Development of single/mixed-amine containing non-aqueous solvent: A significant improvements in CO$_2$ solubility and viscosity

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Abstract

The present study was aimed at developing a non-aqueous solvent (NAS) system for the recovery of CO$_2$ generated from steel making industries. More specifically, the NAS system must show high CO$_2$ solubility and low viscosity (cP < 20) at the whole range of CO$_2$ loading. At the same time, sufficient amine regeneration must occur at a low temperature of 80–90 ºC compared to bench-mark monoethanolamine (MEA). To achieve this target, we have investigated a vast number of synthetic and commercial amines as absorbents and alcohols/no-alcohols as solvents. Several experiments mixing amine(s) with alcohol/non-alcohol were performed to identify high performer NASs. The developed NASs showed high CO$_2$ solubility and low viscosity (cP < 20) homogeneous mixture (single phase) at the whole range of CO$_2$ loading with the advantages of higher absorption and regeneration rates, higher cyclic CO$_2$ capacities, higher regeneration efficiencies, lower specific heats, and lower heats of reaction compared to reference MEA. Some promising mixed-amine containing NAS systems were tested at a bench-scale test plants with capacities of 5 kg-CO$_2$/day and showed promising results in terms of reducing absorbent regeneration energy.

Keywords: Non-aqueous solvent, CO$_2$ absorption capacity, absorption and regeneration rate, cyclic capacity, regeneration efficiency

The latest efforts in aqueous amine solvents are exciting and promising, there are still several drawbacks to amine-based CO$_2$ capture solvents including high volatility and corrosiveness of the amine solutions as well as the high parasitic energy penalty during the solvent regeneration step.

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Therefore, the development of new alternative non-aqueous/water-lean solvents (3rd generation CO₂ capture solvents) that can overcome above mentioned drawbacks and can capable of processing larger quantities of CO₂ with lower energy demand will be a high demand for practical application.

To identify cost-effective approaches for CO₂ capture, the past decade has witnessed the development of various new solvents, including concentrated non-aqueous/water-lean solvents. Non-aqueous amine solvents have potential advantages over aqueous amines, specifically lower heat capacity (approximately one-half), lower heat of vaporization of organic solvents, and higher boiling temperature compared to that of water. Many formulations of non-aqueous CO₂ selective solvents have been tested, including amine-based non-aqueous solvents, CO₂-binding organic liquids, aminosilicones, alkylimidazole blended with amine, room temperature ionic liquids (RTILs), amino-functionalized task-specific ionic liquids (TSILs) and mixed RTILs with alkanolamines. All these non-aqueous absorbents possess several advantages over the aqueous absorbents namely, high-boiling-point, low vapor pressure, thermally stability with a lower heat capacity than that of water. Despite their potential for CO₂ capture, non-aqueous solvents possess some challenges: the non-linear increase in viscosity once CO₂ is absorbed, precipitate formation, or solvent gelation leading to a highly viscous gel or waxy solid.

To overcome the aforementioned drawbacks, this work focuses on the development of a non-aqueous absorbent system that will increase CO₂ solubility and reduce the viscosity of the CO₂ loaded solution and will not form any precipitate, viscous gel, or waxy solid upon exposure to CO₂. More specifically, the non-aqueous absorbent system must be a homogeneous mixture (single phase) within the whole CO₂ loading range. At the same time, sufficient amine regeneration at a low temperature range of 80–90 ºC is desired. This makes it possible to use waste low temperature heat for regeneration at a low cost, resulting in a more cost-effective CO₂ absorption process. Another critical issue in the use of non-aqueous solvents is how to control the water, because water is omnipresent in the process, as it is introduced via the flue gas. The water tolerance of the non-aqueous solvent system will also briefly be discussed.

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