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Study on the regeneration performance of alcoholamine absorbent for CO_2 capturing assisted by electric field

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ABSTRACT

The traditional alcoholamine CO_2 capture method requires a desorption temperature of 120 °C, which is energy-intensive and costly; the study of a CO_2 capture method with low energy consumption and low cost is the key to realising the CCUS. In this paper, based on the alcoholamine chemical absorption method of CO_2, N-methyldiethanolamine (MDEA) solution was used as the CO_2 capture absorbent, and its desorption performance was compared between the traditional heating and the electric field-assisted action, so as to investigate the enhancement effect of the electric field-assisted action on the rich-liquid regeneration and desorption of the alcoholamine absorbent under different conditions. The optimum reaction conditions and the maximum desorption rate of the electric field-assisted desorption were explored by changing the experimental factors such as voltage and temperature. The results showed that at the desorption temperature of 105 °C, the desorption rate of conventional heating was only 55.18%; when the desorption temperature was still 105 °C but with the addition of 4.5 V voltage assistance, the desorption rate could reach 97.92%; It has better cyclic regeneration performance, with a 1% decrease in CO_2 desorption after 5 cycles. By comprehensively comparing the desorption performance of organic amine desorption of CO_2 under the conditions of traditional heating and electric field-assisted heating, it can be seen that the appropriate low-voltage electric field has a promotional effect on the desorption of CO_2 from alcoholamine solution, and the development of this technology is of great significance to effectively improve the regeneration efficiency of carbon capture absorbents and reduce the energy consumption in the process of CO_2 desorption.

Keywords: Alcoholamine absorbent, Carbon capture, Electric field, Regeneration

1. INTRODUCTION

CO_2 Capture, Utilization and Storage (CCUS) is an emerging and important technology that enables large-scale, low-carbon use of traditional fossil energy sources[1]. Today, 80% of the world's energy comes from fossil fuels such as coal, oil and natural gas[2]. Hydroelectric and nuclear power are not expensive, but environmental conditions limit the scale of their development[3]. As for new energy sources such as wind, solar and biomass, although the environmental outlook is promising[4], these new energy sources are still in the exploratory stage due to objective factors such as high cost and immature technology, and it will take a long time before they can be developed on a large scale commercially[5]. Therefore, carbon capture and storage technology, which develops reliable technology and reduces greenhouse gas emissions from fossil fuels, has emerged.

Currently, the chemical absorption method of carbon capture process, which adopts alcohol-amine solution as the CO2 chemical absorbent, has been developed faster and applied more widely[6], but there are shortcomings such as high regeneration energy consumption and high absorbent loss in the existing CO_2 capture process with alcohol-amine absorbent[7].Therefore, in recent years, for the carbon capture technology of alcohol-amine solution, the more popular optimisation directions are mainly in the following two aspects: for the problem of high loss of absorbent and low regeneration rate, design and develop new mixed alcohol-amine absorbent, and improve the alcohol-amine absorbent so that it has high absorption efficiency[8]; for the problem of high energy

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consumption of regeneration, improve the traditional thermal desorption process, such as the use of microwave/electric field/ultrasound and other physical fields. Assisted desorption technology, on the basis of traditional heating, try to choose the desorption method with lower energy consumption and higher desorption efficiency[9].

The selection of absorbent in carbon capture process is a key link, in order to find a suitable alcohol amine solution, it is necessary to make a study on the nature of the alcohol amine and the mechanism of CO_2 absorption, and comprehensively select the alcohol amine as the experimental object which has a high absorption rate, a large absorption capacity, and a lower energy consumption of desorption of the absorption products. In this study, N-methyldiethanolamine (MDEA) was mainly used as the absorber to study the electric field-assisted desorption of CO_2[10]. The advantages of MDEA over primary and secondary amines include its high equilibrium loading capacity and its low heat of reaction with CO_2[11, 12], which leads to lower energy required for regeneration[13, 14], MDEA reacts with CO_2 to produce bicarbonate ions with good desorption effect[15], so the aqueous solution of MDEA was chosen as the absorbent in this experiment to investigate the desorption conditions.

For the optimisation of the desorption process, a physical field can be added to the desorption process to strengthen the desorption, and the mainstream of the current research includes microwave-assisted heating desorption and ultrasonic assistance[16].

Microwave heating is carried out through the direct interaction of molecules and electromagnetic radiation, which has the advantages of instantaneous and volumetric heating, and is not subject to the heat transfer limitations and heat loss of traditional conductive or convective heating modes. Instantaneous and volumetric heating can increase the heating rate to reduce the loss of alcoholamine thus reducing the cost of carbon capture[17]. It has been found that at fairly low temperatures (70 °C – 90 °C) microwaves can regenerate solutions faster than conventional heating[18]. The efficiency of microwave desorption can be improved by adjusting the desorption conditions such as heating temperature and microwave power.

When ultrasound is introduced into a solution, alternating pressures are generated, and sound waves above the cavitation threshold propagate through the liquid creating cavitation bubbles and significantly increasing the rate of mass transfer of gases from the solution to the bubbles. This property makes ultrasound more suitable for enhancing the CO_2 desorption process at low temperatures[19]. An in-depth study of the ultrasonic reactor to enhance the desorption of CO_2 from alcoholic amine solutions, examining the effects of parameters such as desorption temperature, solution flow rate, CO_2 loading, and absorbent concentration on the ultrasonic enhancement effect, can be effectively utilised to reduce the energy consumption of desorption and the solvent loss[20].

On the basis of the conventional heating desorption, adding a certain electric field, electric field alcoholamine rich liquid desorption plays an auxiliary role. The electric field promotes the migration and diffusion of carbamate ions or carbamate ions generated by the reaction between the alcoholic amine solution and carbon dioxide in the alcoholic amine-rich liquid, increases the intermolecular collision, and thus enhances the effect of enhanced desorption. The present study is to compare the effect of conventional desorption with that of the electric field-assisted desorption of carbon dioxide, so as to determine whether the electric field has a promotional role in the process, and on the basis of which, through the measurement of the desorption effect, to judge the appropriate desorption temperature and the voltage range of the assisted electric field, and to determine the recycling effect of the alcoholamine solution.

2. EXPERIMENTS

2.1 Materials and Instruments

N-methyldiethanolamine (MDEA) analytically pure, product of Sinopharm Group Chemical Reagent Company; carbon dioxide (CO_2) product of Karamay Zhongke Gas Limited Liability Company; deionised water, homemade.

2.2 Experimental setup and procedure

The experiment is divided into two parts of study: absorption and desorption experiments. The first part is the measurement of the absorption of carbon dioxide by heating the solution at a certain temperature, and the second part is a measurement to investigate the rate, temperature, and voltage of carbon dioxide desorption from the alcoholamine solution under the action of an electric field. The experimental setup for this experiment is described as shown below.

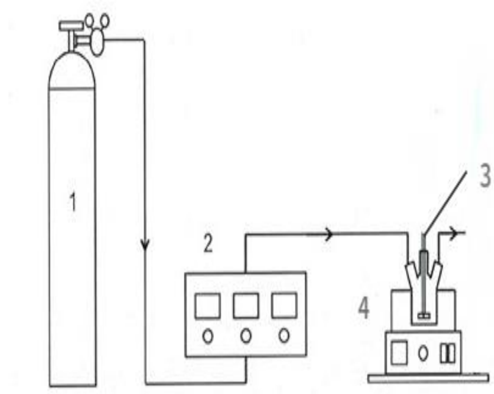

Fig. 1.
Carbon dioxide absorption device diagram of alcohol ammoni a solution
1-CO_2cylinder； 2-gas flowmeter;3-magneton;4-magnetic stirring heater

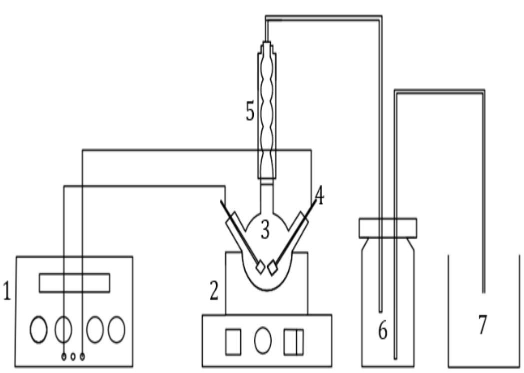

Fig. 2.
Carbon dioxide desorption device diagram of alcohol ammoni a solution
1-diret-current power;2- magnetic stirring heater;3-three-necked flask;
4-platinum electrode;5-allihn condenser;6-drain bottle;7-plastic beaker

2.3 Alcohol amine CO_2 absorption experiment

2.3.1 Effect of temperature on CO_2 uptake loads

MDEA was used as the absorbent for CO_2 absorption experiments, the configuration of 20% mass fraction of alcoholamine solution, set the reaction temperature in the order of 25 ℃, 30 ℃, 35 ℃, 40 ℃, 45 ℃,50 ℃, the reaction time of 15 min, to be passed into the CO_2 absorption saturation, the rich solution was weighed, the mass of CO_2 absorption by alcoholamine solution at different temperatures was recorded, and the effect of temperature on the absorption of CO_2 was investigated. The mass of CO_2 absorbed was recorded at different temperatures to study the effect of temperature on CO2 absorption.

2.3.2 Effect of Alcohol Amine Mass Fraction on Absorption Loads

The solutions were configured with 10%, 15%, 20%, 25%, 30% mass fraction of alcoholamine using MDEA as solute and deionised water as solvent. The absorption temperature was set at 30 ℃, and the rest of the operation was as 2.3.1. The effect of the mass fraction of alcoholamine absorption solution on the CO_2 absorption was investigated.

2.4 Electric field assisted desorption of alcohol-amine enriched liquids tests

2.4.1 Effect of temperature on the desorption of carbon dioxide from MDEA solutions

The CO_2 absorption experiments were completed with the absorption saturated rich solution with 20% mass fraction of alcohol and amine, and the heating desorption test and electric field assisted desorption test were carried out respectively, respectively, the points were taken at every interval of 5 ℃ between 80 ℃ and 120 ℃ to measure the desorption CO_2 time and the drainage volume, the desorption time was set to be 20 min the solution absorbed the mass of CO_2 was noted as m_1, and the volume of desorbed CO_2 was recorded by the drainage method, and the desorption rate was calculated based on Dalton's law of partial pressure and the measured CO_2 density. Based on Dalton's law of partial pressure and the measured CO_2 density, the mass of desorbed CO_2, m_2, was calculated, and the CO_2 desorption rate was further calculated by Eq. (1), and the CO_2 desorption effects were compared at different temperatures.

$$c = \frac{m_2}{m_1} \times 100\% \quad (1)$$

2.4.2 Electric field assisted regeneration performance studys

Electric field-assisted desorption was carried out on the absorbed saturated rich liquid with both alcohol and amine mass fractions of 20 % at a temperature of 105 °C, with the voltage set to a low range from 1 V to 6 V. The rest of the operation was carried out as in 2.4.1, to investigate the effect of different voltages on the CO_2 desorption rate.

2.4.3 Electric field assisted regeneration performance study

Cyclic regeneration and desorption experiments were carried out with 20% mass fraction (15 gMDEA+60 g water) of alcoholic amine solution, and the rest of the reaction conditions were set according to the optimal conditions determined earlier, with each cycle absorbing CO_2 for 15 min and desorption time set at 20 min. the performance and efficiency of cyclic decarbonisation of the absorbent can be verified by repeating the above operation 6 times using the absorbent solution repeatedly.

3. RESULTS AND DISCUSSION

3.1 Determination of process conditions for carbon dioxide absorption by MDEA

3.1.1 Effect of temperature on CO_2 uptake load

The results of the experiment to investigate the influence of temperature on the effect of CO_2 absorption through the comparison of variable temperature are shown in Fig. 3, the absorption of MDEA at various temperatures reached saturation in 8 min, and when the absorption temperature was raised from 25 °C to 30 °C, the effect of absorbing CO_2 was significantly improved, and further from the energy consumption point of view, under the same absorption effect, 30 ℃ consumed less energy, therefore, the subsequent absorption test set the temperature to be 30 ℃.

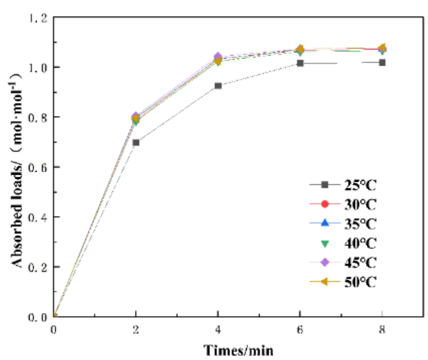

Fig. 3. effect of time on the quality of absorbed carbon dioxide

3.1.2 Effect of MDEA mass fraction on CO_2 uptake loading

Fig. 4 shows the comparison of CO_2 absorption curves with time for MDEA under different mass fraction conditions. From the figure, it can be seen that the absorber has the best absorption capacity when the mass fraction of the absorber is 20%. Therefore, all subsequent desorption tests were carried out using the mixed amine solution with a mass fraction of 20%.

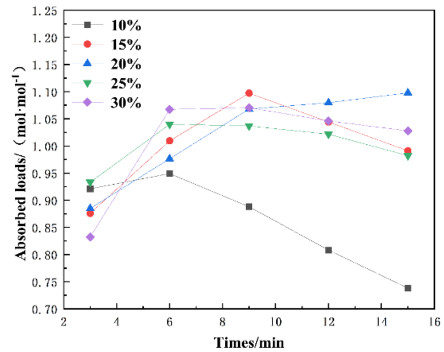

Fig. 4. effect of MDEA concentration on absorption

3.2 Determination of process conditions for the desorption of carbon dioxide by MDEA

3.2.1 Effect of temperature on the desorption of carbon dioxide from MDEA solutions

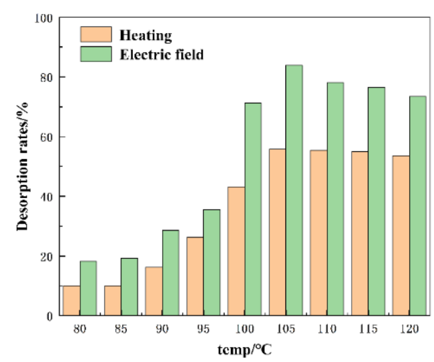

Fig. 5. effect of temperature on carbon dioxide desorption rate in MDEA solution

As can be seen from Fig. 5, in the temperature range from 80 °C to 105 °C, with the increase of temperature, whether it is traditional desorption or under the effect of electric field assistance, the desorption rate of MDEA rich liquid shows an increasing trend, and reaches a maximum higher value at 105 °C, respectively, 55.18% and 83.84%, and in the interval from 105 °C to 120 °C, the desorption rate of MEDA-rich liquid shows a decreasing or relatively flat trend. And it can be seen that under the addition of auxiliary electric field, the efficiency of carbon dioxide desorption of the alcoholamine rich liquid was greatly improved compared with that under the conventional heating, and reached the maximum value at 105 ℃, which determined that the electric field had a certain promotion effect on the desorption of the alcoholamine rich liquid.

3.2.2 Effect of low voltage electric field on the rate of carbon dioxide desorption from MDEA solutions

The addition of electric field has a certain promotion effect on the desorption of carbon dioxide from the alcoholic amine solution, which can improve the desorption rate of carbon dioxide. As can be seen from the figure, the desorption rate of carbon dioxide increased with the voltage increased from 1 V to 4.5 V, and the desorption rate increased from 56.55% to 97.92%, and the desorption rate of carbon dioxide decreased when it continued to be increased from 4.5 V to 6 V. Due to the enhancement of the voltage of the electric field, it promotes the carbamate ions or carbamate ions generated from the reaction between the alcoholic amine solution and carbon dioxide to migrate and diffuse in the rich alcoholic amine solution. The desorption rate was enhanced due to the enhanced electric field voltage, which promoted the migration and diffusion of carbamate ions or carbamate ions generated from the reaction between the alcoholamine solution and carbon dioxide in the alcoholamine rich liquid, and the intermolecular collision was intensified. In the low-voltage electric field range from 0 V to 6 V, the 4.5 V voltage promoted the desorption process best, and the desorption rate was the highest.

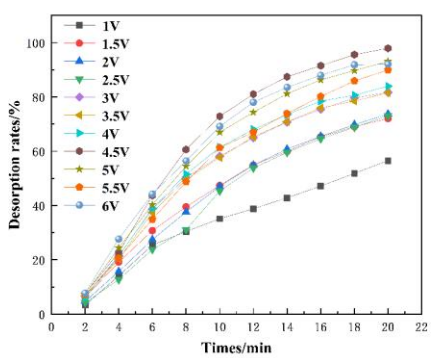

Fig. 6. effect of voltage on desorption rate

3.3 Electric field assisted regeneration performance study

As can be seen from the figure, the amount of carbon dioxide desorbed from the alcoholic amine solution with the assistance of the electric field is more compared to the conventional heated desorption. The absorption of alcoholic amine solution can be maintained at about 3.4 g and the desorption mass is between 4.26 g and 4.6 g after several cycles under the action of electric field, while under the condition of conventional heating desorption, the cyclic absorption is lower than 3 g and the desorption mass is lower than 4 g. It can be seen that the cyclic regeneration of alcoholic amine solution is good under the action of electric field assistance, and the electric field-assisted desorption is better than the conventional heating desorption.

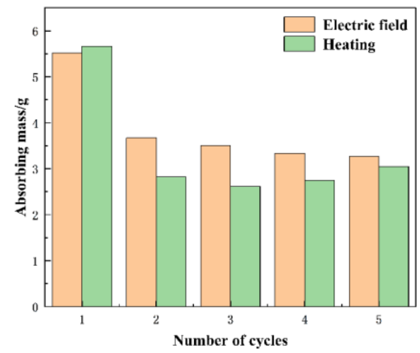

Fig. 7. the change of absorption amount of recycling

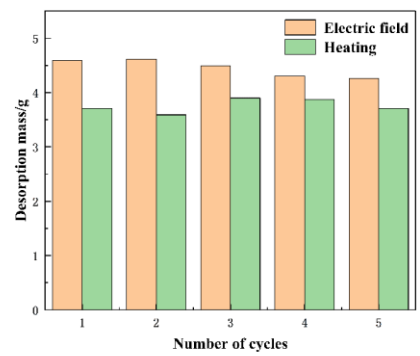

Fig. 8. the change of desorption amount of recycling

4. CONCLUSION

In this study, based on the chemical absorption process, N-methyldiethanolamine (MDEA) solution was used as the absorbent to study its desorption performance under conventional heating conditions and electric field assistance. MDEA is a widely used tertiary amine, which has the advantages of high CO_2 loading, higher selectivity, lower volatility, lower heat of reaction, and fewer foams, etc. Moreover, MDEA reacts with CO_2 to form carbonate and bicarbonate ions, which makes desorption easier and the regeneration energy consumption is low. The study firstly determined the suitable conditions for the absorption process, then compared the traditional heating desorption with the electric field-assisted heating desorption of carbon dioxide to investigate the feasibility and advantages of the electric field-assisted desorption, and finally optimised the desorption conditions through experiments to screen out the optimal desorption temperature and desorption voltage. The specific conclusions are as follows:

(1) The appropriate temperature can reduce the energy loss in the absorption process, and the temperature setting of the CO_2 absorption process of MDEA solution should not be too high, and it is most suitable to set the absorption temperature at 30 °C. With the increase of the absorption temperature from 25 °C to 30 °C, the amount of CO_2 absorbed increased obviously, but with the continued increase of the temperature, the amount of CO_2 absorbed didn't change much, therefore, it is most suitable to choose 30 °C.

(2) In the range of 80 ℃ to 120 ℃, the desorption rate reached the highest value at 105 ℃, in which the desorption rate of conventional heating reached 55.18%, and the desorption rate under the effect of electric field assistance was as high as 97.92%, which shows that the low voltage electric field assistance can promote the efficiency of CO_2 desorption from alcohol-amine-rich liquids, and 105 ℃ is the optimal desorption temperature.

(3) Under the traditional heating desorption conditions, the desorption rate was more in 30%~40%, and in the low-voltage assisted electric field from 0 V to 6 V, the desorption rate reached the highest value of 97.92% under the voltage of 4.5 V, which is obviously a remarkable improvement compared with the traditional heating desorption.

(4) After 5 cycles of regeneration experiments, it can be seen in the electric field assisted cyclic absorption desorption rate is higher, the effect is better, the initial absorption of carbon dioxide under the action of the electric field in the alcoholic amine solution can be up to 5.52 g, and after many cycles of absorption can be maintained at about 3.4 g, and desorption of the quality of 4.26 g to 4.6 g, and under the conditions of the conventional heating desorption, the cyclic absorption is lower than 3 g, and desorption of quality at Under the conventional heating desorption condition, the cyclic absorption was lower than 3 g, and the desorption mass was lower than 4 g. Therefore, the cyclic regeneration performance of the alcoholic amine solution with the aid of electric field was better than that of the conventional heating desorption.

DECLARATION OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All authors read and approved the final manuscript.

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