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Mini Review

Research progress on CO2 capture technology by Chemical absorption method

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Abstract: The rapid growth of industrial activities in developing nations has led to a significant surge in global carbon dioxide (CO2) emissions, contributing to climate change accounts for over 70% of greenhouse gases responsible for the greenhouse effect. Industrial sources, including steel, cement, and chemical production, contribute about 25% of global emissions. Carbon capture technologies are crucial for mitigating these emissions. This review focuses on different studies on carbon capture by chemical absorption methods, focusing on Organic Amine Solution, Ammonia, and Sodium Hydroxide Solution.

Index Terms: Carbon dioxide emissions, Chemical absorption, Organic Amine, Carbon capture

1 Introduction

With the rapid development of society and economy, carbon dioxide (CO2) emissions from human activities have caused global climate change. A large part of CO2 emissions is produced from the rapid growth of industry in developing countries [1]. In 2022, global carbon dioxide emissions reached a record high of 36.8 gigatons (Gt) [2]. Since 1990, annual global CO2 emissions have increased by more than 60 percent [3]. Unfortunately, the atmospheric CO2 concentration has increased rapidly from 280 parts per million (ppm) since the beginning of the industrial era (the early 1800s) up to over 420 ppm by January 2023 (increase rate: ~0.5 ppm per year). [4]. According to statistics, CO2 is the main gas causing the greenhouse effect, accounting for more than 70% of the global greenhouse gas, and the rest are methane, nitrous oxide, and various fluoride-noted gases [5].

Carbon dioxide emissions from industrial sources are considerable, contributing around 25 % of global emissions. In addition to natural gas processing, CO2 is a by-product of several manufacturing processes, including steel, cement, and chemicals production, all of which are necessary in modern society and require decarbonization. Carbon capture technology refers to the process of separating CO2 from relevant emissions [6]. In general, there are three types of CO2 capture technologies such as pre-combustion capture, post-combustion capture, and oxyfuel combustion technology. Because pre-combustion capture and oxy-fuel combustion capture technologies require appropriate materials and certain conditions to meet high-temperature requirements, the application research and development of these two technologies are relatively few. In contrast, post-combustion capture is a widely used and mature technology in the industry, with good CO2 selectivity and capture efficiency. There are various post-combustion capture techniques, including chemical absorption, physical adsorption, membrane, cryogenics, hydrate, and microbial. Among them, Chemical absorption is considered the most advanced route for post-combustion at industrial applications such as power plants [5]. this review explored only the Chemical absorption method with its challenges and prospects identified.

2 CHEMICAL ABSORPTION METHOD

Chemical absorption is a method that uses chemical solvents to react with CO2 to generate compounds and then realizes the desorption of CO2 by changing external conditions such as pressure and temperature so that the absorbent can be recycled. At present, the absorbents studied mainly include organic amine solution, ammonia solution, and sodium hydroxide solution [5].

2.1 Organic amine solution

The Organic Amine Solution method, also known as amine scrubbing, is a widely utilized process for capturing carbon dioxide (CO2) from industrial emissions. This method involves the use of organic amines, which react with CO2 to form a chemical bond, effectively removing it from flue gases. The process generally consists of absorption, separation, regeneration, and amine recycling stages [7]. The technology of using organic amine solutions to capture carbon dioxide (CO2) has seen significant advancement. This approach has become increasingly efficient in capturing and separating CO2. Scholars have conducted numerous studies to explore the effectiveness of organic amine solutions in absorbing CO2, highlighting their excellent capture capacity and separation efficiency. This indicates a growing interest and investment in this method for mitigating CO2 emissions.

2.1.1 Characteristics of CO2 fixation by chemical conversion to carbonate salts.

In this study, amine solutions were used to make carbonates and calcium ions. were used for CO2 fixation. Primary (MEA), secondary (DEA), and tertiary (MDEA) amines were selected for use in a 10 or 30 wt.% amine solution with H2O and Ca2+ in a CO2-saturated solution. Table. 1 shows differences in CO2 absorption are attributed to the composition of the amines [8]. According to Porcheron et al, rich CO2 loading values per mole of amine are 0.522 for MEA, 0.494 for DEA, and 0.536 for MDEA in 30 wt.% amine solutions [9]. This study yielded different results due to variations in CO2 absorption reaction times. MDEA exhibited slower CO2 absorption kinetics compared to MEA and DEA. The study demonstrated reproducibility, with MEA showing the highest CO2 loading capacity under similar conditions. Due to varying reaction times, it was expected that 30 wt.% amine solutions would require over three times as much vent gas to reach 15 vol% CO2 at the analyzer. Therefore, total CO2 loading was considered to determine the amount of CO2 in each saturated solution. This information provides insights into the CO2 absorption characteristics of different amine solutions under varying concentrations and reaction times [8].

Table. 1: CO_2 absorption of the amines for different compositions.

Concentration of amine solution	Amine type	Absorbed 0.293 mol of CO_2 (mol)
10 wt.%	Monoethanolamine (MEA)	0.293
	Diethanolamine (DEA)	0.173
	Methyl diethanolamine (MDEA)	0.180
30 wt.%	Monoethanolamine (MEA)	1.097
	Diethanolamine (DEA)	0.499
	Methyl diethanolamine (MDEA)	0.323

2.1.2 Barium carbonate precipitation as a method to fix and utilize carbon dioxide.

This study focuses on the use of amine solutions in a Carbon Capture and Utilization method through a Carbon Capture and Storage process. The objective is to develop a novel system for forming barium carbonate, a topic previously explored by other researchers. The method involves utilizing an amine solution and barium chloride in a reaction with calcium/magnesium and aqueous CO_2. The study specifically examines the potential for reusing the spent amine solution and analyzes differences in particle size characteristics of the formed carbonates across multiple cycles.

The findings indicate that the amine solution used in the first experiment can reabsorb CO_2 to form aqueous CO_2. Additionally, the majority of converted CO_2 transforms into $BaCO_3$ with the addition of $BaCl_2$ solution. Notably, the particle size of the second batch is larger due to a lower absorbed CO_2 concentration in the amine solution during the second step.

This method might have the potential to mitigate industrial CO_2 emissions under moderate conditions. Barium ions demonstrate a similar capability to calcium and magnesium ions in fixing CO_2. The study aims to optimize the method by adjusting parameters like metal ion concentration, temperature, and time to control the particle size of the metal carbonate. These results hold promise for practical applications in the industrial capture and utilization of CO_2.[10].

2.1.2 Characteristics of carbon dioxide desorption from MEA-based organic solvent absorbents.

This study delves into the critical aspect of CO_2 desorption from absorbents within the context of a CO_2 absorption system. Four monoethanolamine (MEA) - based absorbents, namely MEA/water, MEA/ethanol, and two variations of MEA/ethanol/water, were rigorously examined for their CO_2 absorption and desorption characteristics.

MEA/ethanol stood out with superior performance, showcasing a higher absorption rate, increased regeneration fraction, and a lower desorption temperature for CO_2 compared to the other absorbents. Notably, it displayed a 20°C lower desorption temperature, a 41.72% higher average desorption rate (within the initial 20 minutes), and a 5.52 percentage point higher regeneration fraction compared to MEA/water.

Conversely, MEA/ethanol/water exhibited notably poor desorption performance, with regeneration fractions ranging from 64% to 82%.

Furthermore, the study demonstrated that MEA/ethanol required significantly less desorption energy compared to MEA/water across all absorbent CO_2 loading ratios. Specifically, at a CO_2 loading of 0.07 mol CO_2/mol MEA, the desorption energy requirement for MEA/ethanol was 80% lower than that of MEA/water. The desorption process was observed to take 3–5 times longer than required for absorption equilibrium to be achieved for all absorbents. Additionally, the study highlighted the significant influence of absorbent CO_2 loading on CO_2 absorption, showing a higher absorption rate at lower CO_2 loading.
Lastly, the results indicated that the addition of organic solvents like ethanol could lead to reduced desorption energy consumption and desorption temperature. This finding holds importance for both absorption efficiency and the selection of the appropriate absorbent for CO_2 capture processes [11].

2.2 Ammonia

The process of CO_2 absorption using aqueous ammonia is similar to organic amine solutions. However, its efficiency is lower, and there's a higher risk of ammonia escaping, making it less commonly used. The reaction involves $NH_3 + CO_2 + H_2O \leftrightarrows 2NH_4HCO_3$, with specific steps outlined:

$$2NH_3 + CO_2 \leftrightarrows NH_2COONH_4$$

$$NH_2COONH_4 + H_2O \leftrightarrows NH_4HCO_3 + NH_3$$

$$NH_4HCO_3 + NH_3 \leftrightarrows (NH_4)_2CO_3$$

$$(NH_4)_2CO_3 + H_2O + CO_2 \leftrightarrows 2NH_4HCO_3$$

Advantages of CO_2 capture by aqueous ammonia include low energy consumption, low corrosiveness, and cost-effectiveness. However, controlling ammonia escape remains a significant challenge. Overall, ammonia-based CO_2 capture holds promising applications in the field [5].

2.2.1 A low-energy aqueous ammonia CO2 capture process.

The study demonstrates that the energy consumption of the developed capture alternative is comparable to existing ammonia-based processes and significantly lower than the MEA solvent. Notably, 90% capture can be achieved using a 15 wt.% NH_3 solvent, even at absorber temperatures above 10°C. A thermodynamic analysis indicates that the slip (residual CO_2) can be reduced to 100 ppm with a CO_2-loaded solution and water wash [12].

2.2.2 Performance investigation of a new renewable energy-based carbon dioxide capturing system with aqueous ammonia.

This study introduces a novel approach to carbon dioxide (CO_2) capture using wind energy as a power source. The system employs aqueous ammonia-based capturing technology and utilizes wind turbines for on-site ammonia synthesis and hydrogen production. Hydrogen is generated using a proton exchange membrane electrolysis system, and ammonia synthesis is achieved through the Haber-Bosch technique. The performance of the system for CO_2 capture is assessed from economic, energy, and exergy perspectives. The cost of CO_2 capture is estimated to range from 0.1 to 0.23 dollars per kilogram of CO_2. Additionally, the system is capable of capturing CO_2 at a rate of 3.5 kilograms per second. In terms of energy consumption, it is found to be 640.1 kilograms of CO_2 per megawatt-hour for each unit mass of CO_2 captured [13].

2.3 Sodium hydroxide solution

Sodium hydroxide (NaOH) solution is gaining prominence for its cost-effectiveness and robust CO_2 absorption capabilities. The mechanism behind this lies in NaOH's strong basic properties, allowing it to readily react with CO_2. This reaction can be represented as:

$$NaOH + CO_2 \leftrightarrows Na_2CO_3 + H_2O$$

Continued exposure to CO_2 leads to the formation of bicarbonates:

$$Na_2CO_3 + H_2O + CO_2 \leftrightarrows 2NaHCO_3$$

This indicates that carbonates are produced during the absorption process. However, if the absorbent needs to be regenerated and CO_2 separated from the carbonate, it significantly raises the capture cost. Hence, addressing the high energy requirements for absorbent regeneration is crucial for effective CO_2 capture using sodium hydroxide [5].

2.3.1 Carbon dioxide capture capacity of sodium hydroxide aqueous solution.

This study explores the effectiveness of NaOH aqueous solution in capturing carbon dioxide (CO_2) from flue gas with high CO_2 concentration. The CO_2 absorption process involves sequential reactions forming Na_2CO_3 and $NaHCO_3$. The absorption rate and efficiency vary with NaOH concentration, which is crucial in Na_2CO_3 production. In contrast, $NaHCO_3$ production remains constant regardless of NaOH concentration. The actual CO_2 absorption falls slightly short of the theoretical value due to limited trona production, reducing CO_2 absorption in NaOH solution. The mass ratio of absorbed CO_2 participating in Na_2CO_3, $NaHCO_3$, and trona production is determined as 20:17:1, respectively [14].

2.3.2 Carbon dioxide capture by sodium hydroxide-glycerol aqueous solution in a rotating packed bed.

This study addresses the challenges of carbon dioxide (CO_2) capture by chemical absorption, a widely used method, which faces limitations due to low CO_2 solubility in water and high energy requirements for absorbent regeneration. To mitigate these issues, the study introduces glycerol, a by-product of biodiesel production, into a sodium hydroxide (NaOH) aqueous solution. This modified solution acts as an efficient absorbent in a rotating packed bed (RPB) for CO_2 capture.

Experimental results demonstrate that the inclusion of glycerol significantly enhances the overall CO2 absorption efficiency, achieving over 90% efficiency. Particularly under high rotational speeds (referred to as high G condition), the chemical enhancement factor surpasses 50, indicating a substantial improvement in the CO2 capture process. Furthermore, even with the addition of viscous glycerol, the mass transfer coefficients (KGa) double due to the intensified centrifugal field. This implies that glycerol augmentation in NaOH solution not only enhances mass transfer performance but also presents the potential for utilizing biodiesel by-products in the CO2 capture process [15].

3 CONCLUSION

Chemical absorption is a pivotal method in carbon capture, exploiting chemical reactions between the absorbed substance (CO2) and a solvent to form a concentrated liquid. This approach, often used in post-combustion scenarios, plays a significant role in separating and concentrating carbon dioxide from various gas mixtures, including flue gas and ambient air. Notable solvents in this process include organic amine solutions, ammonia, and sodium hydroxide solutions, each with distinct advantages and applications. Organic amine solutions, despite potential energy-intensive regeneration, offer versatility across industries. Ammonia-based absorption stands out for its high absorption capacity and relatively low regeneration energy requirements, making it suitable for large-scale applications. Sodium hydroxide, or caustic soda, is effective in post-combustion contexts, converting CO2 into stable carbonates. Continued research and development in these chemical absorption methods are crucial for maximizing their potential in combatting climate change.

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