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Review of Post Combustion CO_2 Capture Technologies

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Abstract— Emissions of carbon dioxide (CO_2) and other greenhouse gases (GHG) must be reduced to minimize global warming. The primary sources of CO_2 emissions are power plants (coal and gas), transportation (burning fuels), and chemical industries (cement and aluminum). Therefore, it is essential to capture CO_2 to keep emissions levels up to standards. Various techniques have been proposed for capturing carbon. Pre-combustion, post-combustion, oxy-fuel combustion are the three main types of carbon capture technologies. This article presents a description of the CO_2 removal process of post-combustion. Post-combustion grip combusted fossil fuels to produce energy, and CO_2 is removed from the gas after combustion. There are several options for post-combustion carbon capture from the flue gas. That processes and their advantages and disadvantages are described in this review article.

Index Terms— Absorption, Carbon capture, carbon dioxide, post combustion,
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1. INTRODUCTION

The amount of CO_2 at the atmosphere is increasing rapidly. CO_2 is a main greenhouse gas and it impact to global climate change. Fossil fuel bases power plants, cement industries, steel manufacturing, deforestation, burning fossil fuels are some of the main contributors that release the CO_2 to the atmosphere. One of the remaining solutions for maintaining a green environment is carbon capture and storage. CCS technology is a technology that can capture of the carbon dioxide (CO_2) emissions and prevent it from entering the atmosphere. Capture, Transportation and store are the three part of consists the CCS chain. Pre-combustion, post-combustion and oxy-fuel combustion are main three type of carbon capture technologies. CO_2 is captured before fuel is burned is called as pre-combustion. The CO_2 is removed after combustion is called as post combustion CO_2 capture. And the CO_2 captured during fuel combustion is called as oxy-fuel combustion.

The post combustion CO_2 capture system (Fig.1.) is the scheme that would be applied to fossil-fuel burning power plant. Carbon dioxide is captured from flue gases at power station or other large point sources. The technology is well understood and it currently used in other industrial application. This post combustion CO_2 capture is applicable to the majority of existing coal-fired power plants. This technology is so far considered most viable method due to its “end-of-pipe” characteristic for CO_2 capture from existing coal-fired power plant. Post combustion CO_2 capture technology be either retrofitted into existing plants without significant modifications to the original plant or built as end of pipe capture technology for new plant. One bigger challenge to the application of post combustion CO_2 capture in coal-fired power plant is present atmospheric pressure of CO in the fuel gas. It has 13-15 % concentration in the fuel gas is present at atmospheric pressure and the CO, so driving force for CO separation is very low [1]. And the other hand the flow rate of flue gas is usually 5-10 times larger than streams usually treated in natural gas and chemical industries [1].

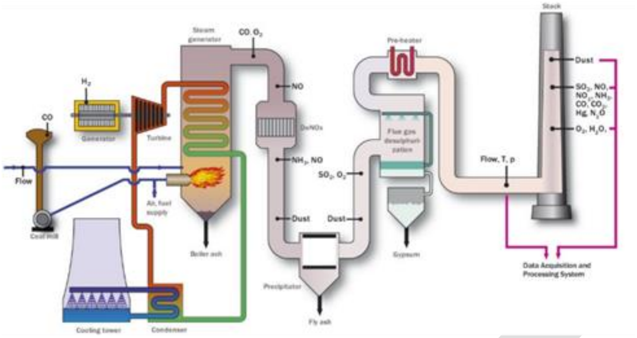

Fig. 1. Post combustion CO_2 capture

Several post combustion gas separation and capture technologies have namely; absorption (chemical absorption and physical absorption), membrane separation, cryogenic separation and adsorption (Fig.2.) are available [2].

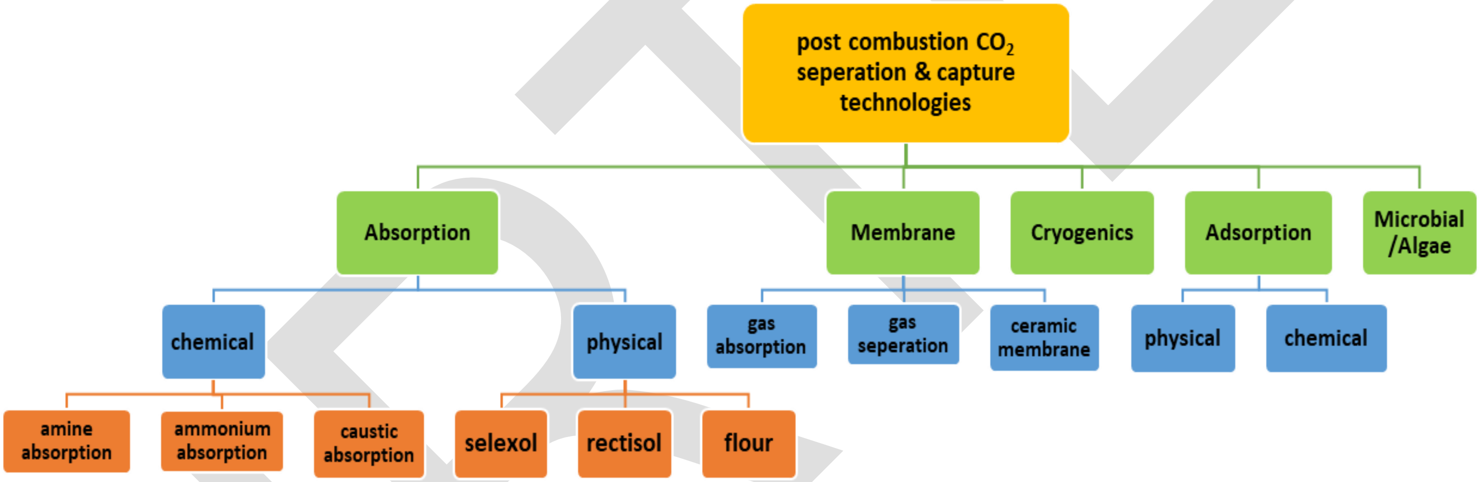

Fig. 2. Different technologies of post combustion CO_2 separation and capture

2. CO2 POST COMBUSTION TECHNOLOGIES

2.1 Absorption

Absorption is a process of species in a gas mixture in contact with a liquid phase dissolved to the liquid bulk by selective mass transfer. The flue gas regenerated at high temperature, when solvent scrubbing involves using a chemical solvent that reacts with the CO_2 produce purified CO_2 stream suitable for compression and storage.

2.1.1 Chemical absorption

Chemical absorption is the most viable and standard purification technology. The preferred option for post-combustion capture of CO_2 at present is the chemical absorption system. Absorption process work by contacting the gas to be captured. Bypassing the flue gas through a continuous scrubbing system, CO_2 is separated from the flue gas. Pure CO_2 is released in a desorption column. Simultaneously, the purified gas is processed further or released to air, through the combustion of temperature changes and pressure changes in advanced or straightforward process design—chemical absorption where the solvent (alkanolamines) chemically reacts with CO_2. The solvent (absorption medium) must have specific properties; thus, that only responded with the CO_2 and left the other gasses to pass through.

2.1.1.1 Amine absorption process

The absorption process using amine solutions (Fig.3.), such as Monoethanolamine (MEA), is a commercialized technology used in the natural gas industry. MEA has a high absorptive capacity. The MEA reacts with CO_2 in the gas stream to form CO_2 in the gas stream. The MEA solution with CO_2 is sent to a stripper where it is reheated to release. This amine absorption process general uneconomic as it requires intensive energy input and large equipment size. The schematic diagram of the chemical absorption process is given in the Fig. 3.

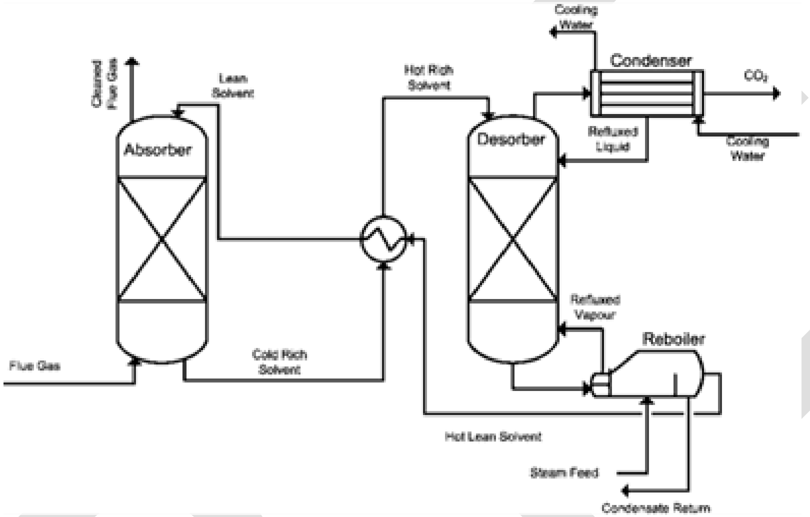

Fig. 3. Basic chemical absorption process for amine solution

2.1.1.2 Ammonium absorption process

In the ammonium absorption process, use aqueous ammonia as CO_2 sorbent with the capability of multi-component control. Flue gas needs to be pretreated by oxidizing NO and SO_2 to NO_2 and SO_3, respectively. The flue gas reacts with aqueous ammonia in a wet scrubber. The regeneration requires heat input to thermally decompose ammonium bicarbonate and ammonium carbonate of ammonium. The ammonium absorption process's major by-products are ammonium sulfate, ammonium bicarbonate, ammonium sulfate, and ammonium nitrate.

2.1.1.3 Caustic absorption process

CO_2 can also be captured by using NaOH aqueous solution as absorption. The CO_2 capacity of NaOH solution is higher than to MEA absorption. And NaOH is more abundant, cheaper, and more familiar than MEA. But NaOH cannot be rapidly regenerated compared to MEA because NaOH cannot quickly regenerate from $NaHCO_3$. Firstly, Na+ and OH- are utterly ionized in pure water. Hen gaseous CO_2 is fed into the NaOH solution to be absorbed. During the overall reaction, aqueous CO_2 does not exist in the solution because following its formation is immediately react with OH.

The maturity of technology, high capture efficiency, and regeneration of solvent are advantages of chemical absorption technology. High thermal energy demand for solvent regeneration, cost of solvent, equipment corrosion, and emission-related to solvent degradation are some of the disadvantages of chemical absorption technology. It has a 90% capture efficiency [3].

2.1.2 Physical absorption

Physical absorption processes are recommended for separate CO_2. Physical absorption is based on the solubility of CO_2 to the solution without chemical reactions. Physical solvents use organic solvents to absorb acid gas components rather than chemically react physically [4]. It is desirable to obtain optimal performance of the physical absorption process in terms of high partial pressures, absorption ratios, and solubility equilibria of CO_2 and low temperatures. Some procedures that use physical solvents are currently commercially available and are discussed below.

2.1.2.1 Selexol

The Selexol process has been widely used in the refining industry, natural gas sweetening, syngas processing, cement industry, and fertilizer production and has proven to be effective. Selexol naturally absorbs CO_2 from various natural and synthetic gas streams. It has performed well under high pressure, low temperature, and high acid gas process conditions. In the Selexol process, the tube gas must be dehydrated before being introduced into the absorption column. The dehydrated tube gas enters the absorber at 30 atm and 0–5 at C, and the acid gas component is absorbed into the solvent along the column. The CO_2-loaded solution is sent to the regeneration process, whereby the solution regains its original capacity either by reducing pressure or by eliminating inert gases. The recovered (thin) solvent is recycled back to the absorber, and the high purity CO_2 regenerates and compresses.

Non-thermal solvent regeneration, Non-corrosive solvent, and Dry gas leaves from the absorber are the advantages, and most efficient at elevated pressures is the disadvantage of this process.

2.1.2.2 Rectisol

The Rectisol process is used to remove CO_2 from the Syngas streams, mainly from the heavy oil and coal gasification. This technique uses a cooled methanol solvent and can be used for low and moderate CO_2 concentrated airflows. Due to the high vapor pressure in the solution, the absorption phase should be carried out at shallow temperatures to minimize fluid loss. The Rectisol process, after absorption of sulfur, is in contact with cold methanol in the sulfur-free Syngas absorber, operating in the range of 50 atm and temperature[−100 ° C, −30 ° C]. The rich solvent is sent to the regeneration stage, and the CO_2 is released by flashing. The thin solution is recycled back to the absorber [5]. Non-foaming solvent, high chemical and thermal stability, non-corrosive solubility are the advantages of the Rectisol process. The disadvantages are high refrigeration cost, high capital cost, and formation of amalgams at low temperatures.

2.1.2.3 Flour

The most suitable physical absorption process to be applied to high CO_2 partial pressure syngas flows is the fluoride process. Propylene carbonate (C_4H6O_3) is used as a solvent and has a lower vapor pressure than those used by Rectisol ™ and Selexol. The solution has little or no H_2S and can be applied in sizeable CO_2 removal applications [6][7]. During the flow process, physical absorption ranges from moderate to high pressure at 30 to 80 bar and ambient temperature. The tube gas must be dehydrated before the gas enters the absorption column to prevent water from forming in the solvent. As mentioned earlier, H_2S must also be removed before CO_2 absorption can occur. After absorbing CO_2, the solution loaded with CO_2 is ignited to release CO_2 and regains its original capacity. The thin solvent is recycled back to the absorber, and the high purity CO_2 regenerates and compresses and stores. The advantages of the flour process are high CO_2 solubility, non-thermal regeneration, simple reactivity, non-corrosive solubility, and disadvantages are high solubility circulation rate and high solubility.

2.2 Membrane separation

The separation of CO_2 by using flue gases has greatly enhanced the greenhouse effect in the world. The percentage of gases, mainly CO_2, continuously increased the earth's temperature. When the CO_2 rate decreases dramatically, reduce global warming. The membrane separation is one of the separation methods of CO_2 capture by using post-combustion carbon capture. The membrane separation is an alternative method that attracted the scientific community due to its high CO_2 capture efficiency, lower capital cost, natural scale up, low energy consumption, and simple process design. Since 1980, this technology is commercially available for gas purification—carbon dioxide (CO_2) separation by membranes proposed for a range of storage strategies and carbon capture [8]. The Membrane performs as a filter. It allows individual molecules to permeate through, while blocks other specific molecules from entering the Membrane, as demonstrated in **(**Fig.4)**.**

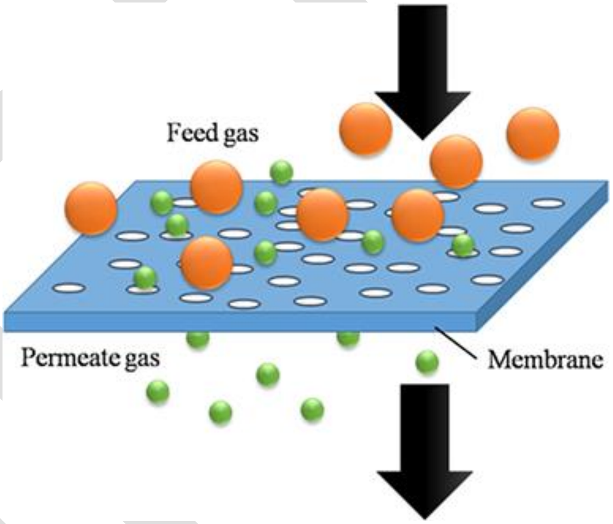

Fig. 4. The schematic view of membrane separation for gas mixtures.

2.2.1Membrane separation methods

2.2.1.1. Gas Separation

The Membrane can use to separate gas mixture where they act as a permeable barrier through that different compound move across at different rates or not move at all. The gas mixture can effectively be separated by using synthetic membranes made by using polymers. These polymeric membranes are technologically and economically use. Gas separation through a membrane is a pressure-driven process. It drives the force is a difference in pressure between the inlet of the raw material and the outlet of the product. The performances of the Membrane depend on selectivity and permeability. Permeability is affecting by the penetrant size. The solubility can express as the ratio of the concentration of the gas in contact with it. The ability of the Membrane allows the permeating gas to diffuse through the material of the Membrane. It enables the permeating gas to spread through the Membrane's content as a consequence of the pressure difference over the Membrane can be measured in terms of permeate flow rate, the pressure difference across the membrane and membrane thickness is the ability of the permeability [9].

The equipment of membrane gas separation typically pumps gas into the targeted gas, and modules are separated based on the difference in solubility and diffusivity. The gas separation of the Membrane can do in two ways. Those are polyphenylene oxide and polydimethylsiloxane. Gas separation is one method of membrane separation.

2.2.1.2 Gas Absorption

The membrane gas absorption process is a gas-liquid contacting operation. The core in the membrane gas absorption process is a microporous hollow fiber membrane in the gas absorption of the Membrane using polyethene polymer. In here, use hollow fibers used as hydrophobic and hydrophilic polymers. The membrane absorption process, a hydrophilic or hydrophilic hollow fiber contactor, is used to separate a feed solution containing a solute from the receiving gas phase. Here the stripping process and the solute to transfer are included in the gas phase. The penetration of the liquid solution or gas phase into the Membrane pores those filled with liquid or gas to determine the hydrophilic or hydrophilic character of the Membrane. The solute transfer through the Membrane is achieved according to the following steps those are presented by (Fig.5). The steps are below [9].

1. The solute transfer through a boundary layer of the gas phase at the membrane surface
2. The solute gas transfer through the air gap that fills the pores
3. The equilibrium of the phase between the feed solutions at the gas phase retained in the membrane pores for the hydrophobic Membrane and the membrane surface.
4. The mass transport of absorbed solute into the bulk receiving liquid phase

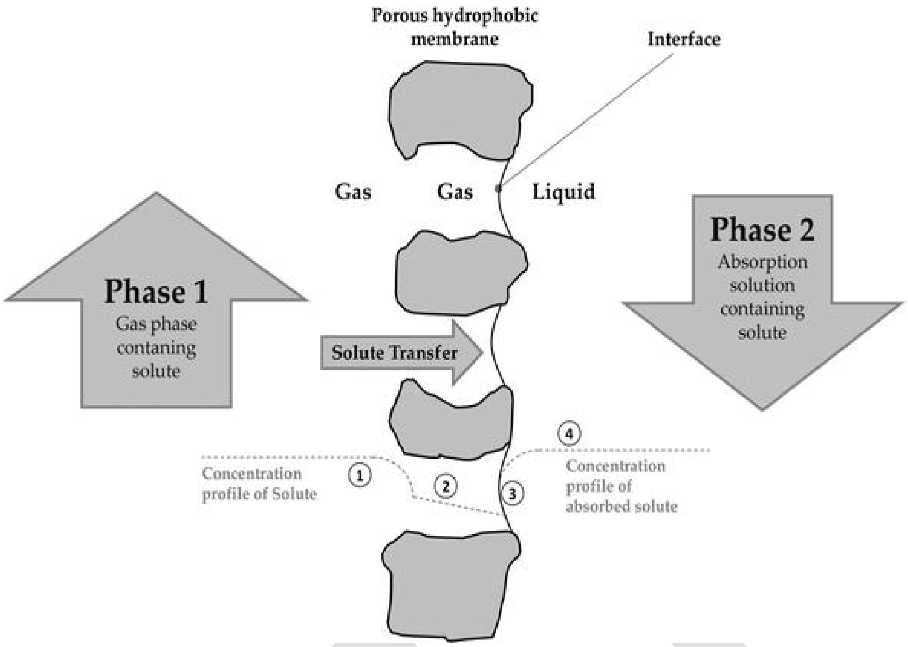

Fig. 5. The outline of the membrane absorption process of the hydrophobic membrane**.**

2.2.1.3 Ceramic Membrane

The ceramic Membrane is the type of artificial Membrane made using Inorganic materials like alumina, Titania, silicon carbide, and some glass materials. These are using membrane operation for liquid filtrations. It can be used in separations where aggressive media are present by contrast with polymeric membrane technology. These ceramic membranes have excellent thermal stability which makes them usable in high- temperature membrane operation [10]. The shape of the ceramic Membrane is in (Fig.6.).

Fig. 6. The shape of the ceramic membrane

2.2.2 Membrane technology used for CO_2 separation

2.2.2.1 Polymeric membranes

Polymeric membranes (organic membranes) encompass a family of liquid separation technologies that are industry-leading in both performance and efficiency. Polymeric membranes can generally identify in four primary categories, based on performance characteristics and specific separation attributes. The primary groups are microfiltration, ultrafiltration, Nanofiltration, and reverse osmosis. The polymers utilized in the production of those membrane categories are carefully selected to ensure optimal performance in a chosen process environment. It is compatible with the fluids to be processed, as well as with cleaning agents necessary to aid in hygienic and performance stability must take into consideration.

The flux of CO_2 decreases with time due to plasticization effects—high performance of CO_2 separation. The polymeric membranes can be achieved by increasing the solubility of CO_2 in Membrane and increasing the CO_2 diffusion through the Membrane. The solubility increases through changes in polymer composition and CO_2 diffusion increase by increasing free space volume. The free amount can increase by using the insertion of bulk substitution groups. Composite polymeric membranes also used in the world. These composite membranes consist of a glassy segment which is a hard and rubbery segment which is soft. The hard-polymeric section makes the structural backbone, and soft or rubbery portion makes a thin film on hard support. When using the resultant Membrane, it has high selectivity due to the dense skin layer and high permeability due to porous support [11].

2.2.2.2 Inorganic membranes

The inorganic membranes, as its stability at high temperature, present an attractive way of gas separation. The inorganic membranes can classify into porous and non-porous. The Non-porous inorganic Membrane, such as palladium, is mostly used for separation of hydrogen. The Non-porous Membrane is costly compare to porous, but its selectivity is high relative to porous.

Simple molecular sieving is not possible in the case of CO_2 due to smaller gas molecules of H_2. In the inorganic Membrane, a functional layer adds onto the thin casting layer. Having a high affinity for the CO_2 is a possible solution, so saturation occurs, and surface diffusion occurs, which increases the permeability of CO_2. When compared with polymeric Membrane, the inorganic Membrane is more selective and permeable and can withstand more extreme conditions [12].

2.3 Cryogenic separation

The cryogenic method uses a low temperature to ensure the separation, condensation and purification of CO_2 from the flue gases (the freezing point of pure CO_2 is 195.5 K at atmospheric pressure). Therefore, under the cryogenic separation process, the components can be separated by a series of expansion, compression, and cooling steps. Liquid pumping allows it to directly produce liquid CO_2 that can be stored or separated at high pressure.

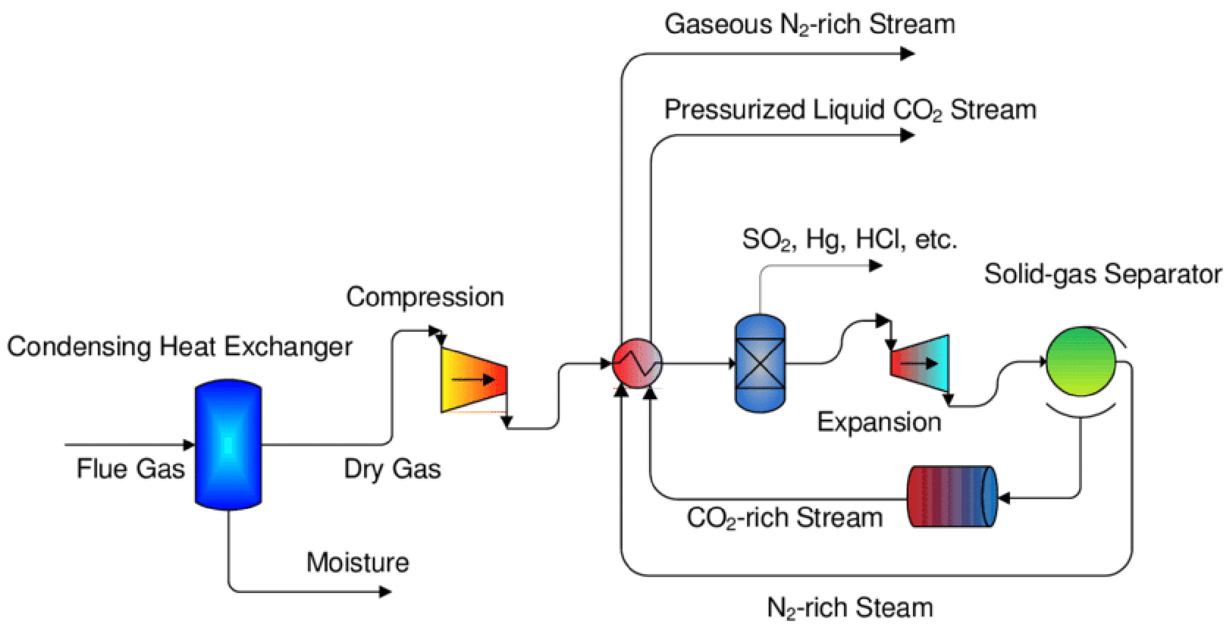

Fig. 7. Simple schematic diagram of the cryogenic carbon capture process.

Cryogenic CO_2 absorption process (Fig.7.) dries and cools flue gas from existing systems, Modestly compress it and cool it to a temperature just above the CO2 solid, The gas expands for further cooling and accelerates the amount of CO_2 as solid depends on the final temperature value, By reheating the temperature, CO_2 pressure and reheats the CO_2 and the remaining flue gas by cooling the Incoming gases. The end result is a flow of CO_2 and gaseous nitrogen in a liquid phase. Efficiency of CO_2 capture depends primarily on the pressure and temperature at the end of the expansion process [13, 14, 15].

The advantages of this technique can be summarized as follows,

- Liquid CO_2 is produced directly, making it relatively easy to store or ship for an improved oil recovery.
- The technique is relatively simple, with no solvents or other components.
- Cryogenic separation can be easily scaled to industrial scale uses.
- Chemical reactions are not required
- Suitable for high pressure air flow with high CO2 concentration (> 50 vol%)

The main disadvantages of this process are the large amounts of energy required to provide refrigeration and CO_2 solidification at low temperatures, resulting in several operational problems. Therefore, more studies are needed to reduce the cost of cryogenic separation. The refrigerator also has significant energy penalty, High capital expenditure and Processes Need to remove water, Sox, NOx and other trace to prevent freezing and eventual blockage of process equipment [16].

It is not currently used for dilute CO_2 currents, such as conventional power plants. Significant energy is required to separate from this technology.

2.4 Adsorption

Adsorption is the process of removing one or more components of a mixture with the help of a surface coating. Adsorption processes are based on significant intermolecular forces between gases (including CO_2) and on the surfaces of adsorbents such as activated carbon derived from the rubber tire of the waste. Depending on the temperature, pressure and percentage of the active load, the gases can be absorbed into single or multiple layers. Adsorption is different from absorption because in absorption, the fluid (absorbate) is dissolved by a solid or liquid (absorbent). Adsorption is occurred on the surface while absorption entails the whole material volume. Adsorption may take place physically; this will involve weak van der Waals forces (physi-sorption). It may take place chemically, which will involve covalent bonding (chemi-sorption) and it may occur due to electrostatic attraction. Adsorption has a major advantage with regard to the ease of adsorbent regeneration by thermal or pressure modulation, reducing the energy of Post-Combustion Carbon Capture [17]. Important factors in adsorption include;

- ease of regeneration of adsorbed CO_2
- durability of adsorbent
- selectivity of adsorbent for CO_2
- adsorption capacity
- stability of the adsorbent after several adsorption/desorption cycle

In the absorption of CO_2 by adsorption technology, a packaged column is mainly filled with a spherical adsorbent, and the CO_2-carrying flow passes through the column. Carbon dioxide attracts towards the adsorbent and adheres to the adsorbent surface. Once equilibrium is achieved, desalination and regenerative adsorbent temperature rise can be used to obtain CO_2 in pure form. The renewable adsorbent can be used for further cycles. S sorbents have the potential for significant energy savings over liquid solvents, since they do not require a large amount of water to be reheated and cooled to regenerate the solvent. However, adsorption presents lower energy requirements and avoids shortcomings compared to absorption. In the post-combustion process, adsorption has been identified as an attractive process for capturing CO_2 from piped gases due to its low energy requirements.

2.4.1 Physical adsorbents

Compared to chemical sorbents and CCS, physical sorbents and inorganic porous materials (e.g. organic matter and zeolites) consume less energy than CO_2. This is because there is no new bond between sorbate and sorbent, so less energy is required for CO_2 regeneration. However, some known materials (ex: activated carbon) have the disadvantage of choosing low CO_2. If the challenges of physical sorbents and membranes are successfully overcome, using them to capture CO_2 could be a potential source of energy savings through leading amine-based absorption systems. Zeolites show more selectivity, but also have the disadvantage of low CO_2 loading and their efficiency in the presence of water. Furthermore, molecular filter membranes have great potential, however, the use of conventional molecular filters (ex: zeolite) to separate CO_2 is limited by the similar kinetic diameters of CO_2 (3.3 Å). Examples of physical adsorbents are activated carbon, zeolite, hydrotalcite, carbon nanotubes (CNTs), and coal. Activated carbon has a high absorption capacity for CO_2, high hygroscopicity, low cost, renewable energy requirement and is not sensitive to moisture. On the other hand, zeolite has a better selectivity for CO_2 than organic materials. However, there are disadvantages of applying only activated carbon to high pressure gases, which have higher sensitivity and lower selectivity at higher temperatures. Zeolites have a high crystallographic structure, a high surface area, and the ability to change their composition and ratio. Zeolite has very low selectivity, zeolite is hydrophilic, and as the moisture content of the gas decreases, the CO_2 absorption capacity decreases. In general, the physical process requires less energy than the normal process of using chemical sorbents to absorb CO_2. As mentioned earlier, this is due to the lack of newly formed chemical bonds between sorbate and sorbent, which reduces the energy requirement for regeneration [17].

2.4.2 Chemical adsorbents

Some examples of chemical absorbers studied for carbon capture are calcium oxide (CaO), magnesium oxide (MgO), and lithium oxide (ex: Li_2ZrO_3, Li_4SiO_4). When heated to 850ºC, calcium carbonate ($CaCO_3$, limestone) releases CO_2 (calcine), which is converted to calcium oxide (CaO) which rejoins with CO_2 at 650ºC. These reactive industrial processes have a long service history. The CaO / $CaCO_3$ system is attractive because of its high CO_2 absorption capacity and long running records. Furthermore, it allows for power plant configurations:

- Maximizing the benefits of feeding oxygen more expensive than air (thereby avoiding the need for post-combustion CO_2 / N_2 separation).
- Utilizing high potential heat.
- Enhances energy efficiency by generating vapors from the heat emitted by the carbonation reaction.

As a result, CO_2 / $CaCO_3$-based CO_2 capture is at the center of ongoing research activities. Alkaline metal-based sorbents also absorb CO_2, primarily by reacting with metal carbonate bicarbonate as a vapor co-reactant when CO_2 reacts with aqueous carbonate solvents. Sodium-based sorbents with high permeability are more efficient than aqueous amines (25-120ºC), but their CO_2 capture capacity is significantly lower. Lithium-based sorbents that work well at 400-500ºC offer higher CO_2 capacity. The long-term stability and brittleness of alkali-based sorbents under real pipe gas conditions have been established. Capture of CO_2 by non-stationary amines in porous sorbents is an increasingly active field of research; A practical system for capturing CO_2 has been deployed in a space mission life support system. Various amino acids, sorbent support and stabilization methods have been tried and the results are quite good. Several amine-derived sorbents show high CO_2 uptake / release capacity and stability in the 50- to 120ºC range. Furthermore, the lack of a large amount of circulating water should significantly reduce the thermal energy requirements for CO_2 release, such as amine-based absorption / removal. In order to be commercially viable, as mentioned above, in the case of alkaline-based sorbents, these sorbents must be stable for a long time under real tube gas conditions. Many carbon capture / separation processes involve the interaction between chemicals that lead to the formation of CO_2-based molecular structures in chemical absorption and absorption processes, which are then regenerated by heating with the captured CO_2 temperature. This process (i.e. regeneration) consumes most of the energy requirements of the CCS. Therefore, operating costs can be greatly reduced by reducing the cost of regeneration by using efficient materials and processes to capture CO_2 [18].

2.5 Microbial / Algae:

In addition to the physicochemical methods of CO_2 removal, biological methods using algae, bacteria and plants have also been adopted. Bio fixation of carbon dioxide microalgae in photosynthesis has recently gained renewed interest in reducing CO_2. Adequate lighting limits the growth of microorganisms and therefore reduces CO_2 emissions. The use of chemoautotrophic microorganisms that use inorganic chemicals instead of light energy to remove CO_2 has also been successfully tried.

Recently, there has been considerable interest and investment in the development of micro algae for biofuel production. The advantages of microbial based biofuels are higher production fields and available land area (compared to terrestrial crops); The ability of algae to capture CO_2 as bicarbonate in ponds, reducing atmospheric CO_2 emissions; And reduce competition for land, especially cultivable land that can be used for food production. Algae are estimated to produce twice or ten times the biomass per unit area than the best terrestrial systems. There are several reasons why land plants and algae have a higher biomass field yield. In general, algae have more photosynthetic efficiency than terrestrial plants, so they are more likely to capture light and convert it into usable chemical energy. Incomplete Growth Conditions Algae concentrate most of their energy on cell division (6 to 12 hours), allowing faster biomass accumulation. Also, unlike plants, single cellular algae do not divide large biomass into supporting structures such as stems and roots. In addition, algae have a carbon concentration mechanism that suppresses photography [19].

8 CONCLUSION

Reducing CO_2 in the air is the primary environmental pollution problem in the world. The emission of greenhouse gases, such as CO_2 is the leading cause of global warming in the world. To reduce CO_2 percentage in the air using many carbon dioxides capturing and separation methods. One of them is post-combustion Carbon Dioxide capture. For this, there are many methods of use in the world. They are Absorption, Membrane separation, adsorption, cryogenic and Microbial. In this review article, we discussed all the ways that are using post-combustion Carbon Dioxide capture.

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