REVIEW OF POST-COMBUSTION CARBON DIOXIDE CAPTURE

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Abstract

The emission of Carbon dioxide has drastically increased nowadays due to various factors, and fossil fuel-based power plants and different kinds of industrial processes are the primary cause for them. The environment has led to vast pollution and has resulted in global warming and climatic change. It is essential to focus on carbon-capturing methods to minimize the negative impact on the environment and use it for better applications. Efficient CO_2 mitigation techniques will become increasingly demanding due to these environmental issues. Several methods have been reviewed by scientists such as switching to renewable energies like wind power, solar power, improving process the efficiency of the power plants, and CO_2 emissions capturing of the power plants and the industries [1]. However, the most practical and realistic option will be carbon capture and storage (CCS) for several decades to maintain a sustainable green environment.

Introduction

The industrialization has paved the way to lead the world in a completely different direction, in terms of development within the production of services and products, raising the quality of living whereas making new job opportunities serving the removal of unemployment. Since then, the emission of harmful gases which harm the environment has been increased. The global industrial sector accounts for about forty-seven percent (47%) of energy connected greenhouse gas emissions, and essential quantities of extra greenhouse gases are released from industrial processes [1, 2, 3].

Carbon dioxide (CO_2) is a well-known greenhouse gas that absorbs and emits thermal radiation. It is the principal anthropogenic contributor for the greenhouse gas effect compared with the other greenhouse gases. This causes the rise of temperature in the environment and ultimately leads to global warming, which is a massive problem in the present. Scientists warn that 1.5°C of warming will likely have catastrophic impacts such as extreme weather events from floods and storms to droughts and heat-waves, bringing substantial social and economic costs in the world. Sea levels will rise due to ice melting, causing flooding of coastal cities and whole island nations. Water scarcity and crop failures will cause food shortages and unprecedented movements of people worldwide and across national borders. Massive, irreversible damages will occur in nature, potentially leading to mass extinctions.

The climate pact represented a vast historic step in re-imagining a fossil-free future for our planet, approved in Paris in December 2015. It is nothing short of amazing that nearly 200 countries around the world agreed to keep global temperature rise well below 2 degrees Celsius, including oil-exporting nations and went even further by deciding to pursue efforts to limit the increase to 1.5 degrees above pre-industrial levels [4].

According to the Intergovernmental Panel on Climate Change IPCC's 2014 report, a concentration of greenhouse gases in the atmosphere of 450 ppm CO_2 equivalent gives a 66% chance to comply with the Paris Agreements 2-degree Celsius (2°C) goal. In the National Oceanic and Atmospheric Administration of the United States Department of Commerce (or NOAA) reports we were already at 496 ppm CO_2 equivalent. All of these confirm the need to end emitting carbon rapidly, while also scaling up sequestration.

The agreement itself implies that it will involve far more than just a transition to clean energy; managing land to support many competing needs also will be part of the solution by committing to the 2-degree. The demand for substitutes, for instance, forests as a fuel source, could place tremendous new pressures on our planet if not managed well if we genuinely move out of fossil fuel fast and furiously [5]. The agreement also points out reducing emissions through "sustainable management of forests and enhancement of forest carbon stocks in developing countries." The agreement says it "aims to strengthen the global response to climate change while not threatening food production." The most appropriate solution for this is the use of carbon-capturing methods. Carbon Dioxide Capture and Storage technology are not widely applicable due to the regeneration process's high energy consumption. There are various methods to capture carbon, such as pre-combustion, post-combustion, and oxy-fuel combustion [5]. This review paper will be focused on the post-combustion carbon dioxide capturing technology processes.

Capture technologies

Capturing materials should be re-generable in carbon capture technologies and that is the key challenge. The efficiency and cost-effectiveness of the process are therefore determined by the energy for regeneration of the material. Their ability to separate carbon dioxide from the gas mixture is a challenging aspect for the capturing materials. The choice of an appropriate CO_2 removal process is directly affected by the CO_2 formed during combustion and the type of combustion.

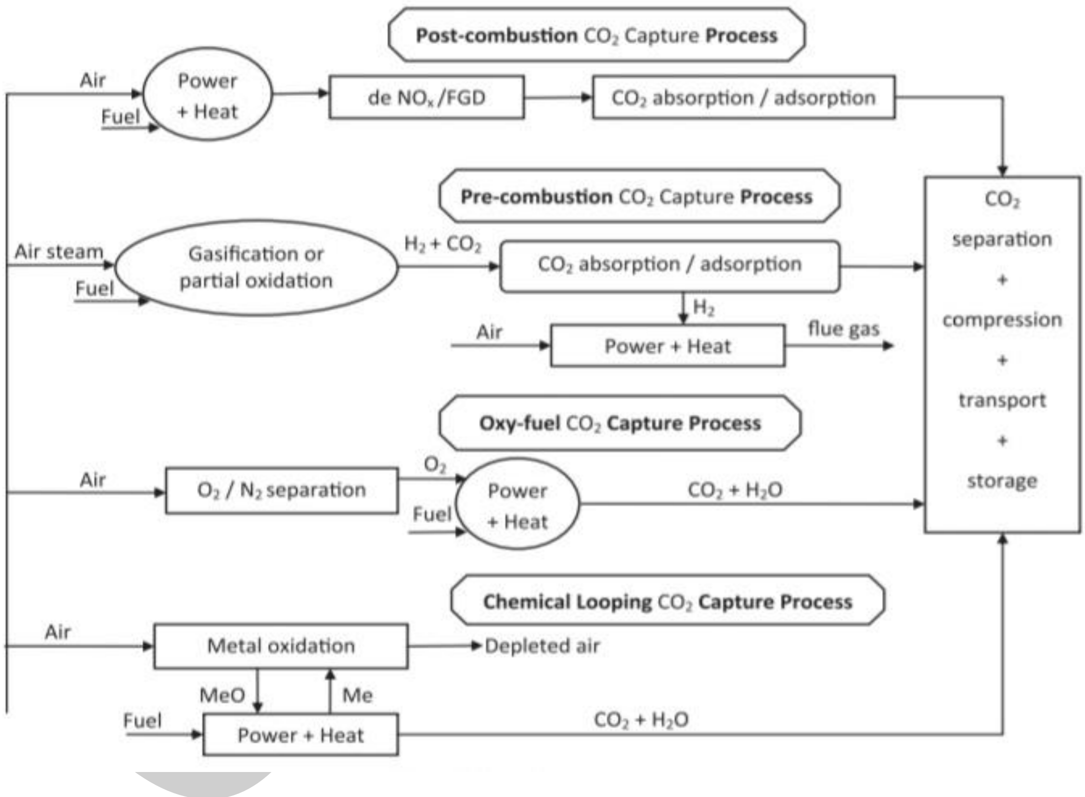

Fig. 01. CO2 Capture Technologies[6]

The available CO_2 capture technologies in the market are costly and around and contribute to approximately 70–80% of a full CCS system's total cost, including capture, transport, and storage. Therefore appropriate research and development efforts have to be focused on the energy penalty and reducing operating costs.

There are three main CO_2 capture systems: post-combustion, pre-combustion, and oxyfuel combustion, associated with different combustion processes. Fig. 01 shows CO_2 Capture Technologies [6]. Pre-combustion is mainly applied in the coal-gasification plants, while post-combustion and oxyfuel combustion can be applied in both coal and gas-fired plants. The most mature process for CO_2 capture is Post-combustion technology. In Pre-combustion High amount of CO_2 concentration enhance the sorption efficiency [6]. It is a fully developed technology and commercially deployed at the required scale in some industrial sectors. There is an opportunity to retrofit to an existing plant.

Oxyfuel combustion has a very high CO_2 concentration that enhances absorption technologies [5]—availability of mature air separation technologies and reduced volume of gas to be treated. Smaller boilers and other equipment are required while CO_2, which is the main combustion product, remains unmixed with N2, thus avoiding energy-intensive air separation.

Current state in post-combustion capture

Post-combustion is widely deployed in the chemical processing industries and involves the capture of CO2 from treated flue gas. As these are the main source of carbon dioxide emission in the atmosphere, the post-combustion capture technology can be retrofitted to the existing large point source of fossil fuel power plants, cement manufacturing industries, or refineries. Wet/dry adsorbents and the principle of adsorption/desorption is used to collect and capture carbon dioxide [6].

The exhaust stream is treated before combustion to reduce the concentration of secondary species in the flue gas such as nitrogen oxide (NOx), sulfur oxide (SOx), water vapor and particulate matter as it might significantly affect the operation, even if present in dilute concentrations, in post-combustion capture technology. Between the stack and the flue gas desulfurization unit, often the capture plant is located. Here, flue gases are maintained at a temperature in the range of 50–150°C and represents between 10% and 15% by volume of CO2 concentration within the atmospheric pressure. In conventional thermoelectric power plants, CO2 is often subjected to post-combustion capture. There the fuel is burned to produce a flue gas and the subsequent compression, transportation, and separation or sequestration of CO2 from the flue gas. After leaving the boiler, the hot flue gas is made to flow through an electrostatic precipitator (ESP). The majority of the large particulate matter is removed at the ESP [7].

Then, ESP the gas is sent to a flue gas desulphurization (FGD) where a limestone slurry contractor is used to absorb SO2 gas to meet the local environmental specification. To treat the flue gas to remove the CO2 from the flue gas exiting the FGD unit, carbon capture technologies such as adsorption, absorption, or membrane separation are applied.

Must overcome the technical challenges associated with it before the implementation, despite, the number of advantages the process on a commercial scale can become a reality [5]. Researchers are putting arduous efforts to address the technical challenges associated with it to make the capture technology efficient both in terms of cost and energy.

Post Combustion

The theory of post-combustion capture is the separation of CO_2 from flue gases. Currently, there are three capture technologies for capturing CO_2 from flue gases as pre-combustion, post-combustion, and oxy-fuel combustion. The post-combustion is widely common among these, as it can be reconfigured for a short to medium term, without any significant technological risks or changes.

Post-combustion involves the capture of CO_2 from treated flue gas and is primarily used in the chemical processing industries. The technology used in post-combustion CO_2 capturing can be upgraded to the existing large point sources of fossil fuel power plants, cement manufacturing industries, or refineries as these are the main sources of carbon dioxide emissions to the atmosphere. It primarily uses dry/wet adsorbents and the adsorption/desorption principle for collecting and capturing CO_2. In post-combustion capture technology, the exhaust flow is treated before combustion to reduce the concentration of secondary species in the flue gas such as nitrogen oxide (NOx), sulphur oxide (SOx), water vapour and particulate matter as there is a possibility to significantly affect the operation, even if it is present in dilute concentrations [6].

Fig. 02 gives a visualization of how the flue gas from a coal-fired plant is treated using post-combustion technology. The hot flue gas flows through an electrostatic precipitator (ESP) after leaving the boiler. At the ESP most of the large particulate matter is removed. After leaving the ESP the gas is transferred to a Flue Gas Desulphurisation (FGD) where the limestone slurry contractor is used for the absorption of SO_2 gas to comply with local environmental specifications. Carbon capture technologies such as adsorption, absorption, or membrane isolation are used for the treatment of flue gas to extract CO_2 from the flue gas that leaves the FGD device [8].

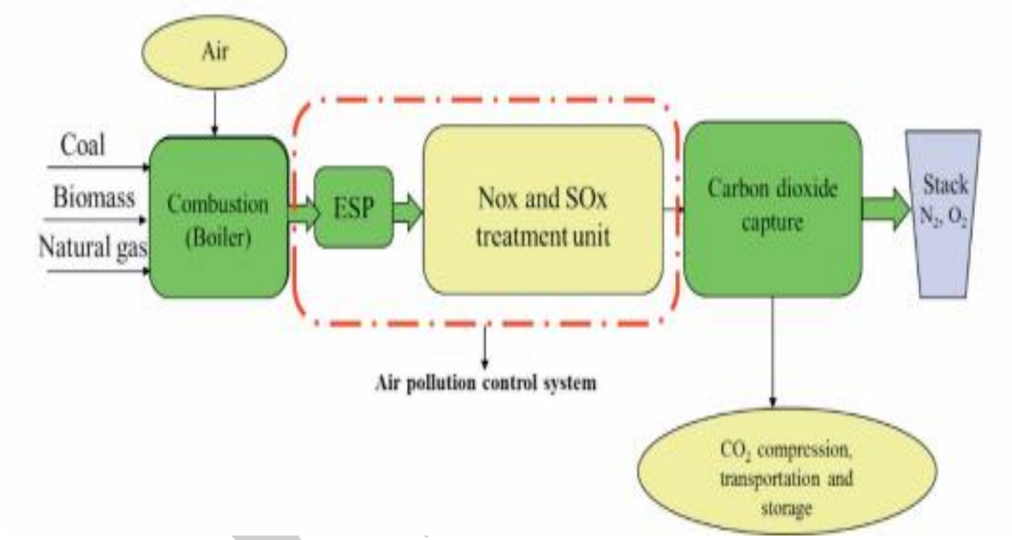

Fig. 02. Post Combustion CO2 Capture Technology [8]

Post Combustion CO2 Capture Technologies

Several post-combustion gas separation and capture technologies are being evaluated, namely; (a) absorption, (b) cryogenic separation, (c) membrane separation, and (d) adsorption of micro-algal bio-fixation. Fig. 03 shows a classification of different technologies used for post-combustion CO2 capture [9, 10].

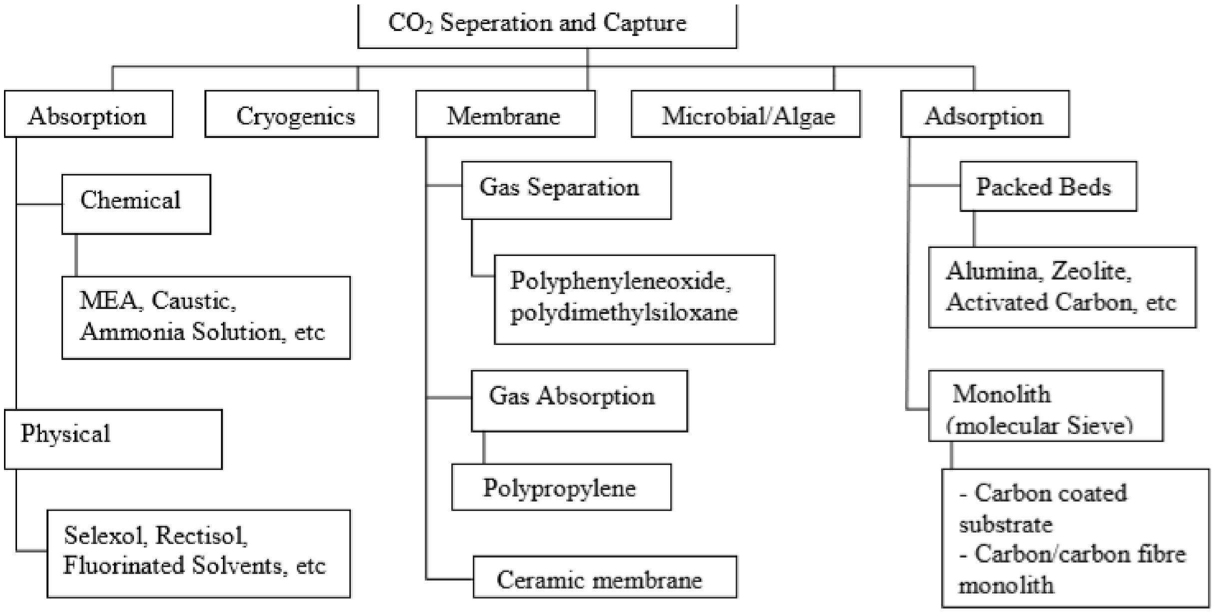

Fig. 03. Different Technologies used for Post Combustion CO2 Capture [11]

Absorption: This is a well-known methodology for the capture of CO_2 primarily used in the chemical and oil industries. The capture of CO_2 using physical or chemical absorption technology is a process in which, slightly acidic carbon dioxide is incorporated from flue gas into amine-based solvents to form dissolved carbonates and bicarbonates by chemical means until equilibrium is reached. Solvent scrubbing usually involves the use of a chemical solvent in the flue gas that interacts with CO_2 and is regenerated at higher temperatures, creating a purified CO_2 stream ideal for compression and storage.

Chemical absorption employs mono-ethanolamine (MEA) and other amine-based solvents such as Diethanolamine (DEA), tri-ethanolamine (TEA) Diglycolamine (DGA), N-Methyldiethanolamine (MDEA), and 2-amino-2-methyl-1-propanol (AMP), glucosamine (GA) to dissolve CO_2. Alkanolamines are chosen based on their capacity to absorb CO_2 over the other gasses such as ammonia, oxygen, or other flue gases [10, 11]. It is claimed that the amine-based regenerative chemical absorption process tends to be the most effective approach for handling large amounts of pollutants from combustion producing concentrated CO_2 streams for recovery with almost 98 percent effectiveness and is very useful for adjusting CO_2 density.

Cryogenics: This method uses a separation theory based on cooling and condensation where it is based on the principle of liquid state temperature and pressure the gradient in each gas present in the flue gas. This technique is applied to capturing CO_2, where high concentrations of CO_2 are present in the gas stream. What happens is, CO_2 is cooled and condensed, thereby removed from the stream of flue gases. Currently, it is not extended to more dilute CO_2 sources than those found with conventional power plants. This method also requires specific amounts of energy for separation [10].The initial expenditure as one of the post-combustion capture technologies is small and highly efficient, though difficulties remain in the implementation of such techniques on a broad industrial scale.

Membranes: The separation of the gasses is based on the nature of the membrane's physical and chemical properties, the diffusiveness of the gas molecules in the membrane, and the gradient in partial gas pressures. Selective membrane separation of carbon dioxide uses polymer or ceramic-based material or mixed matrix membranes to filter out the CO_2 gas faster at elevated pressure [10].

Use of microbial/algae: Besides the physicochemical CO_2 reduction techniques, biological approaches were often introduced using fungi, microbes, and plants. Micro-algal bio-fixation of carbon dioxide in photo-bio-reactors has recently acquired revived interest in reducing CO_2 pollution. However, insufficient lighting will restrict the development of the micro-organism and therefore reduce the removal of CO_2. Therefore, the use of chemoautotrophic microorganisms that use inorganic chemicals rather than light energy for CO_2 removal has also been successfully attempted [11].

Adsorption: The capture of CO_2 by adsorption is typically performed in a lined column filled with dry carbonaceous adsorbents. At a reasonable temperature (25-65 ° C) and ambient pressure, then the CO_2 carrying stream is moved through the column. The whole process occurs in two steps, and they are CO_2 adsorption accompanied by desorption to extract pure CO_2 by a pressure swing (PSA), thermal swing (TSA) method, or the mixture of both to render the whole process cost-effective [11]. Pressure swing adsorption: The PSA is a cyclic adsorption method that enables the continuous bulk isolation of the target constituent from a mixture/gas stream under pressure control according to the molecular characteristics and attraction for an adsorbent substance [11]. Temperature swing adsorption: This technique is called temperature swing as the bed temperature switches between adsorption and regeneration. This is an alternative method to swing adsorption in which flue gas is spread over the bed. In which adsorption happens exclusively on the adsorbent before equilibrium is achieved [11]. First, the CO2 molecules are adsorbed on the non-polar surface of the activated charcoal, which is mainly regulated by oxygenated functional groups such as carboxylic, lactonic (acidic) and carbonyl or ether (non-acidic); followed by achieving the equilibrium between the adsorbate and the adsorbent at a mild temperature, because it is exothermic in nature [11]. Finally, the adsorbent surface is recovered by reversing the adsorption state such that it can be reused again during the next adsorption process, which leads to the high output of the multiple adsorption-desorption methods. The adsorption method is advantageous because it is reversible and it can increase the adsorption efficiency by fabricating the surface of the adsorbent materials. Adsorption is seen as one of the cost-effective solutions for the separation of CO2 owing to its benefits, such as removal of regeneration energy requirement by either thermal or pressure modulation mainly due to the absence of water, effective in the dilute gas mixture, improved CO2 carrying power, ease of handling across a fairly large temperature range and pressures, higher response levels and lowering of the minimum pressure drops. Further, the performance of the capture technologies would also rely similarly on the recovery potential of the solid adsorbents functionalized with amine or nitrogen [11]. Advantages and Disadvantages associated with the post-combustion capture technologies are given below [11].

Advantages

This technology can be easily applied to current sources of emission, hence, considered as one of the most environmentally friendly and economic innovations of greatest significance. An efficient way of reducing the amount of greenhouse gas emissions that can be added through retrofitting of current power stations. Compliant with upgraded combustion technologies, without any major changes in them. Its maintenance does not impact the plant operation and can be regulated or controlled easily. The usage of activated carbon as one of the adsorbents makes the cycle eco-friendly.

Disadvantages

Require effective (dry) adsorbent production for fairly limited usage streams to make it more cost- and energy-efficient. A relatively limited supply of ideal sorbent for carbon dioxide capture during combustion. Extra energy is needed to compress the captured Carbon dioxide. High energy demand is required for sorbent regeneration. Ex: Amine Solvent

Conclusion

The rapid increase of carbon emissions to the atmosphere from various industrial and energy sectors is the primary contributor to global warming and associated climate change. Thus, various post-combustion capture methods are established to extract CO2 from point sources and they are absorption by liquid solvent, membrane separation, cryogenic distillation and adsorption, and so on. Among them, some CO2 capture technologies with a special emphasis on post-combustion carbon capture were discussed in detail in this article. Different technologies used under this process were also discussed further.

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