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Ultrasound-assisted Desorption of CO_2 from Carbon Dioxide Binding Organic Liquids

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Abstract

CO_2 absorption/desorption performance of 2-tert-Butyl-1,1,3,3-tetramethylguanidine (BTMG) and 1-Hexanol blend, which is a novel carbon dioxide binding organic liquid (CO_2BOL) system, was studied in order to investigate the behavior of ultrasound-assisted desorption. Pure CO_2 was first absorbed into a 10 wt percent BTMG solution in a semi-batch stirred reactor at 303 K and at 2 atm until equilibrium was reached, followed by ultrasound-assisted desorption at 353 K under nitrogen atmosphere. Experiments were repeated in the absence of ultrasound, keeping everything else the same. The CO_2 loading of BTMG:1-Hexanol solvent system was found to be a very favourable ratio of 1.05 mol CO_2/mol BTMG. When compared with conventional desorption, ultrasound-assisted desorption resulted in enhanced desorption rate so that the solvent regeneration time was significantly shortened. Enhancement of desorption rate was most significant/vigorous at the initial stages of desorption process. Further, regeneration of this CO_2BOL was possible at 353 K without any phase change. Experimental results clearly show that the ultrasound-assisted desorption is an effective process intensification tool leading to significantly minimised energy consumption for regeneration. To ensure effectiveness of regeneration, reversibility of the solvent system was also investigated by using Fourier transform infrared spectrometry.

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1. Introduction

The increasing concentration of atmospheric CO_2 is now a problem of global concern. Although the consequences of atmospheric CO_2 are still evolving, there is compelling evidence that the global environmental system is undergoing profound changes, such as warming. These global problems, directly resulting from the elevated atmospheric CO_2, will ultimately affect everyone. Therefore there is an urgent need for efficient carbon dioxide capture from point sources such as thermal power plants, as well as specific process plants. To that effect, it is universally accepted that the chemical absorption is the most appropriate technology. Here, an optimized solvent must possess appropriate dual function, that is, it must increase CO_2 loading while also enhancing the absorption rate. Recently, a novel organic solvent system termed carbon dioxide binding organic liquids (CO_2BOL) has been proposed for CO_2 capture [1]. CO_2BOL is based on a liquid mixture of a linear alcohol and an amidine or guanidine base that chemically binds CO_2 to form an amidinium or guanidinium alkyl carbonate salt. The reaction of CO_2BOL and carbon dioxide can be reversed without the need to boil the solvent system, thus eliminating the need for latent heat of evaporation. Although there is a considerable amount of published work for absorption kinetics of some of the CO_2BOL [1, 3], there is hardly any work for CO_2 desorption from them. Indeed, desorption studies from any amine-based solvent are limited even though the energy requirement –therefore the feasibility- of absorption/desorption process heavily depends on the stripping efficiency.

This paper suggests a promising method (that is, ultrasound-assisted desorption) which is superior to conventional stripping process since it could significantly reduce the regeneration temperature –hence, solvent degradation [4-7] (According to Davis and Rochelle, a reduction in desorption temperature by 17 °C reduces degradation of the MEA solution 4 times [8]). In addition, it reduces energy consumption, increases desorption capacity and often shortens the duration of desorption. A new process, which does not require vaporization enthalpy for the solvent regeneration (hence reboiler) and does not contain conventional desorption column (desorberless), will be developed when the ultrasonic desorption performed as an example of process intensification.

The aim of this work is twofold. First, it considers absorption/desorption behaviour of one of the promising CO_2BOLs, namely 2-tert-Butil-1,1,3,3-tetrametilguanidin (BTMG)/ 1-Hekzanol. BTMG, which is a guanidine, was chosen since it reacts with CO_2 at a rate comparable to commercially exploited amines such as alkanolamine solutions [3]. Second, effect of ultrasound irradiation is investigated since it is envisaged that regeneration at a temperature range much below the boiling point of solvent may not be as vigorous as the conventional reboiler. It is a well-known fact that ultrasound leads to cavitation and nucleation in the liquid and thus the formation of bubbles [2]. Once formed, it could be relatively easy for bubbles to grow as more gas diffuses to the bubbles and becomes part of the bubble. In this way ultrasound irradiation makes it easy for gas to escape in the form of bubbles. The enhanced desorption at lower temperatures -which will lead to a reduction of the CO_2 capture cost- is the main incentive behind ultrasound application.

2. Experimental

2.1. Reagents

BTMG: 2-tert-Butyl-1,1,3,3-tetramethylguanidine with ≥97.0 purity (CAS no. 29166-72-1) was supplied by Sigma-Aldrich (St. Louis, MO, USA). 1-Hexanol (reagent-grade, CAS no. 111-27-3) with 98% purity were purchased by