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Research paper

Selection of amine combination for CO_2 capture in a packed bed scrubber

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Abstract

This investigation was to test different blends of tertiary amine; triethanolamine (TEA) into primary amine; Monoethanolamine (MEA) used to capture CO_2 in packed bed scrubber with recycle stream. Four different operating parameters: Amine Combination (A), Dilution Water (B), Liquid Flow rate (C), and Gas Flow rate (D) were varied to study the behavior of the system. Moreover, Taguchi method was employed to establish the order of importance of different parameters in the process. A 4 factor and 3 level was chosen for the study and it was explored using L9 (3^4) orthogonal array design. According to 3-level design 0%, 20% and 30% were chosen for A, 10%, 20% and 30% for B, 1 $Lmin^{-1}$, 1.5 $Lmin^{-1}$ and 2 $Lmin^{-1}$ for C, 8 $Lmin^{-1}$, 16 $Lmin^{-1}$ and 20 $Lmin^{-1}$ for D. To understand the effectiveness order of different operating parameters, three factors namely Absorption efficiency (E), Absorption Rate (RA), and Scrubbing Factor (E) were calculated upon which the order was compared. The highest efficiency of 92.2% was achieved with 20% TEA. However, with 30% of TEA and 20% solvent mix maximum scrubbing factor (E) of 0.63 mol-CO_2/mol-Solvent was achieved. As per Taguchi analysis the significance sequence for absorption efficiency (ϕ) was B > C > D > A; for absorption rate C > B > D > A and for scrubbing factor it was C > B > D > A. The blending of tertiary amine seemed advantageous for carbon dioxide capture process.

Keywords: Absorption efficiency; Absorption rate; Monoethanolamine (MEA); Scrubbing factor; Taguchi method; Triethanolamine (TEA)

1. Introduction

Global warming issue is at its alarming level worldwide nowadays. Catastrophic global warming is an intense form of greenhouse effect. Greenhouse gases are responsible for such effects. In an adequate amount such effect is necessary to keep the average temperature of earth's surface enough to sustain life but addition of more and more greenhouse gases into the atmosphere is intensifying the process and altering the conditions of earth in untoward manner. CO_2, CH_4, N_2O, and chlorofluorocarbons (CFCs) are different greenhouse gases listed by IPCC. Roughly one-third of the solar energy that reaches the top of Earth's atmosphere is reflected directly back to space. The remaining two-thirds is absorbed by the surface and, to a lesser extent, by the greenhouse gases in the atmosphere [1]. The more the greenhouse gases in the atmosphere the more radiation they absorb leading to the higher temperature of the earth's surface. It has become renowned as one of the gravest environmental issues to catch the attention of the globe in recent decades. CO_2, more than any other greenhouse gases, has contributed the most to climate change. As CO_2 carries the highest radiation, it contributes significantly to the climate change. Moreover, it has a remarkably long lifespan with half-life of 100 years in the atmosphere [2]. There are multiple sources like agriculture processing, industry activities, electricity production, mining etc. from where CO_2 is added directly into the atmosphere. Most of the sources of CO_2 use fossil fuels as the energy source directly or indirectly. According to the global carbon budget 87% of the CO_2 comes from the burning of the fossil fuels [3]. Considering the harm done by CO_2, capturing such greenhouse gas before it is vented out into atmosphere was taken as a challenge to solve. Furthermore, due to the high costs usually ascribed to separation and purification operations in process industries, the search for low-cost, non-conventional and alternatives has generated much academic research worldwide [4].

The most natural solution to the CO_2 dumping problem is reducing the use of fossil fuels but practicality is a major issue. Renewable energy and nuclear energy are at rise but according to international energy outlook 2014, 80% of the world energy

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through 2040 will be provided by fossil fuels. By then, it is necessary to mitigate the condition raised by the use of fossil fuel by reducing the amount of CO_2 being dumped in the atmosphere. A conventional method of absorbing CO_2 by CaO is studied by using ASPEN Plus process simulator to understand-steady state model of air–steam gasification of biomass [5]. The model will analyze the effect of CaO sorbent for in-situ CO_2 capture.

There are many methods adopted for CO_2 capturing like using physical adsorbent [6], catalytic conversion [7] and capturing CO_2 using different solvents like Monoethanol Amine (MEA), Ammonia, tetrahydrofuran, and tetra-n-butyl ammonium bromide [8–10]. Among all, the solvent scrubbing technique is considered to be the most advanced post-combustion capture technology [6].

Focusing on solvent based CO_2 capturing, MEA is one of the predominant solvents due to its commercial availability, relatively low cost, fast absorption rate and rich experience in industrial applications [11]. However, there are limitations of using MEA solution alone, i.e. degradation in the presence of O_2, SO_x and NO_x [12], corrosive nature of MEA [13] and high regeneration energy requirements [11]. To mitigate such limitations MEA is blended with other solvents like Triethanolamine (TEA) [14], 2-amino-2-methyl-1-propanol (AMP), benzylamine (BZA) [15], and methyldiethanolamine (MDEA) [16]. There are several advantages of blending these amines: viz.,

- Improved thermodynamic efficiency [17].
- Reduction in issues relating to degradation and operation of the solvent caused by corrosion [18].
- Flexibility in the range of amines available to tailor and optimize the composition of the solvent to achieve the highest absorption efficiency.
- High absorption rates observed in single amine solvents can often be maintained in blends of the individual components.
- Energy requirement for solvent regeneration can be reduced [19].

With significant CO_2 loading capacity TEA shows great regeneration efficiency. Additionally, with limited literature available on TEA blended MEA, there is wide scope of investigating the potential of TEA as a blended amine. Moreover, MEA + TEA blended amines system was suggested in order to capitalize the performance of TEA (tertiary) and MEA (primary) amines. The low energy requirement for regeneration and high absorption capacity of tertiary amine coupled with the fast reaction kinetics of primary amine are an ideal combination for CO_2 sequestration.

The present research was commenced primarily for: (1) Investigating the potential of TEA as a blend for MEA solution in the scrubbing of CO_2 by a continuous process; (2) Incorporating Recycle stream of solvent in the continuous scrubbing and observing equilibrium of the process; and (3) Evaluating the influence of different parameters on the process with the help of Taguchi analysis.

2. Materials and methods

MEA and TEA of laboratory grade were used as solvents. A CO_2 (99.99% pure) cylinder was used as the source of the inlet gas. Deionized water was used during every cycle of the experiment.

2.1. Experimental set-up

A Pyrex glass column of 1.15 m height and internal diameter of 0.285 m served as the scrubbing column as given in Fig. 1.

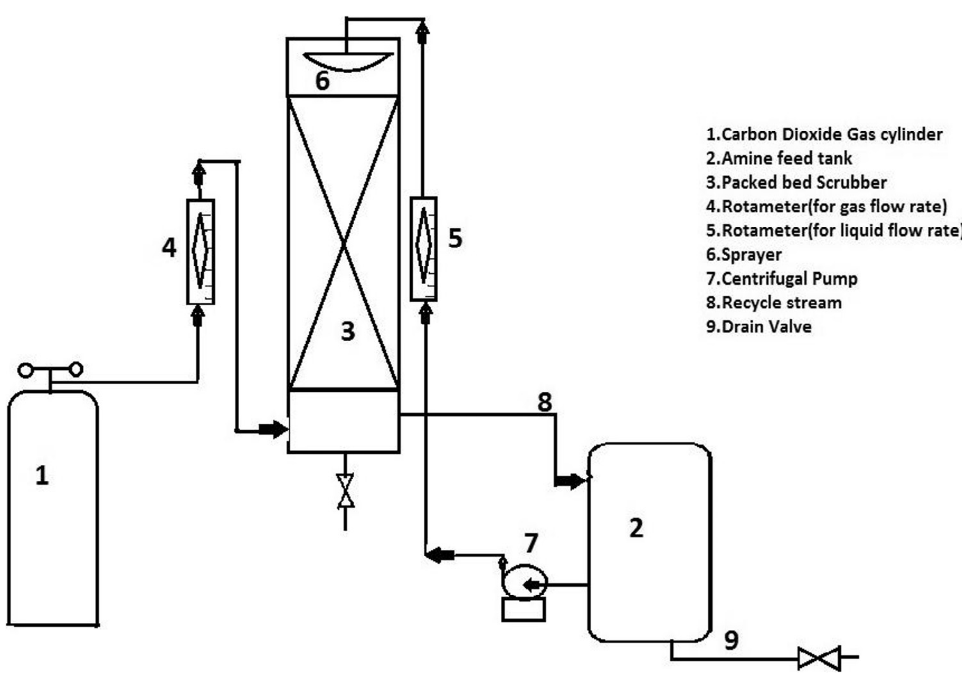

Fig. 1. Experimental set-up for CO_2 capture using amines.