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Review Article

Carbon Capture Technology and its Potential to Global Emission: Mini-Review

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Abstract - *Carbon capture is one of the most effective measures to mitigate greenhouse gas emissions. With the evolution of several techniques, some implications are encountered based on design implementation and cost of operation. Estimations have shown that greenhouse emissions will incur a 30% increase by 2040. As the global world population increases, one common challenge is maintaining the world energy demand, thereby regulating the rate at which greenhouse gases are emitted. As a result, the need to provide an efficient and cost-effective way to capture these gases becomes imminent. Several studies have described the various technologies involved in carbon capture and their limitations. This review paper described the carbon capture technologies used in today's industries and how recent innovations were captured on those existing designs.*

Keywords - *CO_2 capture, Greenhouse gas, Global emission.*

1. Introduction

CO_2 capture has been one of the major processes functional in the industry today. Several strategies to mitigate the emission of greenhouse gases have been a concern to many scientists [1]. As such, it is important to investigate the various means by which this gas can be recovered for subsequent utilization.

The monumental amount of greenhouse gases in the atmosphere has adversely contributed to rising environmental problems. One such problem is the intermittent rising sea water level due to global warming. About 85% of the world's energy is supplied by fossil fuel plants (coal, gas, oil) [2], where about 40% of emission is attributed to CO2 and coal-fired plants. About 60% of global emissions are attributed to CO_2 gas due to many industrial processes involved in releasing the gas [3]. Several authors have explained different scenarios in which carbon capture can be implemented based on its corresponding process.

2. CO_2 Capture By Absorption

Absorption is one of the most common techniques used to capture CO_2 gas. This capture is based on Henry's law. [4] reviewed the absorption and adsorption technique of CO_2 recovery by considering various scenarios to which this technique can be applied. One of these techniques is the physical absorption process. CO_2 is usually absorbed under high pressure and low temperature. It is then desorbed at reduced pressure and increased temperature. This synthesis technology has widely been used in process industries.

Like natural gas, synthesis gas, hydrogen production with other industrial processes predominantly involves high CO_2 content [5].

[6] designed an absorption system that employed chilled ammonia to absorb CO_2 at a low temperature. A direct contact cooler was used to cool the flue gas containing the CO_2 at the entrance of the process, and the temperature range was between 0 and 10℃. One of the functions of using low temperature is that it decreases the vapor pressure of the compounds. The flue gas containing the CO_2 is sent into a regeneration subsystem. The cold flue gas enters the bottom of the absorber while the CO_2-lean stream enters the top of it. The lean stream consists of water, ammonia and carbon dioxide. The pressure in the absorber is kept close to atmospheric pressure, while the temperature should range from 0 to 20℃. The low temperature prevents the ammonia from evaporating. It was also shown from the assessment that the solid phases consisting of ammonium carbonate and bicarbonate are formed in the absorber.

[7] evaluated the opportunities associated with post-combustion CO_2 capture at a world-scale complex refinery. The studies showed that the emission of CO_2 in refineries could be reduced by considering different scenarios. One is through energy conservation; however, no matter how efficient a refinery is, there will still be a surplus amount of CO_2 gas released into the atmosphere. The second way is the carbon capture technique.

According to [7], three different routes were recognized for the CO_2 capture:

- Oxyfiring: in this case, pure oxygen is used in place of air for combustion. It produces a stream that contains carbon dioxide and water.
- Pre-combustion capture: for this process, carbon dioxide is removed from hydrogen, which benefits operating at a higher pressure and, thus, makes removing carbon dioxide easier.
- Post-combustion capture: an end-of-pipe solution where CO_2 is removed from the flue gas before the flue gas is emitted to the atmosphere through the stack.

To understand the efficacy of carbon capture, it is necessary to consider the process's physical operations and the underlying factors associated with the properties of CO_2 [8]. Hence properties like the working temperature of the flue gas should be studied. A study by [9] to generally and critically review the emerging technologies that will help expedite carbon capture efficiency was done. In this review, attention was given to specific routes with a substantial increase in technical readiness toward a large-scale CO_2 capture system.

- High-temperature looping system: the process depends on a gas-solid reaction that operates at a very high temperature. The reaction is mostly reversible by considering the bulk phase of solid particles with oxygen. The gas separation occurs at a very high temperature, allowing efficient integration with the existing steam cycle for power generation.
- Solid sorbents: this technology works on the ability of gases to be adsorbed on a solid surface. This gas separation technology is mature in many large-scale industrial applications for different target gases and concentrations.
- Membranes: this process relies on the selective permeation of a target gas from one side to the other of solid membrane material. This technology has substantially gotten traction in the power sector. A polymeric membrane that targets the separation of CO_2 from flue gas has experienced the greatest advances in the last 10 years.

[3] described a mathematical model of a cross-flow membrane contactor used to remove CO2 from flue gas using a 1-ethyl-3-methylimidazolium ethylsulfate as the solvent. In the description, the mass transfer flux of carbon dioxide in the gas phase was calculated using:

$$N_{CO_{2.g}} = \frac{Q_g}{A}\left(C_{CO_{2(g),in}} - C_{CO_{2(g),out}}\right) \quad (1)$$

Were Q_g is the gas flow rate, and A is the membrane area. The overall mass transfer was shown to be calculated using the equation:

$$N_{CO_{2.g}} = K_{overall}\left(\frac{\Delta y_{lm} P_t}{RT}\right) \quad (2)$$

P_t is the total pressure of the gas, Δy_{lm} is the logarithmic mean of the driving force based on the gas phase molar fractions and the carbon dioxide concentration of the inlet and outlet of the contactor.

A microscopic model based on laminar flow was applied. A membrane mass transfer coefficient of k_m to be $3.78*10^{-6}m*s^{-1}$, which was five times higher than that obtained in the macroscopic model. The selective absorption of carbon dioxide is a critical issue for most industries. [10] predicted the bulk absorption properties of the functionalized framework towards CO_2 and CH_4.

It was used to capture the direct impact of molecular-level interactions on the macroscopic behavior of the crystalline metal-organic material (MOF). [11] reviewed the recent technological development on CO_2 capture using an amine-based process. The author indicated that amin-based technology is the most dominant process of capturing CO_2. The amine scrubbing technology was described as one of the most economical technologies for post-combustion CO_2 capture.

The amine scrubber captures carbon dioxide with an aqueous amine solution. In the amine scrubber, the flue gas passes through a scrubber that contains the amine solution. The amine solution absorbs the CO2 and then is sent to a stripper, where it is heated with steam, usually from a steam power plant. The carbon dioxide released is further compressed for transportation. In some cases, this process degrades the amine solution's effectiveness. One common way to study the degradation of amines is to leave them at a high temperature for a longer period.

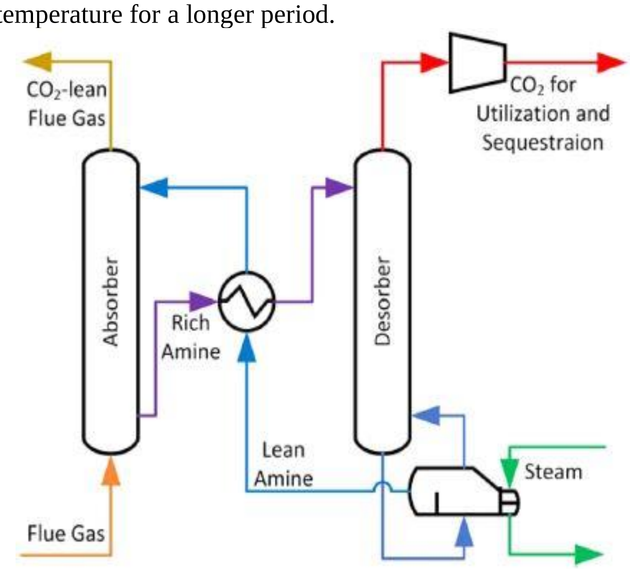

Fig. 1 A typical Amine scrubbing unit [11]

Another study on the recovery of CO_2 by amine-based solvents was investigated by [12]. However, the absorption study used secondary alkanolamine solutions such as MDEA and DEA. This study examined the loading capacity, the heat of the reaction of CO2, and the absorption rates of the absorbents. A structure performance relationship was visualized (Fig 2).

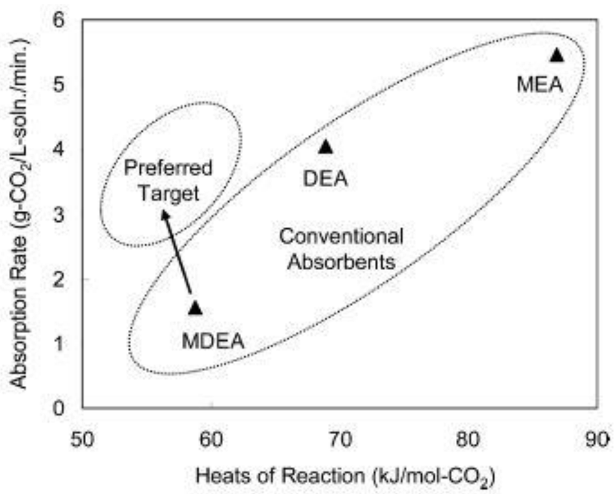

Fig. 2 Relationship between CO_2 absorption rate and heat of reaction for aqueous solutions for conventional amines [12]

It was also observed that MEA reacts faster with CO_2 than DEA, and DEA reacts faster than MDEA. It indicated that the heat of the reaction and absorption rates of alkanolamines depend on the substituents attached to the nitrogen atoms. CO2 reacts with the amine in aqueous solutions to form stable carbamate anions, while the tertiary amines produce bicarbonate ions.

While CO_2 poses an environmental threat, it is important to effectively search for appropriate adsorbents to bind the carbon dioxide gas molecule over a wide temperature range [13]. However, some limitations might arise, which will make the economic feasibility of selection poor. It could be the process design limitations or the operating specification. It was stated earlier that CO_2 capture was categorized into 3. These are the post-combustion, pre-combustion, and oxy-combustion processes; however, it is necessary to note that this categorization applies to fossil fuels and biomass. In the carbon capture and storage (CCS) train, the capture of CO_2 is the most expensive. [14] presented a systematic approach to chain capture, transportation and sequestration costs and emissions. This process is also applicable to all carbon capture categories.

A patent review on the recent technology applicable to CO_2 capture was done by [15]. The study used advanced search keywords to conduct a patent search. It was also observed that many technical challenges are faced with large-scale implementation of CO_2 capture in power plants [16]. A major challenge in the operation of CO_2 capture technology is that the decreasing fossil fuel-fired plant capacity without any countermeasures endangers the security of the energy supply [56]; thus, the importance of improvising measures inhibiting the recourse should be a priority. Oil refineries and power plants are the most contributors to carbon dioxide emissions [18]. It is because surplus fuel consumption contributes daily to an increasing greenhouse emission. Although it has been suggested by [19] that one of the best ways of reducing emissions is to reduce energy consumption by increasing energy conversion efficiency. That is, switching to less carbon-generated fuels such as biomass, which is technically renewable energy.

It is said that the global emission of CO_2 should be at least increase by 30% in the year 2040 [20]; however, the emission rate could be subject to the efficiency and rate at which carbon capture can be actualized. Although, the global energy need is also seen to have an exponential increase.

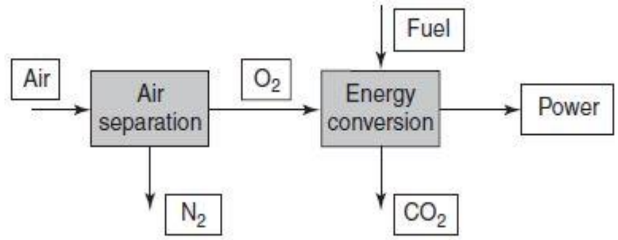

Fig. 3 Schematic showing post-combustion, oxy-combustion and pre-combustion processes, respectively [14]

3. Membrane CO_2 Carbon Capture

Studies have shown that membrane-based technologies have a greater significance than other technologies. According to [21], using membrane separation, three systems are considered the basis for CO2 capture. The first is the non-dispersive contact via a microporous membrane, the second is gas permeation, and the third is the supported liquid membrane. The non-dispersive absorption uses a gas-liquid contactor, indicating a greater advantage over other conventional technologies. It is mainly applied in post-combustion capture. The use of membrane separators has more operational flexibility due to the independent control of gas and liquid flow rates, control and known interfacial area, and a linear scale-up.

3.1. Mass Transfer Related to Membrane Absorption

It is shown that the absorption flux in a membrane contactor depends on different parameters: the membrane structure and morphology and the operating conditions of the absorption process. The mass transfer through the membrane can be defined as the overall mass transfer coefficient.

[22] investigated the application and potential of using a membrane as an energy-efficient, low-cost carbon capture option. A membrane with CO_2 permeance of greater than 1000gpu was developed. It has an operating selectivity

temperature of 30°C. This set of membranes works in combination with a process that utilizes an incoming combustion air to sweep gas to generate a driving force that could meet the carbon capture cost targets. [23] tested a nanostructured gas separation membrane in the flue gas of a post-combustion power plant. [24] investigated the significance of gas velocity change in a hollow fibre membrane contactor when transporting CO_2 gas. A 2D model was developed for the physical and chemical absorption of carbon dioxide from natural gas, which contains a high percentage of CO_2. The model considered changes in the axial gas velocity as carbon dioxide is being absorbed from the gas mixture. The model was also validated with experimental data and then compared with the previous model.

[25] modelled the carbon dioxide removal from natural gas at high pressure using a membrane reactor, but unlike [24], changes in the axial gas velocity were not considered. The 2D model was developed for the pressure of 50 bar. [26] considered the removal of carbon dioxide from a pressurized CO_2-CH_4 gas mixture using a hollow membrane fiber. The membrane construction included the fabrication of stainless steel, module housing, pre-treatment of ePTFE fibers and the module housing, potting of the fibers and module assembly.

3.2. CO2 Capture using solid sorbents

Carbon dioxide can be removed through a physical sorbent like zeolites, alumina, silica gel and metal-organic framework (MOFs). In most adsorption cases, physiosorption through the use of zeolite or activated carbon, the process can be such that the adsorption mechanism results from van der Walls attraction between the CO_2 molecule and adsorbent surface [27]. [28] reported the effectivity of post-combustion capture applied to coal-fired power plants. It was shown that, of all the post-combustion technologies applicable to coal-fired power plants, chemical absorption was found to be more suitable. However, the leading post-combustion technology in CO_2 capture is solvent scrubbing using amine solvents [29].

3.3. Low-temperature CO2 capture

Carbon capture by physical or chemical absorption and membrane separation has been the most prevalent for most industrial CO_2 capture. Limited attention has been given to low-temperature flue gas and synthesis gas by phase separation [30]. CO_2 capture by low-temperature cooling and phase separation is commonly referred to as cryogenic capture.

The low temperature can either be done by vapor-liquid separation, vapor-solid separation or a combination such as the carbon dioxide slurry separation. One basic advantage of low-temperature CO_2 capture to solvent technologies is that no solvent is needed for CO_2 capture.

[31] presented a combined experimental and theoretical study of an amino-functionalized MIL-53 to illustrate the mechanism behind the efficiency of using metal-organic frameworks to capture CO_2. It was also established that amino groups are only indirectly responsible for the improved separation performance. Ionic liquids have also been shown to be of use in capturing carbon dioxide. An overview by [54] was carried out to elucidate the achievements and difficulties encountered in finding a suitable ionic liquid for CO_2 capture from flue gas systems. [33] also illustrated the CO_2 from flue gas using the covalent organic framework (COF). This study provided stability, low- and high-pressure uptake, selectivity, and breakthrough performance of CO2 capture. [34] reviewed the effect of using ionic liquid-amine blends and CO_2BOLs as a solvent for sweetening natural gas and CO_2 capture technology.

[35] investigated inter-cooling effects for monoethanolamine (MEA) and diethanolamine (DEA). The studies showed that the best location for intercooling, based on minimizing energy requirements per kg of CO2 captured, is about $1/4^{th}$ of the height of the column from the bottom.

In the cement industry, the study has shown that cement production accounts for about 7% of the global emission of CO2 [36], where about two-thirds of the emission results from process operations mainly generated by the calcination of limestone. This industrial operation not only gives an attribution factor to the emission rate but also affects the system's cost performance and techno-economic assessment [37]. The feasibility of capturing CO_2 from cement and steel plants using membranes was investigated by [38]. This assessment observed that coal power flue gas contains about 13-15% of carbon dioxide, while types of cement and steel flue gas contain about 20-30% carbon dioxide. Membrane-based systems were able to capture 80% of the CO_2 emitted.
CO_2 capture from cement plants using oxyfired pre-calcination and calcium looping was studied [39]. Material and energy synergies with calcium looping technologies were designed for the first part of the study, and the second part implemented an oxyfired circulating fluidized bed pre-calcination. However, calcium looping has been considered a post-combustion CO2 capture technology [40] based on the cyclic calcination and carbonation of a $CaCO_3$-containing sorbent.

In membrane capture applicable to the cement industry, significant studies are sometimes given to the sensitivity analysis of single-stage membrane systems. Still, as the case may be, multi-stage membrane capture has indicated substantial efficacy in post-combustion technology [41]. The types of cement plants are mostly characterized by a single emission source [42], the cooled flue gas from a preheater.

[43] presented a criterion determining the most CO_2 capture technology in the cement industry's integrated carbon capture system. The author also described how CO_2

sequestration potential in proximity to a cement plant generates a critical factor in determining the suitability to host a commercial carbon capture system demonstration.

In the oil and gas industry, CO_2 has gained traction in the enhanced oil recovery scheme [44]. A miscible CO_2-EOR has become one of the many choices used in depleted reservoirs to recover oil and gas. However, potential risks may arise from CO2 leakage from pipelines and other storage systems. For this reason, several mitigation techniques have been employed to enhance oil recovery where the usage of CO_2 capture is optimal. [45] evaluated the potential of a particle swarm optimization algorithm with least square support vector machine intelligent as a low parameter technique for phase equilibrium modelling of semiclathrate hydrates of carbon dioxide in the presence of some ionic liquid promoters. [46] reviewed the most recent developments in the carbon capture and utilization field while considering challenges that pose a problem to the industry. [55] identified the main problems of carbon capture in China, outlining suggested energy networks that will help mitigate the adverse effects of global warming.

4. Conclusion

CO_2 capture technology is utilized and implemented via several optimal processes. However, A benchmark description for carbon capture technology was given. However, it is also necessary to consider the techno-economic evaluation of each given technology, like the PCC technology [48]. We also looked at how the oil and gas industry played a role in developing carbon capture and storage as mitigation options for climatic effects [49]. The oil industry is a major trade-exposed [50]. Hence most oil-related industries depend solely on the exportation of oil and gas. It will be necessary to capture potential strategies to help mitigate environmental hazards due to oil leakages and emissions and enhance oil productivity via intelligent systems[51]. Likewise, automated systems are encouraged to optimize these carbon capture technology [52].

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