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The Post Combustion Carbon Dioxide Capture

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Abstract – The major greenhouse gas that contributes to global warming more than 60% is carbon dioxide. The thermal power plant is one of the main sources that release carbon dioxide into the atmosphere. The reduction of carbon dioxide emissions from particular industries is an essential thing. So, carbon dioxide capture methods are used to reduce carbon dioxide emissions into the atmosphere. There are three basic capture methods at present. The post-combustion capture, pre-combustion capture, and oxy-fuel combustion are them. This review paper discusses the post-combustion carbon dioxide capture methods.

Index Terms –Chemical absorption, cryogenics, gas absorption, and microbial algae CO2 capture method, packed bed absorption, physical absorption, and post-combustion CO_2 capture

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1 INTRODUCTION

Carbon dioxide is considered one of the leading greenhouse gases that cause global warming and climate change. The combustion of fossil fuels is the primary source of the increase in atmospheric carbon dioxide concentrations. Since 1751, from fossil fuels and cement production-consumption, roughly 321 billion tons of carbon have been released to the atmosphere [1]. In 2002, the global fossil-fuel carbon dioxide emission estimate was about 6975 Mt of carbon. Due to those reasons, the development of an efficient and cost-effective carbon dioxide capture technique is the essential thing. The post-combustion carbon dioxide capture method is one of the leading CO_2 capture methods.

Post-combustion capture's main advantage is that it is the only practical technology able to minimize emissions from existing power stations and new ones. The post-combustion capture (PCC) technology is based on absorption processes. PCC methods produce a very pure CO_2 stream in several ways and flexible technology with high adaptability. The post-combustion capture technology can be applied to the existing large point source of fossil fuel-based power plants, refineries, and cement manufacturing industries as these are the main sources of carbon dioxide emission in the atmosphere [2]. Fig. 1 shows the post-combustion CO_2 capture concept.

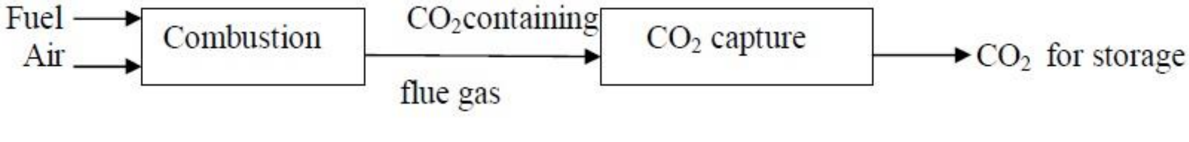

Fig. 1. The post-combustion CO_2 capture concept [1]

The separation of CO2 from the flue gases is the principal of the post-combustion capture method. When considering this method specifically for coal-fired thermal power plants, post-combustion capture is viewed as the best available technology. The lead contending technology is currently based on solvent scrubbing with amine solvents or a solvent based on sterically hindered amines. Insolvent scrubbing, a chemical solvent is used, which reacts with the CO_2 in the flue gas and is regenerated at a higher temperature, producing a purified CO_2 stream suitable for compression and storage. The retrofitting to existing power plants and industries in suitable locations, and commercially proven on a small scale are some advantages of amine scrubbing for post-combustion capture. There is much post-combustion gas separation, and capture methods have been investigated [1]. Fig. 2 shows the various technology options for post-combustion CO_2 capture.

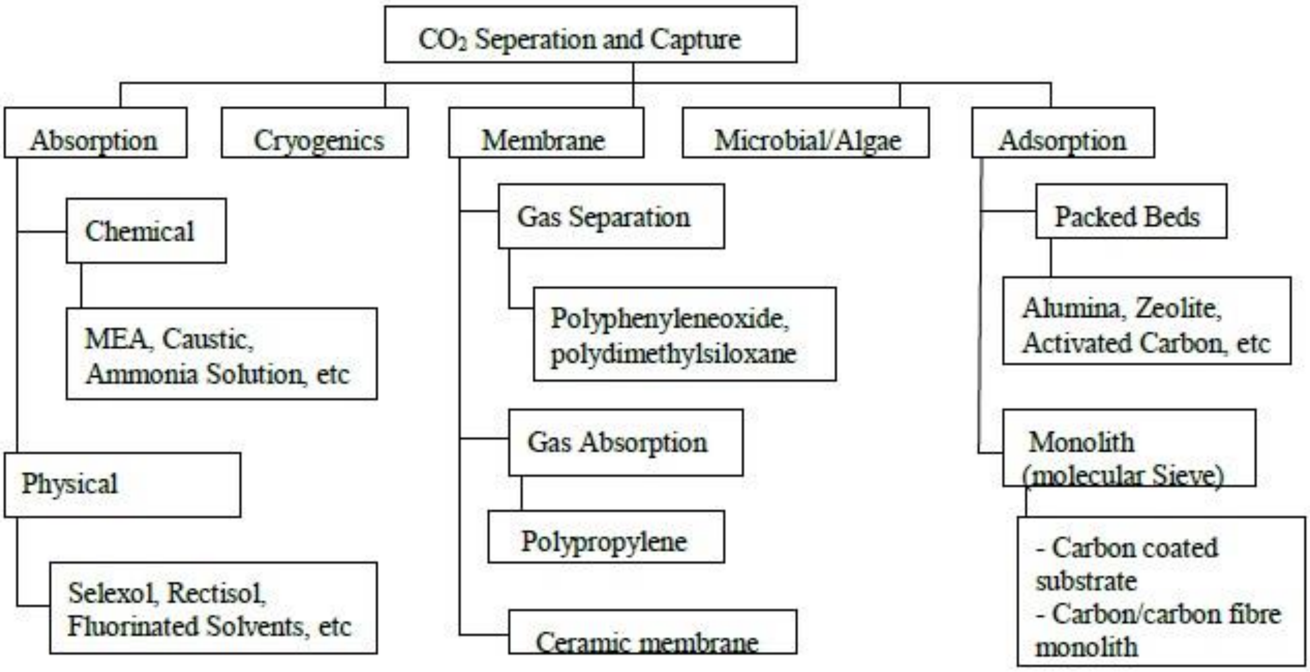

Fig. 2. The various technology options for post-combustion CO_2 capture [1]

2 GAS ABSORPTION

When capturing CO_2 by gas absorption, the membrane is used for that. The membrane gas absorption method is an effective alternative CO_2 capture and customarily installed at the outlet of the wet flue gas desulfurization (WFGD) system. The membrane gas absorption method is a process that leads to smaller absorbers through the use of small-diameter hollow fibre membranes. Fig. 3 shows the principle of that method. The porous polymer membrane is the essential element in a membrane absorber. As a result of the membrane's hydrophobicity, the gas phase remains separated from the liquid absorbent. Along the one side of the membrane, a flue gas stream is fed. The components which are to be separated from the gas stream can flow through the membrane's gas-filled pores.They will absorb into the absorption liquid on the other side of the membrane [3]. To be absorbed, the concentration gradient provides a driving force for CO_2. The CO_2 is counter currently brought into contact with the amine solution in the membrane absorber. The amine solution is fed via a heat exchanger to the regenerator, where CO_2 is released at high temperatures. Fig. 4 shows the flow sheet of the membrane gas absorption process. The gas absorption of the membrane has some advantages: effective contact area, extensibility and modularity, operational flexibility, and prospect for industrial applications [4].

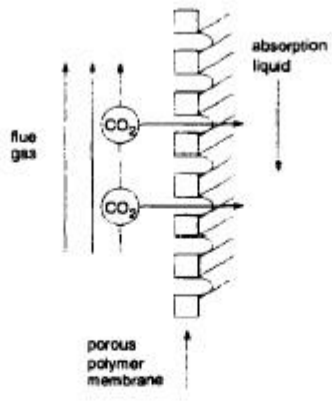

Fig. 3. The principle of Membrane Gas absorption [3]

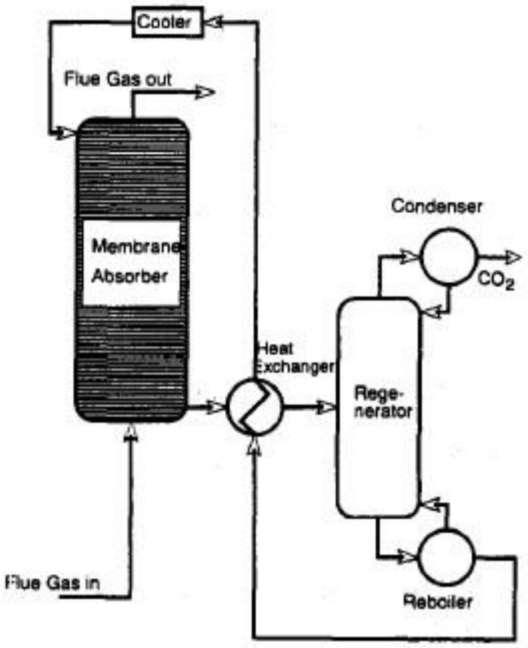

Fig. 4. Flowsheet of the membrane gas absorption process [3]

3 SOLID SORBENT BASED CO_2 CAPTURE METHOD

This method can introduce as a profitable way to capture CO_2 for coal-fired power generation. When considering the efficiency of the plants' metal-organic framework gain value of 32% and solid amine base sorbents gain value of 29%. And also solid sorbents achieved a better situation relative to the liquid system. Another advantage that presents on this system is the ability to generate more electricity because the materials used as solid sorbent have a low requirement of heat. But the main disadvantage of this system can be identified as the low knowledge of preparation of the optimal size of the reactor and execution of the overall system. The process can identify as cleaning the flue gases, adsorption of CO_2, desorption of CO_2, preparing the sorbents and post-capture treatment. When cleaning flue gases SO_2 polisher apply to remove SO_2 gas from flue gas and to cool flue gas, then the flue gas pulled through a flue gas blower. When adsorbing CO_2 bubbling and fixed beds apply to the process and it seems as continues reactor type or batch type. When desorbing CO_2 gases pulled from regenerator and directed to dehydration and compression block. When preparing sorbents the heated solid stream directed to a rotary contact cooler, and then to temporary storage and take to regeneration. When at the post-capture treatment stage CO_2 which was captured weakens and compressed to an excellent state then stored at geological storage [5].

4 SOLVENT BASED CO_2 CAPTURE METHOD

This method applies to the post-combustion CO_2 capture with power generation related to oil industries and gas industries, and solvent-based CO_2 capture is executed as a part of the power station—solvent-based CO_2 capture units used for combustion flue gas scrubbing when at lower CO_2 removal [6]. Post-combustion CO_2 capture at power generation proceeds by absorbing CO_2 of gas streams with aqueous amines. Usually, the gases used to be treated are oxygen-free and at a high level than the atmospheric pressure. To decide the state of the solvents used in this process overall electricity output penalty can be used. The solvent parameters that will effective for the efficiency of the power generations are solvent, thermal stability, and desorbed pressure. This method has the advantage of losing efficiency at a high value. But it can reduce by optimizing process flow. Some of the process modifications that can identify as intercooler absorber, rich solvent recycle, inter-heated absorber, rich solvent splitting, rich solvent preheating, rich solvent flashing, parallel economizer arrangement, lean vapor compression, rich vapor compression, integrated heat pump, and multi pressure striper [7].

5 CHEMICAL ABSORPTION

The two-film theory is used for this method. The chemical absorption method used to remove CO_2 from gas streams at oil industries, chemical industries and gas industries. The process used to remove CO_2 proceeds by direct the flue gas through a continuous scrubbing system. And also this system included with an absorber and a disrober. The absorption process is happened by chemically reacting an aqueous alkaline solvent as an amine with CO_2. Disrober used to remove CO_2 from the solvent and direct fresh CO_2 stream to the compressor. And the regenerate solvent direct back to the absorber and the solvent heated to the necessary temperature by heating the reboiler. But the disadvantage of this method is that the energy loss due to pumps and blowers which used to compress and store CO_2. The solvent systems that used for chemical absorption can identify as MEA (methyldiethanol), AMP, mixed amine blends, potassium carbonate, chilled ammonia, MEA/AMP blends, DEA (diethanolamine), DGA (diglycolamine), MEA/MDEA blends, DIPA (diisopropylamine), TEA (triethanolamine), sodium carbonate, water-free solvents and aminisilicones [8].

6 PHYSICAL ABSORPTION

For a range of nonreactive sorbents including carbonaceous materials and crystalline materials known as zeolites, carbon dioxide may be removed from the flue gas. High porosities include 10-15% by weight of activated carbon and charcoal with CO_2 capture capacities. Our selectivity's for CO_2 / $N_2$is however fairly small. Because of this drawback, the expected capture costs, including compression costs, are such that carbon-based systems only become feasible if the required CO_2 purity is not more than 90%. On the other hand, zeolite materials offer selectivity of CO_2 / N_2 5-10 times greater than those of carbonaceous materials. Yet their capacity for CO_2 is 2-3 times lower. Besides, zeolite efficiency is affected by the presence of water vapour. 16 To be competitive with liquid solvents, solid sorbents must be less prone to steam and give far greater CO_2 capacities and selectivity than soft sorbents are currently available[9].

7 REACTIVE ABSORPTION WITH ‘MEA’ AND NEW SOLVENT

CO_2 capture by reactive absorption-stripping is considered one of the most effective solutions to reduce industrial carbon dioxide emissions [10]. The ideal chemical solvent should have high CO_2 reactivity, high absorption capacity, low cost of regeneration, high thermal stability, reduced degradation of solvents, low environmental impact, and low cost of solvents. Chemical solvents provide fast kinetics to allow the capture of low CO_2 partial pressure streams. Also, wet-scrubbing allows for good thermal integration and ease of heat management [11]. The amine-based scrubbing solvents mono-ethanol amine (MEA) and ammonia solutions are two of the most important and well-studied solvents. Using MEA as a solvent produces a higher capability for CO_2 capture and lower energy consumption. However, these solvent types have several weaknesses in thermodynamic properties, corrosively, and toxicity [11]. Moreover, a high energy demand during the regeneration cycle is a main disadvantage of the MEA based carbon capture process, which is the re-boiler duty in the stripper column [12].

7.1 Available solvents

There are various types of amines, some of which are categorized. These amines are classified as primary (MEA, DGA) amines, secondary (DEA) amines, tertiary amines (MDEA, TEA), hindered amines (AMP), and cyclic amines (Piperazine). Primary amines are formed when an alkyl group is substituted for one of the three hydrogen atoms in ammonia. Secondary amines are created by replacing two alkyl groups in two hydrogen atoms and three groups of alkyls react with nitrogen and form tertiary amines. Cyclic amines are formed by a 3-member ring called aziridine or 6-member ring piperidine. Hindered amines are created by the amine functional group that is surrounded by a steric environment. Alkanolamines are composed of both hydroxyl (OH-) and amino (-NH2) groups. The hydroxyl segment helps minimize vapour pressure and increases water solubility, while the amino group provides the alkalinity needed in a solution for acid gas reactions [13]. Basic information on some of the amines is provided in Table 1.

Table 1. Properties of Amines [13]

Amine	MEA	DEA	DGA	MDEA
Chemical formula	C_2H_7NO	C4H11NO2	C2H11NO2	C5H13NO2
Amines category	Primary	Secondary	Primary	Tertiary
Molecular weight [g/mol]	61.08	105.14	105.14	119.163
Density [g/cm^3]	1.012	1.090	1.06	1.043
Boiling point[°C]	170	217	223	247

7.2 MEA based 2 capture process

Capture method based on the MEA CO2 Process flow diagram shown in Fig.5. The main components are the absorber, stripper, pump, heat exchanger, and so on.

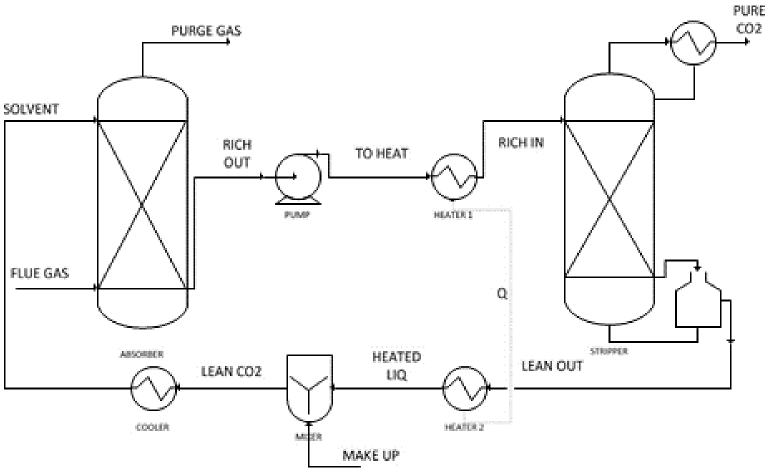

Fig. 5. Process flow diagram [14]

Flue gas (FLUE GAS) enters the absorber from the bottom while the solvent (SOLVENT) is entering the top during the chemical absorption process. The reactions start between MEA and CO2 when the column (packing bed) flows through. The column is left by an unreacted gas (PURGE GAS), whereas the carbon-rich solvent releases the column to the lower (RICH OUT). The rich solvent passes by the temperature exchanger until it is sent to the strippers. The rich, heated MEA (RICH IN) stream then reaches the top stripper. Steam is used in the stripper for the regeneration process. Separated gases are then left at the top of the stripper (PURE CO2). The lean MEA leaves the system at the bottom (LEAN OUT) and passes through the heat exchanger. MEA and water are added to the lean MEA stream (makeup) to balance the component before being recycled back to the absorber unit [14, 15, 16].The main reactions in aqueous MEA and CO2 systems are shown in Fig.6.

$$2H_2O \Leftrightarrow H_3O^+ + OH^-$$

$$CO_2 + 2H_2O \Leftrightarrow H_3O^+ + HCO_3^-$$

$$HCO_3^- + H_2O \Leftrightarrow H_3O^+ + CO_3^{2-}$$

$$2MEA + CO_2 \Leftrightarrow MEAH^+ + MEACOO^-$$

$$MEA^+ + H_2O \Leftrightarrow MEA + H_3O^+$$

$$MEACOO^- + H_2O \Leftrightarrow MEA + HCO_3^-$$

Fig. 6. Main reactions taking place in aqueous systems of MEA and CO2 [17]

8 CO2 CAPTURE BY USING CaO

Oxy-fuel and amine-based post-combustion plants are the most frequently proposed configurations for short-term steam-based CO2 capture plants. An alternative option is discussed in which calcium oxide (CaO) is a solid sorbent for post-combustion capture [18].

Solid sorbents for CO2 separation include sodium and potassium oxides, zeolites, carbonates, amine-rich sorbents, and so on. One of these, calcium sorbents (CaO) is commonly used in fluidized bed combustion due to their low cost to control the emission of sulfur pollutants. It has also been well established that the fresh calcined lime can be rapidly carbonated by carbon dioxide at a suitable temperature. Calcium-based sorbents have therefore been suggested as an attractive carbon dioxide removal material due to its low cost, high adsorption capacity, and high reversibility of CO2. The CO2 capture mechanism for calcium sorbent can be divided into two steps, carbonation and calcination [19].

$$CaO + CO_2 \rightarrow CaCO_3 \qquad (1)$$
$$CaCO_3 \rightarrow CaO + CO_2 \qquad (2)$$

Calcination of CaCO3 is an endothermic reaction, which means that the forward reaction is favourable at higher temperatures.CO2 separation from flue gas by CaO based sorbents in fluidized bed combustion (FBC) is a highly researched technology for the reduction of CO2 emissions [19]. The typical scheme of the CO2 removal process could be shown in Fig.7.

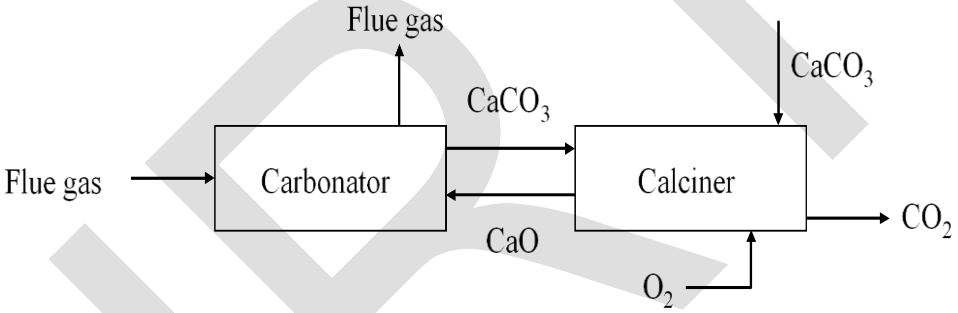

Fig. 7. The CO2 separation loop scheme by CaO-based sorbents[19]

According to the above, the carbonation process of calcium sorbents (CaO) with CO2 is the basic reaction of the capture technology in this high-temperature CaO / CaCO3 cycle system.

All CaO sorbents used in this loop come from the CaCO3 calcination cycle, at around 800~900°C. In the carbonator, high porous CaO sorbents were treated with diluted CO2 stream and CaCO3 was further formed at a temperature of more than 600°C. Active sorbents were regenerated by a calcination reaction at a higher temperature of between 850~900°C and the CO2 component was separated from the loop. After being reduced in a separate (cracker) vessel, CaCO3 transfers to CaO and returns to the carbonation vessel for CO2 capture [19].

9 PACKED BED ABSORPTION

Based on the occasional activation of cryogenic chilled packaged beds, a new cryptocurrency concept for post-combustion CO2 capture from pipe gases has been studied. Using frozen packaged beds, it is possible to distinguish between H2O, CO2, and permanent gases at atmospheric pressures due to changes in dew and peaks. H2O and CO2 are deposited on the packing surface at different locations, respectively, and permanent gases pass through the bed. In this work, the evolution of the axial temperature and concentration profiles during continuous capture, recovery, and cooling cycles are examined in detail by experimental and numerical simulations, feeding the concentrations of CO2 and H2O, explaining the effect of the initial bed temperature. Furthermore, the cooling tariffs required for different CO2 concentrations in the tube air and the starting bed temperature were calculated. Cold duty required to recover 99% CO2 from 10 %% voltage CO2 and 1-volt pipe gas. H2O is estimated to be 1.8 MJ / kg CO2, where the lower CO2 concentrations of the inputs and the higher initial bed temperature increase the cooling duty per captured CO2 mass.

10 CO_2 CAPTURE BY MICROBIAL ALGAE

The term "microalgae" is commonly used for eukaryotic microalgae, including prokaryotic blue-green algae (cyanobacteria) and green algae, red algae and diatoms. Microalgae are expected to be attractive bio-factories for the preparation of CO2 and the simultaneous collection of renewable biofuels, food, animal and aquatic food products and cosmetics, nutrients, cement, bio-fertilizers, bioactive materials. Microalgae have a CO2 concentration mechanism (CCM) for efficient photosynthesis by obtaining inorganic carbon. These microorganisms outperform other nutrients in terms of their ability to thrive in marginal environments and their simple but multifunctional nutritional needs. Microalgae do not need cultivable land and can live well in areas where saline-alkaline water, land and other crops such as wastewater are uninhabitable. Furthermore, microalgae can feed on pollutant pollutants such as CO2 and NOx, pipe gases such as SOx, inorganic and organic carbon, N, P, and pollutants from agricultural, industrial and wastewater sources. Biology, valuable products and models that cause the least harm to the environment. Due to the uncomplicated cellular structures and the rapid growth of micro-algae, CO2 fixation efficiency is 10-50 times higher than that of terrestrial plants.

Recently, many research studies have shown positive effects of microorganisms growing in the form of pure gaseous CO2, real or imitated tube gas or bicarbonate (bicarbonate) at high concentrations of CI, resulting in higher carbon biosynthesis and biomass results. Does the fate of the supplied carbs may end up making a skeleton for lipids, proteins, sugars and pigments? The production of microalgae was previously economically unfeasible. Recent technological economic analyzes and life cycle assessments of microbial-based production systems have suggested that the only way to achieve potential production is to make full use of biomass in an integrated bioremediation process

11 CO_2 CAPTURE BY CRYOGENICS

Capture, use and storage of CO2 have been identified as a vital option to mitigate the climate change caused by fossil fuel use. Several CO2 capture strategies have been developed, such as absorption, adsorption, membrane, chemical loops, hydrate, and biodegradation. Among the various technologies, special attention has been paid to the absorption of cryogenic CO2 by phase modification. The objective of this study is to increase the interest in cryogenic technologies for CO2 capture by providing an overview of the true state of CCS. To achieve this goal, key strategies and technologies for capturing CO2 from fossil fuel combustion have been reviewed. Current challenges to overcome cryogenic technology include cold energy sources, capture costs, and waste. Finally, opportunities for the future development of cryogenic technologies are discussed. The results of this investigation show that cryogenic CO2 capture processes can be easily reprogrammed into existing industrial emission facilities and avoid challenges with chemical solvents or physical sorbents.

12 DISCUSSION

In this review paper, briefly discuss 10 types of post-combustion CO2 capture methods. Solid sorbent based CO_2 capture method can introduce as a profitable way to capture CO_2 for coal-fired power generation. The process can identify as cleaning the flue gases, adsorbing of CO_2, desorption and preparing the sorbents. The main disadvantage of this system can be identified as the low knowledge of preparation of the optimal size of the reactor. Solvent-based CO_2 capture method can capture the post-combustion CO_2 at power generation proceed by absorbing CO_2 of gas streams with aqueous amines. Usually, the gases which used to be treated are oxygen-free and at a high level than the atmospheric pressure. The solvent parameters that will effective for the efficiency of the power generations are solvent thermal stability and disrober pressure. Chemical absorption method used to remove CO_2 from gas streams at oil and chemical industries. Directs flue gas through a continuous scrubbing system. Absorption process happened by chemically reacting an aqueous alkaline solvent as an amine with CO_2. But the disadvantage of this method is that the energy loss due to pumps and blowers which used to compress and store CO_2. Physical adsorption method has a range of nonreactive sorbents including carbonaceous materials and crystalline materials known as zeolites, carbon dioxide may be removed from the flue gas. High porosities include 10-15% by weight of activated carbon and charcoal with CO_2 capture capacities. Our selectivities for CO_2 / N_2 are fairly small. Packed bed adsorption method is a new concept for post-combustion CO_2 capture from pipe gases has been studied. Using frozen packaged beds, it is possible to distinguish between H_2O, CO_2, and permanent gases at atmospheric pressures. Cold duty required to recover 99% CO_2 from 10 volt CO_2 and 1-volt pipe gas is estimated to be 1.8 MJ / kg CO_2. Microbial algae CO_2 capture method, the term "microalgae" is commonly used for eukaryotic microalgae, including prokaryotic blue-green algae (cyanobacteria) and green algae, red algae and diatoms. Microalgae are expected to be attractive bio-factories for the preparation of CO_2 and the simultaneous collection of renewable biofuels. The fate of the supplied carbs may end up making a skeleton for lipids, proteins, sugars and pigments. Cryogenics CO_2capture method gets Fossil fuel capture is a vital option to mitigate climate change caused by fossil fuel use. This study aims to increase interest in cryogenic technologies for CO2 capture by providing an overview of the true state of CCS. Current challenges to overcome cryogenic technology include cold energy sources, capture costs and waste. The membrane gas absorption method is a process that leads to smaller absorbers through the use of small-diameter hollow fibre membranes. The porous polymer membrane is the essential element in a membrane absorber. Along the one side of the membrane, a flue gas stream is fed. The components to be removed from the gas stream will diffuse through the gas-filled pores and absorb into the absorption liquid on the other side. Oxy-fuel and amine-based post-combustion plants are the most frequently proposed configurations for short-term steam-based CO_2 capture plants. An alternative option is discussed in which calcium oxide (CaO) is a solid sorbent. Calcium-based sorbents have been suggested as an attractive carbon dioxide removal material due to their low cost, high adsorption capacity, and high reversibility of CO_2. CO_2 separation from flue gas by CaO based Sorbents in fluidized bed combustion is a highly researched technology.

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