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ADVANCES IN CARBON CAPTURE TECHNOLOGIES FOR MITIGATING CLIMATE CHANGE: A REVIEW

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Abstract

Anthropogenic carbon dioxide emission in the atmosphere cause a major change in the environment such as global warming. The major source of CO_2 emission is coal-fired thermal power plants. Coal combustion produces the flue gas which contains hazardous gases such as CO_2, SO_2, NO_2, etc. CO_2 is the great contributor to the global climate change. Presently, approximately 30 billion tons of CO_2 is generated by us per year. So there is need to develop technologies to mitigate this problem. Carbon capture and sequestration technology used as a mitigation tool to avoid the CO_2 emissions in the atmosphere. To reduce CO_2 emissions three methods are used: Post-Combustion Capture, Pre-Combustion Capture and Oxy-Combustion Capture. These three approaches are at an early stage of development. These technologies remove about 75-90% of CO_2 from coal-fired power plants. Advanced power plants allow many new opportunities for CO_2 capture. Other emerging technologies are also useful in capturing CO_2 in various industries such as absorption, adsorption, membranes and cryogenic separation. In this paper we present the development of the carbon capture and sequestration technologies. The main Moto of these methods is to avoid the CO_2 emissions in the atmosphere.

Key words: *CO_2 emission, Carbon dioxide capture, Pre-combustion, Post-combustion, Oxy-combustion.*

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1. INTRODUCTION

Increasing CO_2 emission in environment is an issue of great concern today which is leading global warming [1]. The climate variability and changes are one of the evidence for global warming, results to increase in the average temperature rise of the globe [3]. Many climate scientists believe that a major cause of global climate changes is the anthropogenic emission of greenhouse gases (GHGS) into the atmosphere [4]. Green house gases such as water vapour, CO_2, methane and other atmospheric gases absorb outgoing infrared radiation which causing an increase of earth's temperature, this phenomenon called as Greenhouse effect[1]. Being a member of GHGs, CO_2 is the major contributor for global warming and it has the greatest antagonist which accounts approximately 55% of the observed global warming. About 64% of the only CO_2 is responsible for the enhanced Greenhouse effect [1]. The emission of greenhouse gas is increased when comparing with the initial revolution of the industries [3]. About 60% of the CO_2 is emitted by industrial power system, due to the usage of fossil fuels [5]. Coal is mainly used in the power sector and it consumes 70% of the Indian economy. Looking into current scenario it is necessary to minimize the global warming effect due to emission of CO_2 [3].Currently, approximately 30 billion tons of CO_2each year is generated by us [18]. And supply of about 80% of the world energy until 2040 is depending on the fossil fuels. [11]

In 1990, nearly 80% of global warming potential (GWP) weighted CO_2 emission from fossil fuel combustion. From 1990 to 1999 emission of $CO_2$from this source was increased about 13% [10]. During November 1991, the International Energy Agency (IEA) Greenhouse Gas (GHGS) programme launched and it has 17 member countries and 7 industrial sponsors [8]. This International co-operation focus to identify and evaluate technologies for reducing emission of GHGs which arising from the usage of fossil fuel [8]. Its Primary technical focus is carbon capture and sequestration [8]. The Energy Information Administration (EIA) within the U.S. Department of Energy (DOE) appraise that consumption of fossil fuel such as coal, petroleum and natural gas will increases by 27% over the next 20 years, thus increasing U.S. CO_2 emission from the current 6000 million tonnes per year to 8000 million tonnes per year by 2030. Especially the EIA estimates that the combined CO_2 emission from China and India in 2030 from coal use will be three times that of the United States. According to advance declaration of Intergovernmental panel on climate change (IPCC), by the year 2100, the atmosphere may contain up to 570 ppmv of CO_2causing a rise of mean global temperature of around 1.9^oC and an increase in mean sea level of 3.8m[1]. It has becomes an important research issue of global approach as more international attention is focused on global warming [1].It has been predicted that the global average rise temperature will be 0.3-0.7 ^0C between 2016 and 2035 [16]. In order to reduce the increase in temperature of globe which causing global warming under a threshold of 2^oC, carbon capture and sequestration technologies may be implemented with less risk [20].

One approach that keep promise for reducing GHG emission is Carbon Capture and Sequestration (CCS)[4]. Carbon dioxide capture and sequestration is the process of separation of CO_2 from the emitting sources of $CO_2$and that captured CO_2 is then stored in the carbon sinks [2]. CO_2will be stored in underground sedimentary basins, saline aquifers and coal reservoirs [3]. The main target of the CCS technology is to reduce the CO_2 concentration in the atmosphere [3]. This approach bring thesequestratedCO_2storage for thousands of years[4].Advanced coal power plant allow many new opportunities for CO_2capture. For example to integrate CO_2capture with an Integrated Gasification Combined Cycle (IGCC) [21].Current captured technologies can remove about 75 to 90% of the CO_2emitted from the combustion of fossil fuels. By reducing the cost of capture and sequestration technologies motives the both arrangements of capture and sequestration technologies [19].The advanced plant designed reduces the CCS energy requirement and will also the overall environmental impact and cost [14]

National Energy Technology Laboratory (NETL) organized the Department of Energy (DOE) carbon sequestration program which follows the five technological paths for reducing the GHG emissions. They are CO_2 separation & capture, carbon sequestration (storage), monitoring, mitigation and verification of stored CO_2, control of non-CO_2 GHGs and breakthrough concepts related to CCS (Figueroa et al. 2007) DOE's targeting the mandatory technology ready for the large scale field testing. It should become necessary to force required limits on CO_2emission. Three technological pathway follows for CO_2capture from the coal used power plants are post-combustion capture, pre-combustion capture and oxy-combustion. These three pathways are under the continue research and development to decline the GHG emissions and to significantly improve performance with great cost reduction [4].

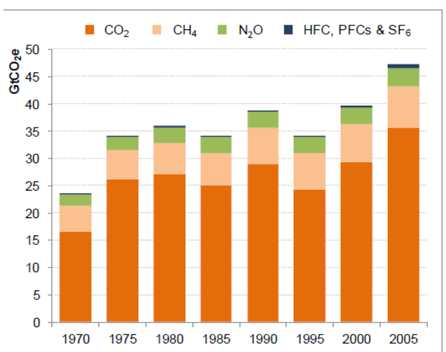

Fig-1: GHG Emission (By Gases) 1970-2005[5]

There are various existing and emerging technologies available for CO_2capture such as adsorption, absorption, cryogenic separation, gas separation membrane etc. For improving overall reduction of CO_2 (in the absorption process) there is need to consider the advancement in the absorption process such as; development of new solvent, development of suitable corrosion inhibitors and modification of the processes. If we know the composition of CO_2flue gas streams, quantity of CO_2capture and uses of captured CO_2, then we can recommend a suitable technology for CO_2capture. (Mondal et al.2012). All these existing technologies need to improve the performance, reduction of cost and energy for CO_2 separation[1].

This paper reviews the existing and emerging technologies for the separation and capture of CO_2 from the power plants. The main goal of the carbon capture and sequestration technologies is to reduce the amount of CO_2 emission in the environment.

1.1 Motivation For CO_2 Capture And Sequestration

Coal fired power plants are the major source of CO_2 emissions which causing a major change in the environment such as global warming. There is need to reduce carbon emissions from the fossil fuels. To eliminating the CO_2 emission from the fossil fuel power plants, cost effective carbon capture and sequestration technology used as a key need for dealing with CO_2 impact on global climate change. These technologies capture the CO_2 from fossil fuel power plants and stored the captured CO_2 in the geological formations or oceans[19]. Based on this motivation, we studied the advanced carbon capture and sequestration technologies.

1.2 Objective

- Reducing the CO_2 emissions by applying CCS to power plants.
- Utilization of CO_2.
- To reduce future retrofit costs, new plant designs could take future CCS application into account.

2. CO_2 CAPTURE TECHNOLOGIES

2.1 Post-Combustion Capture:

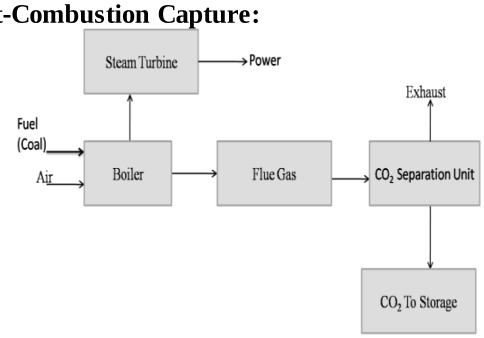

Fig-2: Post-Combustion Capture

Post-combustion capture method is used to remove the CO_2 from the flue gases. Air used in the power plants consist almost four-fifth of Nitrogen for the combustion(Figueroa et al. 2007) and generate a flue gas at atmospheric pressure and typically having the CO_2 concentration less than 15%. In the power generation system coal is burnt in the boiler with the help of air, for the generation of the steam. Steam drives the turbine and it generates the electricity. [3]. The exhaust contain CO_2 and N_2 flue gases. The greatest challenge in this method is the separation of the low concentration of CO_2in power plant flue gas (13-15% for coal fired power plant) out of the high concentration of N_2 gas (73-77%). [1,6]. Post combustion carbon capture having the high potential to reduce the GHG emissions in the power sector. Because it can be retrofitted to existing plants that generates two-third of the CO_2 emissions. [1]. Post-Combustion capture technology is best as compared to the other technologies in the coal-fired power plants. Because it has a higher thermal efficiency for conversion to electricity than the pre-combustion capture technology [3,1]. The post combustion capture technology can also be used in other industries other than power plants like cement, petrochemicals and oil refining [7].

Advantages:

- Applicable to existing power plants for continued operations.
- Retrofit technology option.
- Simple process.

- More process available.

Disadvantages:

- Plot space requirements are significant for post combustion capture.
- Extra costs may be required to fit post-combustion capture at plant location.
- Low CO_2 level.

2.2 Pre-Combustion Capture:

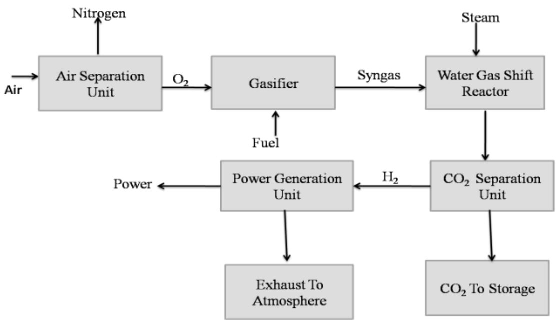

Fig-3: Pre-Combustion Capture

In the pre combustion CO_2 capture, the CO_2 is captured from some process stream, before the fuel is burned (Figueroa et al. 2007). Primarily Oxygen and Nitrogen is separated in the air separation unit. Then the fuel or coal is mixed with oxygen in the gasifier. This mixture forms the synthesis gas at the high temperature as seen in equation (1). It is also called as 'Syngas'. Syngas is the mixture of CO and H_2. This process is called as gasification [3]. Then steam is added in the water-gas reactor where CO is converted into CO_2, as seen in equation (2). In the water gas shift reactor, the addition of steam and decrease in temperature cause the conversion of CO into CO_2 and then it increase the yield of H_2 [1]. In this mixture, 15-50% range of CO_2 is present. After the pre combustion method, CO_2 is separated, transferred, and then sequestrated or stored. [3].This is occurs at a high pressure. (1000 times higher than flue gas in post-combustion) [6]. Pure H_2 is used as a fuel in a gas-based the power plant to produce electricity [1,2]. Hydrogen is also used in the power fuel cells for rising the overall plant efficiency. In future, H_2 would be used as transportation fuel (Mondal et al, 2012). Pre-combustion capture is the more efficient technique for the removal of CO_2 at low pressure from the syngas due to the presence of CO_2 at higher concentration in syngas. So the CO_2 capture is less expensive for pre-combustion as compared to the post-combustion [1, 3]

$C_xH_y + xO_2 \leftrightarrow x\,CO + (y/2)\,H$ ▬▬ ①[2].

$CO + H_2O \leftrightarrow CO_2 + H_2$ ▬▬ ②[2].

Advantage:

- 90 % CO_2 is captured.
- HighCO_2 level.
- Easy separation ofCO_2.
- H_2 used as input to produce electricity.
- Less water is used as compared to post combustion capture.

Disadvantage:

- Applicable mainly to new plants.
- Complicated process.
- Equipment cost is high.
- Applications of gasification are common to pre-combustion capture.

2.3 Oxy-fuel Combustion Capture:

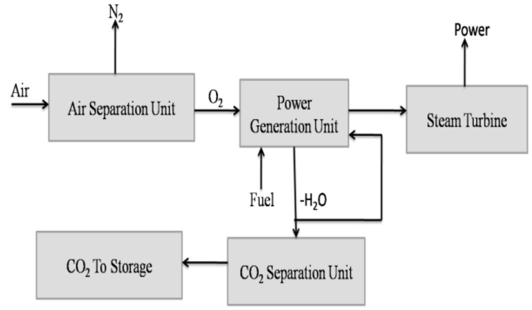

Fig-4: Oxy-fuel Combustion Capture

Combustion of fuel with oxygen is called as oxy-combustion [7]. About 3-15% of conc. CO_2 is present in the fuel gases. For the removal of concentrated CO_2 from the flue gases oxy-fuel combustion method is used [2]. Air separation unit is used to supply the high purity oxygen to the coal fired power plants [4]. The fuel is burned with the pure oxygen (> 95 %) and then this pure O_2 mixed with the recycled flue gas (RFG) in the boiler to maintain the combustion conditions similar to an air fired configuration[1, 4]. This is necessary because currently available materials of construction cannot withstand the high temperatures resulting from coal combustion in pure oxygen (Figueroa et al. 2007). The advantage of this method is that, after the combustion, the flue gas consist CO_2 and water vapour. The water is easily removed by the condensation and remaining CO_2 can be extracted easily at low cost[1]. In an oxy-fuel combustion capture technology, the carbon capture cost is very less as compared to other technologies. But air separation and recycling of flue gas significantly increases the economic cost. Currently oxygen production techniques are very expensive, in order to uses this oxy-fuel combustion technology a wide range of advancement must be required [6].

Advantage:

- Very high CO_2 conc. in flue gas.
- Retrofit technology option.
- 98% CO_2 captured.
- Cost of separation is low.
- Oxy-combustion with CO_2 capture should be at least competitive with pre- and post-combustion CO_2 capture.

Disadvantage:

- Pure form of oxygen is required in power plants.
- Recycling of flue gases increases the cost process.
- Material of construction to withstand at high temp. is needed.

3. EXISTING TECHNOLOGIES:

3.1 Absorption Process:

The mostly used technology for CO_2capture from flue gas is absorption by using the aqueous amine solution like diethanolamine (DEA), monoethanolamine (MEA) and methyl diethanolamine (MDEA).About 98% of CO_2 is recovered by using MEA [13]. This technology is used in the post-combustion capture technology. The major limitation of this technology is that, the impurities present in the flue gases degrade the solvent and affect the performance of solvent. To overcome these limitations, aqueous ammonia as a solvent is used for the CO_2separation. Ammonia also absorbs the other impurities like NO and SO_x from the gas stream. The chilled ammonia causes the fouling of the heat exchanger by the deposition of the ammonium bicarbonate [11]. Aqueous and chilled ammonia processes have the great potential of improve energy efficiency as compared to amine based system [4].

3.2 Adsorption Process:

Removal of the one or more components of a mixture by using a solid surface called as adsorption process [1]. A packed column is used in the adsorption process to capture CO_2. Spherical adsorbent is filled in the column. When the CO_2containing stream is fed to the column, $CO_2$is attracted towards the adsorbent and sticks on the surface of adsorbent. At equilibrium, to get the CO_2in the pure form desorption takes place and adsorbent are regenerated for the further process [1]. Gas is adsorbed on the solid surface of the adsorbents by a van-der Waals force. The most effective adsorbents are zeolites, activated carbon, silica gel and aluminium oxide [15].

Zeolites are mostly used as solid sorbents in CO_2 capture application. CO_2 adsorbed on the zeolites by different procedures [11]. Some factors like adsorbent pore size pore volume, surface area and affinity of the adsorbed gas for the adsorbent are controlled the adsorption capacities and kinetics [12].

3.3 Membrane Technology:

Membranes are the semi permeable barriers which separate the CO_2 and other impurities from the flue gas. The substances are separated by the various mechanisms such as solution, adsorption, diffusion, molecular sieve and ionic transport [1]. If flue gas is pass through the bundle of membrane tubes, when an amine solution flowed into the shell side of the bundle. Then CO_2 would pass through the membrane and absorbed in the amine while impurities blocked from the amine (Figueroa et al. 2007). Amine leaves the membrane bundle and would be regenerate hurriedly before it recycled [1, 4].

Two types of membrane process can be used for separating CO_2 from flue gas:

- Gas separation membrane
- Gas absorption membrane.

3.3.1 Gas Separation Membrane:

It operates on the principle of diffusion [17]. The pores of membrane permit the preferential permeation of mixture constituents. These pores of the membrane permeate the one component through the membrane faster than the other component. The principal design and operational parameter of membrane are selectivity and permeability [1, 17]. This technology is not favourable to separate CO_2 from flue gas because of the large quantity of the flue gas and compression energy requirements [15]. Gas separation membrane consisting ceramic, polymeric and combination of both materials or mixed matrix membranes. [1]

3.3.2 Gas absorption Membrane:

Gas absorption membrane consists of micro porous solid membrane. These membranes are used for the contacting of the gas and aqueous absorbent [1, 17]. CO_2 is diffuses through the membrane and absorbed by the mono-ethanolamine (MEA). This process removes high amount of CO_2 than the gas separation membrane because of the high driving force at any moment [1, 17].

3.4 Cryogenic Separation: Cryogenic separation process is mostly used for the separation ofCO_2 from the stream which contains the high CO_2 concentrations (>50%) [1].This method uses the different boiling point of a various gas species to separate them from gas mixture [15]. This process includes compression and cooling of the gas mixture in various stages to induce phase changes in CO_2 in flue gases [1, 17]. CO_2can be arises as a solid or liquid phase together, depending on the operation conditions [1]. The major advantage of this method is that no chemical absorbent is required and process can be operating at atmospheric pressure. This process gives the high recovery of CO_2. The cost of this process may not be higher than amine absorption process [17].

4. CONCLUSION

In order to reduce the growth of CO_2emissions, carbon can be converted into a supportable form or captured as a gas and stored in the geological formations or oceans. Post combustion technology is the most suitable technology as compared to the pre-combustion and oxy-combustion technology in coal fired power plants. CO_2 is separated from the nitrogen at low pressure and it has the high potential to reduce the GHG emissions from the power sectors. This technology can be retrofitted to the existing plants. Other emerging technologies are also helpful for separation of CO_2. All these existing technologies have their own advantages and limitations. But their accuracy, strength and removal efficiency are the main challenges. There is need to improve the performance and reduce the cost for the CO_2 separation.

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