



# Integration study of a hybrid solvent MEA-Methanol for post combustion carbon dioxide capture in packed bed absorption and regeneration columns



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## ABSTRACT

The present work reported tests of a new solvent 30 wt% MEA-Methanol compared to aqueous 30 wt% MEA solvent in a pilot-plant test bed, which comprises the complete absorption/desorption. The two solvents were studied in the same way in the test bed and detailed results were reported for both solvents. The measurements were carried out at a constant CO<sub>2</sub> removal rate of 90% by an adjustment of the regeneration energy in the desorber for systematically varied L/G ratios, flue gas flow rate and absorber height. Results from these studies indicated that MEA-Methanol solvent had a faster CO<sub>2</sub> absorption rate and a lower regeneration energy consumption compared to aqueous MEA solvent. Regeneration heat duty ( $Q_{reg}$ ) of MEA-Methanol solvent at optimum operating conditions was obviously lower than that of aqueous MEA solvent (3.22 MJ/kg CO<sub>2</sub> and 4.04 MJ/kg CO<sub>2</sub>, respectively), which showed that MEA-Methanol had a potential to replace aqueous MEA solvent in industrial CO<sub>2</sub> pilot plant.

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## 1. Introduction

The world has been heating up since 1980s and the greenhouse gases are the glaringly obvious explanation for the rise in global temperatures according to a report compiled by the National Oceanic and Atmospheric Administration (NOAA) [1]. Among all the Greenhouse gases (GHGs), CO<sub>2</sub> is considered as the major GHG which influence the weather due to the large amount of CO<sub>2</sub> released to the environment compared to other GHGs and the combustion of the fossil fuels in power plants is the main source of CO<sub>2</sub> emissions [2,3]. Over the next 20 years, fossil fuels will continue to be the largest energy source, which means that the emissions of CO<sub>2</sub> will remain an issue, therefore, CO<sub>2</sub> capture and storage technology (CCS) is becoming one of the main technologies to rapidly reduce the emissions of carbon dioxide (CO<sub>2</sub>) in response to the increasing environmental concerns and to the growing world energy demand [4–7]. Generally, there are three typical technologies for capturing CO<sub>2</sub> from coal-fired power plants: post-combustion CO<sub>2</sub> capture, oxy-fuel combustion CO<sub>2</sub> capture and pre-combustion CO<sub>2</sub> capture [8]. Among them, the post-combustion CO<sub>2</sub> capture with amine solvents is the most appropriate technology for a large-scale deploy-

ment [9]. However, the main drawback of the amine-based CO<sub>2</sub> capture process is the huge energy consumption for solvent regeneration which is a main obstruction for industrial use on a large-scale [10,11]. Thus the study of saving energy in the regeneration step and proposing new solvents that need less regeneration cost is of vital importance.

Many novel solvents have been carried out to reduce the regeneration heat duty for CO<sub>2</sub> desorption from solvents. Mangalapally and Hasse [12] studied two new solvents (CESAR1: 0.28 g/g 2-amino-2-methyl-1-propanol + 0.17 g/g piperazine + 0.55 g/g H<sub>2</sub>O and CESAR2: 0.32 g/g 1,2-ethanediamine + 0.68 g/g H<sub>2</sub>O) compared with MEA (0.3 g/g monoethanolamine + 0.7 g/g H<sub>2</sub>O) in the pilot plant and the results showed that CESAR1 with a reduction of about 20% in the regeneration energy and 45% in the solvent flow rate. Zheng et al. [13] studied the CO<sub>2</sub> solubility in an aqueous tertiary amine solution, the results showed that the mixed amine solution of tertiary amine with MEA could reduce the regeneration energy about 20% compared with 30% MEA solvent. Zhang et al. [14] studied the regeneration performance of diethylenetriamine (DETA) solutions in a bench-scale stripper column, and the results showed that the heat duty of DETA was lower than that of MEA for regeneration at the same absorption capacity. However, these novel solvents were not used in large-scale pilot plant because of many drawbacks of them, such as expensiveness of novel amines,

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## Nomenclature

MEA	monoethanolamine	$Q_{sen}$	sensible heat duty
MEA-Methanol	mixed solvent of monoethanolamine and methanol	$Q_{des}$	desorption heat duty
DETA	diethylenetriamine	$T_{top}$	temperature at the top of the absorber
$Q_{reg}$	regeneration heat duty	$L/G$	ratio of the flue gas flow and the solvent flow
$Q_{vap}$	vaporization heat duty		

smaller solubility of primary and secondary amine solutions, slow reaction rates of tertiary amines and sterically hindered amines and precipitation of DETA.

Recently, hybrid solvents which are formed by mixing chemical and physical solvents have been proposed in order to enhance the solubility of CO<sub>2</sub> in the solvent at low CO<sub>2</sub> partial pressure and reduce energy requirement for solvent regeneration [15]. Among several hybrid solvents, MEA in methanol has been proved that it has a faster absorption rate and mass transfer rate than MEA aqueous solvent. Fu et al. [16] have studied the mass transfer and heat transfer of MEA-Methanol solvents in a double-layer glass packed column which showed that it had a faster absorption rate to strip the same amount of CO<sub>2</sub> compared with MEA. Sema et al. [17] have studied the mass transfer performance of CO<sub>2</sub> absorption into three solvents (5 M MEA in methanol, 5 M MEA in 1:1 water-methanol volume ratio, and 5 M MEA aqueous solutions) in an absorption column which showed that 5 M MEA in methanol had higher mass transfer performance than those of 5 M MEA in 1:1 water-methanol volume ratio and 5 M MEA aqueous solutions, respectively. However, the pilot-plant evaluation of MEA/Methanol solvent has not been conducted.

In this study, tests of the 30 wt% MEA-Methanol solvent in a pilot-plant CO<sub>2</sub> capture test bed was reported, and the results were compared to aqueous 30 wt% MEA solvent to study the potential of improvement in CO<sub>2</sub> capture efficiency and regeneration energy. The experimental data achieved in this work were presented and discussed in this paper.

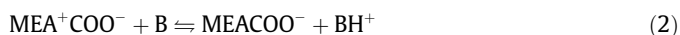
## 2. Materials and methods

### 2.1. Materials

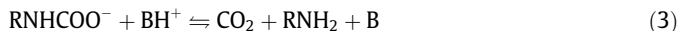
CO<sub>2</sub> and N<sub>2</sub> gases with mole fractions of 0.999 and 0.999 were supplied by Shanghai Shenkai gas company. Analytical grade MEA (purity > 99.9%) and methanol (purity > 99%) were all used as purchased without further purification. The aqueous solution was prepared using distilled water.

### 2.2. Mechanism

The reactions of CO<sub>2</sub> with MEA has been well-established by other researchers [18–20]. And the reaction of CO<sub>2</sub> with MEA-methanol can be explained by zwitterion mechanism. The reaction involves two steps. First step is the formation of the zwitterions and the second step is the deprotonation of the zwitterions.



Thermal decomposition of the carbamate produced by the absorption of CO<sub>2</sub> gives off CO<sub>2</sub> from the solution. Three potential reactions could be responsible for the liberation of CO<sub>2</sub> during the thermal regeneration.



where B is any base existing in the solution, including MEA and Methanol.

### 2.3. Data analysis

Liquid samples are usually collected from the inlet of the stripper (rich solvent) and the outlet of the stripper (lean solvent) when the process is considered to have achieved equilibrium. The amine solvents were verified by titration using a known volume of 1.0 M HCl with methyl orange as the indicator. The CO<sub>2</sub> loading in the liquid samples were determined by the standard method given by the Association of Official Analytical Chemists (AOAC) using a Chittick apparatus [21].

## 3. Pilot plant and process description

The CO<sub>2</sub> capture test bed using in this study was designed on the basis of the 30 wt% aqueous MEA solvent. The test bed consists of an absorber column to capture CO<sub>2</sub> and a stripper column to strip off CO<sub>2</sub> from the solvent. A 150 DN and 2.5 m stainless steel column is used for both absorber and stripper, the absorber consists of two packed beds (1.1 m and 0.9 m) packed with pall rings packing 16 × 16 and the stripper consists of two packed beds (1.1 m and 0.9 m) packed with sulzer packing BX500. In the middle of the columns liquid re-distributors were placed to eliminate the wall effects.

The Schematic diagram and the photo of the experimental setup are shown in Figs. 1 and 2. The gas flow rate of N<sub>2</sub> and CO<sub>2</sub> gases was controlled by mass flow controllers before remixed and the flue gas was then passed through the by-pass tube and tested by the flue gas analyzer to maintain the CO<sub>2</sub> concentration of 15%. The flue gas entered the absorber at the bottom with a temperature of approximately 303–313 K. The lean solvent which was maintained at the desired temperature by water was fed into the top of the absorber by a constant liquid-flow pump to chemically react with the flue gas. The rich solvent from the outlet of the absorber which was pre-heated to the designed temperature in the rich solvent tank was injected into the top of the stripper through a constant liquid-flow pump. The bottom of the stripper contains electrical heating elements for partial evaporation of the solvent and the rich solvent injected into the upper part of the stripper moved down to the lower part and was stripped of by the steam generated from the down part of the stripper. CO<sub>2</sub> containing water moisture moved to the condenser to separate the CO<sub>2</sub> and the condensate. The high-purity CO<sub>2</sub> was released and the condensate was injected to the stripper again. The hot lean solvent outlet the stripper was fed to the stainless steel lean solvent tank.

When the system reached steady state at which the temperature, solvent CO<sub>2</sub> loading and outlet CO<sub>2</sub> concentration were all stable, several samples from the outlet solvent were taken to analyze CO<sub>2</sub> and amine contents. All of the mass balance errors obtained in this work were under 10%.

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