Ministry of University and Research (Ministero dell'Università. e della Ricerca) within the FIS2 call. In particular, this work has been conducted within the AURIGA ("Unvealing 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).

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