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Precipitating solvent design for carbon capture: solvent and active species behaviors

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Abstract

Process intensification and energy efficiency improvements are pivotal for the widespread deployment of Carbon Capture and Storage (CCS) technologies in major industrial emitters such as steel plants, natural gas combined cycle (NGCC) facilities, coal-fired power plants, and cement factories [1]. Reducing energy penalties, mitigating corrosion, and ensuring safer and more efficient processes are critical requirements demanded by these industries. To achieve this, a paradigm shift in CO_2 capture technologies is essential. This work proposes the use of precipitating solvents, which aim to concentrate and reduce the energy penalty per unit volume in cyclic processes [2-4].

The present research provides preliminary results on innovative precipitating solvents for CO_2 capture. The objectives are the identification of the precipitation mechanisms and the key parameters influencing the process. These are milestones toward performances optimization to address the challenges of CCS deployment in energy-intensive industries

To achieve this, the study initially focuses on the effective design of precipitating solvents, emphasizing two key parameters: the anti-solvent fraction and the concentration of the precipitating species. The formulation design is tailored to master key precipitation levers through solvent composition variation, as part of a crystal engineering approach. A screening setup is employed to rapidly provide critical preliminary insights into their influence, facilitating the optimization of formulations (Figure 1). The performances of a series of aqueous/organic mixtures with varying hindered amine content are explored to identify a precipitation window. The samples are visually inspected for the precipitate formation just after the experiment termination and absorption performance is assessed based on weight increase. Special attention is paid to compositions that enable the achievement of specific proportions of precipitated phases with varying mass distributions relative to the liquid phase.

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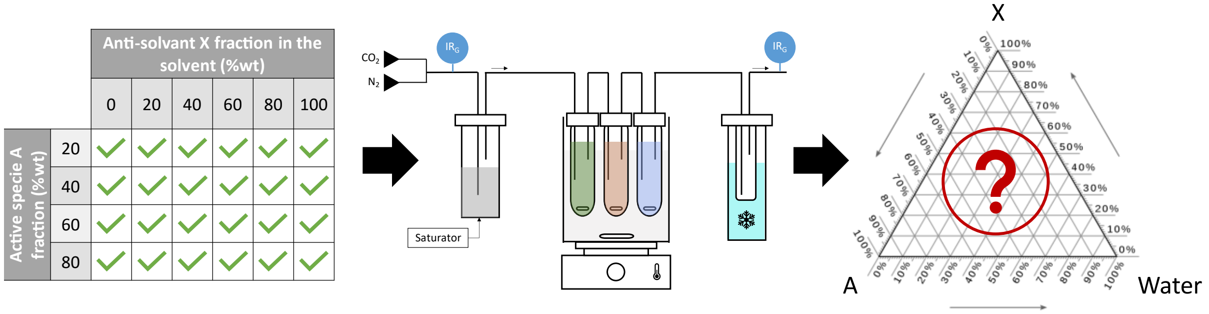

Figure 1: Rapid screening setup to investigate the anti-solvent fraction and the concentration of the precipitating species influence

Subsequently, the precipitation behaviour of the custom-designed solvent is studied on a larger scale, incorporating dynamic and in situ analyses (Figure 2). Advanced techniques including infrared spectroscopy and microscopy are utilized to elucidate the mechanisms governing the precipitation process. These methods aim to elucidate the mechanisms governing the crystallization process and the underlying key parameters through monitoring nucleation, growth and agglomeration dynamics, and the interaction between the solvent and absorbed CO_2. The behaviour of the solvent, including absorption and precipitation performances, is assessed from the onset of CO_2 absorption to the triphasic equilibrium point. Such data are essential for estimating precipitation kinetics, particularly through the development of advanced mathematical models, as part of this project's overarching objectives. Additionally, particular attention is paid to the regeneration potential through precipitate nature identification.

The findings of this study provide essential data to understand and predict the behaviour of such complex triphasic systems.

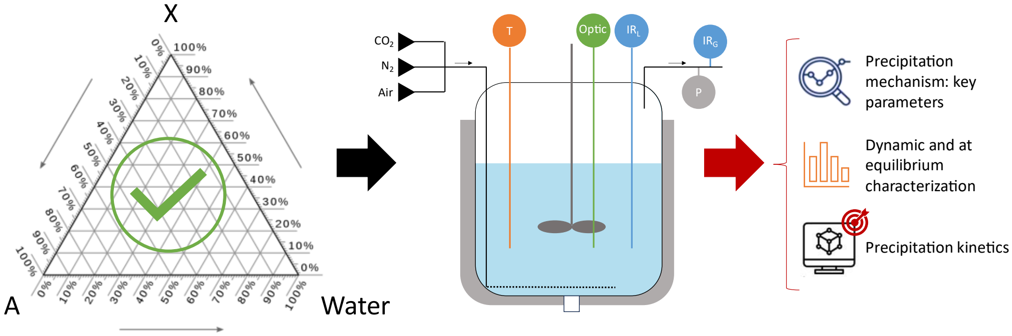

Figure 2: Temperature and pressure resistant instrumented test bench to characterize precipitating solvents for carbon capture

Keywords: Carbon Capture; CCS; Precipitating solvent; Precipitation; Phase-change; Instrumented bench

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