POST COMBUSTION CARBON DIOXIDE CAPTURE

Nanayakkara G.M.C, Peiris K.A.D.U.S, Wijerathna W.M.M.P, Wimalarathne N.R.G.S.S.
Faculty of Technology, University of Sri Jayewardenepura

ABSTRACT

Industrial activities has been a significant cause of a lot of ongoing environmental hazards. Among them, a significant threat is from the gases which emit during several industrial processes. Gases such as CO_2, NO_2, and SO_2 are released into the atmosphere due to fossil fuel burning and other chemical reactions. At present, different institutions and organizations are working together to minimize the damage caused by these emissions to the environment and humans by formulating policies and regulations. Further, we can see most industries are keen to implement strategies to reduce their carbon footprint by reducing the flue gas emissions. Enterprises in achieving this target can use several methods. Among them, post-combustion carbon capture is an effective method capable of reducing a significant amount of CO_2 from the flue gas concentration. This paper will provide an overview of the post-combustion carbon capture technique, different post-combustion carbon capture methods, the pros, and cons of this method, current status, and various post-combustion carbon capture applications. Industries should interest in taking the support of the post-combustion carbon capture system to reduce their CO_2 emissions while minimizing the disadvantages of this method.

INTRODUCTION

Green House gas effect is the accumulation of greenhouse gases in the atmosphere and the consequent rise in the earth's temperature. Although the greenhouse gas effect is a natural phenomenon, excess greenhouse gases release into the environment has accelerated it in a harmful way. Greenhouse gases inhibit the outgoing radiation from the earth and reduce the heat balance. Gases such as carbon dioxide, methane, nitrous oxide, and chlorofluorocarbon are some prominent GHG gases.

An increase of GHG gases will reduce the outgoing infrared radiation when more heat is remaining around the atmosphere; the temperature rises. A small rise in temperature will induce many other changes. Temperature differences change the current climate patterns. It will change cloud patterns and wind patterns also. Another major effect that occurs due to GHG emission is the rise of sea level. There are two ways of rising sea levels. Firstly, the warmer temperature expands the seawater, and sea level rises. Secondly, due to the increase in temperature, glaciers will start melting and add water to the sea. GHG emission potentially Impact on human life too.

As the climate changes happening, the agricultural activities get affected. Farmers have to face natural hazards, insect damages continuously. Temperature rise affects the general atmospheric circulation and changes the precipitation patterns and changes the hydrological cycle, as well as soil moisture content, is changing. When sea level rises, the low-lying coastal areas and island will cover with water, and people who live there will be lost their habitat. And also, rising sea levels will affect the quality of groundwater, as the beaches are shifting. It also effects on aquatic systems. Due to the warming, the fish population is also reduced as it harms the coastal wetlands.

The contribution of carbon dioxide towards the greenhouse effect is 60% of the total contribution [1]. From all GHG gases, carbon dioxide appears to be the primary source of the world's GHG effect. Carbon dioxide naturally occurs in the atmosphere. It serves earth as essential plant nutrition and a necessary determinant of the earth's heat balance. Although Carbon dioxide emits by natural sources due to microbial inspiration and some other behaviors of nature, it doesn't affect the balance of temperature. With the industrial revolution, the amount of carbon dioxide in the

atmosphere has been drastically increased. Emissions are mainly adding by the fossil fuel burning and as a result of manufacturing processes of various industries such as mineral-based industries (cement, glass production, and ceramics), chemical industries, metal industries, and also the products from other sectors such as textile, leather, food and beverages, food processing, etc. Other than industrial emissions, deforestation is another reason for the increase in carbon dioxide emissions [2].

METHODS OF CONTROLLING CARBON DIOXIDE EMISSIONS IN INDUSTRIES

As mentioned in the above chapter, CO_2 is the most abundant greenhouse gas among the others, which adversely affects climate change. As responsible industries, they should be aware of reducing or eliminating CO_2 emission to minimize the CO_2 concentration in the atmosphere. The power stations using fossil fuels, petrochemical industries, cement industries, and other industries, which depend mostly on fossil fuels and natural gas and oil, must be aware of the controlling CO_2. For that, managerial level aspects are essential. Some of them are maintaining the machines and replacing faulty parts to avoid energy losses, which cause high fossil fuel burning and making the industry less fossil fuel dependent by implementing alternative methods. Another initiative is reforestation to reduce the CO_2 concentration in the atmosphere. Conserve CO_2 from one sector and sell it to another industry is another currently practicing technique to mitigate the emissions and control industries' carbon footprint.

According to the intergovernmental panel on climate change, greenhouse gases should be reduced by 50-80 % by 2050 to overcome climate change's adverse effects [3]. Therefore, Carbon Dioxide capture and storage is the best practice to conserve CO_2 by separation from other unnecessary impurities [4]. There are three types of capturing methods: Pre combustion CO_2 capture, Post-combustion of CO_2 capture, and Oxy-fuel capture that reduce the emissions.

Here we mainly focused on post-Combustion CO_2 capture in the review. It is more realistic compared to the other two methods since it can be retrofit into the existing plant and the flexibility of switching between capture mode and non- capture mode while in operation [5]. This type's primary focus is to capture the flue gas from fossil fuel burning in various industries that emit high CO_2 concentration and, after capturing, store for future usage.

POST COMBUSTION CARBON DIOXIDE CAPTURE

The post-combustion CO_2 capture method was used after the combustion, as Figure 1 shows how it traps the flue gas. Flue gas contains many contaminations such as NOx, SOx, and particulate matter. At present, there are various kinds of researches for implementing the best processes for CO_2 capture. Commonly they state that,

- Chemical Absorption
- Physical Absorption
- Adsorption
- Membrane Separation and
- Cryogenic Fractionation as the processes [5].

The following are the most popular methods used within the coal, natural gas, and oil-related industries.

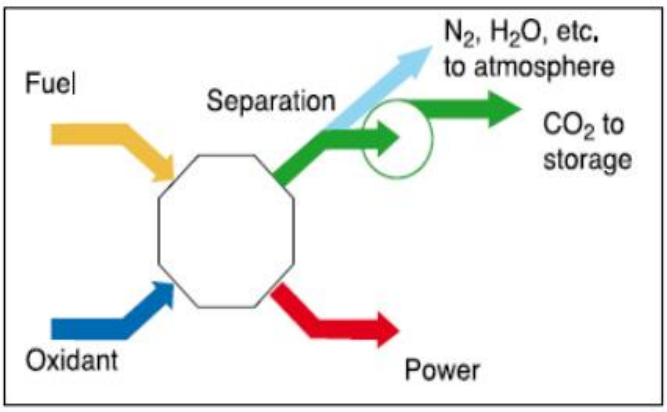

Figure 1. Schematic diagram of a power plant with post-combustion CO_2 capture [6]

Chemical absorption method

Considering all the capturing methods, chemical absorption acquires a principal place, and it is broadly used in gas and oil-related industries [6, 7, 8]. Though the other techniques are also using for some operations, they are yet in developing stages. This method is the oldest one, used to capture CO_2 in ammonia plants in the food industry [9]. This is the method that dissolves the CO_2 in an absorbent by making contact with the flue gas. Then the steam condensate leaving pure CO_2. The Separated CO_2 will be compressed and transported for suitable locations for storing. Ammonia and Amine solutions are the chemicals that use as the absorbent or the solvent. The solution Ammonia provides minimum corrosion and operates efficiently at a lower temperature. Due to the toxicity of the solution, using ammonia should have a well-organized process. Amine solutions are less expensive, relatively non-volatile, and react rapidly with CO_2 [10, 11, 12].

Membrane separation method

A cost-effective method that CO2Capturing costs bring down using different membranes possessed their separation method, thermal and chemical stability, and mechanical strength. Since it doesn't use any chemical, consider as a more environmentally friendly process [13]. The captured CO2 can be compressed and transported to store in geological formations, in the ocean, in mineral carbonates, or used for industrial processes [5].

The gas separation mechanism may vary from the membrane to the membrane. It depends on factors like molecular size, molecular weight, affinity to membrane material, etc. The thickness of these membranes is only several hundred nanometers. Therefore, by pressuring the feed gas and connecting the permeating gas to a vacuum for obtaining a high driving force, a high permeate flux can be achieved [14].

GLOBAL CO_2 GENERATION AND CO_2 CAPTURING

The amount of utilization of fossil fuel and other resources of CO_2 is increased drastically within the past few years. Since the population growth was increasing, the electricity requirement acquires a principal place for CO_2 generation. As shown in Figure 2, coal is the most used resource though there were alternatives [6, 15].

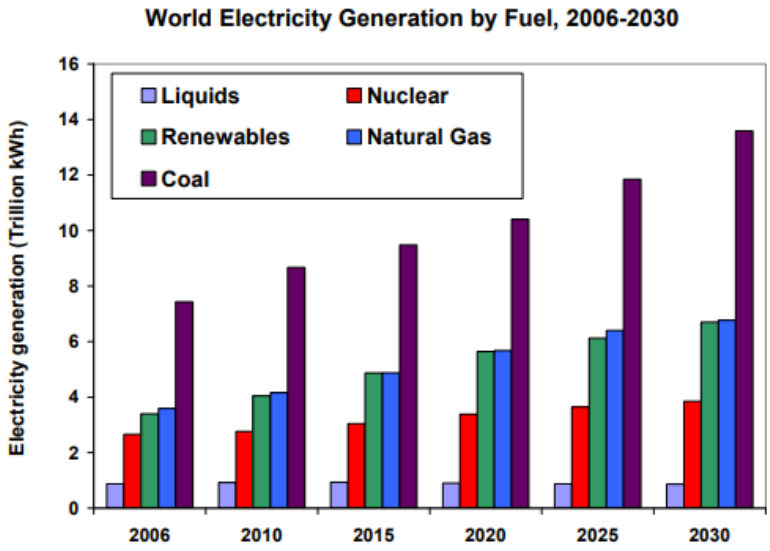

Figure 2. World Electricity Generation by Fuel, 2006-2030 [6]

Therefore, most countries tend to find solutions for this matter, which was a barrier to fulfilling sustainability. Finally, this Carbon Dioxide Capture & Storage method is technically feasible on more reduction of emitted CO_2.

- According to the literature, 16 projects have been started or under construction while only, two of them are based on post-combustion carbon technology [17].
- As mentioned in the literature a pilot study on CO_2 scrubbing plant was commenced in Niederaussem as the first study in Germany, 2009 [5].
- A pilot study was done at Dong Power plant in Denmark that captures 1 ton CO_2/ hour.
- According to the literature, the project of CCS started in SaskPower's demonstration power plant, which is the largest commercial CCS project has captured 1 million ton CO_2 by July 2016 [17].

PROS AND CONS OF POST-COMBUSTION CARBON DIOXIDE CAPTURING METHOD

As discussed above, Post-combustion carbon capture is a technology that captures CO_2 after the operation of specific processes and transports the CO_2 to store underground or for CO_2 utilization. This method is also known as CCS technology, has many advantages as well as disadvantages.

Advantages

- The main advantage of the post-combustion carbon capture is the reduction of CO_2 emission to the environment. CO_2 gas is the major greenhouse gas emission that leads to global warming. With industrialization, the emission of CO_2 increased rapidly. As mentioned in the abstract the concentration of CO_2 has increased by 280 ppmv in 1830 to 310 ppm by volume in 1958, and a rapid increase of 369 ppm by volume in 2005. Prediction of increase in 2100 is 750 ppmv [18, 19]. Because of the rapid increase of CO_2 in the atmosphere, global

warming was increased, and the Ozone layer was depleted, the climate was changed, glaziers melted and the sea level has risen. To reduce the CO_2 emissions to the environment, introducing the technique of Post-combustion carbon capture is beneficial.

- Post-combustion carbon capture technology is a technology with a higher maturity when compared to the other technologies, which is an advantage in fitting easily to the existing plants [17].
- By utilizing CO_2 that captured by post-combustion carbon unit and reuse in industries, production of energy, food beverage productions, used in refrigerants, fire extinguishers and agriculture are some of the indirect advantages.
- The captured CO_2 could be injected into the depleted layers, where the oil and gas reservoirs are located. By this injection, the pressure inside the reservoirs becomes higher and provides the driving force that makes it easier to extract the oil and gas while CO_2 will be stored permanently underground [17].
- Methane from the coal beds can be recovered by injecting the CO2, as in the oil and gas extraction discussed above [17].
- The flexibility of the unit is an important benefit of this technology when compared to the other technologies. Even though the post-combustion carbon capture unit is shut down, the plant could carry on the processes [8].
- The unit provides an option on allowing the increased capacity by restricting the capture process temporarily during the peak power demand [8].
- The re-boiler duty requirement could minimized by the higher CO_2 lean loading from the unit [20].
- In the ammonia absorption process, fertilizers such as ammonium sulfate and ammonium nitrate can be obtained. The SO_2 in the flue gas get reacted by the ammonium carbonates which produces through the process makes ammonium sulfate and ammonium nitrate by reacting with NOx.

Disadvantages

- According to the literature, the National Energy Technology Laboratory of the U.S. has estimated that the cost of electricity would increase by 70% due to the post-combustion carbon capture systems. Recent studies have shown that 32% and 65% increase in electricity cost when using post-combustion carbon capture units in gas and coal power plants respectively [17].
- The effect on the capture efficiency of the unit in coal-fired and gas-fired plants due to the low concentration of CO_2 is a major disadvantage [17].
- Accidents can occur due to the CO2 transporting pipelines. If the water concentration increased above 50 ppm, the formation of carbonic acid leads to the corrosion inside the pipeline, and with the time, the accidents could occur. With the increase in the pipeline accident occurring rate could be increased. According to the literature with the increased pipelines the number of accidents has increased up to 0.76/year for every 1000km in the period of 2002-2008 [17].
- The cost of installing a post-combustion carbon capture unit and maintenance cost is higher and therefore most of the companies are not interested in this technology [5].
- The drop-down of thermal efficiency due to the additional load created by the unit is another disadvantage [8].
- The use of Ammonia solution in the absorption processes shouldn't release to the atmosphere due to the toxicity [8].
-

CONCLUSION

Carbon dioxide emissions associated with industries have affected the earth's atmosphere in a very harmful way. Industries such as the petrochemical industry, cement industry, Textile industry, paper industry, and metal manufacturing, which mostly depend on fossil fuels, should be responsible for controlling their GHG emissions, including CO_2.

Carbon Dioxide capturing and storage is the best practice to conserve CO_2 by separation from other unnecessary impurities in the flue gas. There are three types of capturing methods: Pre combustion CO_2 capture, Post-combustion of CO_2 capture, and Oxy-fuel capture that reduce the emissions. Among them, post-combustion CO_2 capture is more realistic compared to the other two methods since it can be retrofit into the existing plant and the flexibility of switching between capture mode and non- capture mode while in operation. To remove CO_2 from the flue gas emitted from industry, the flue gas should be purified from other contaminants like NOx, SOx, and other impurities.

There are various methods in post-carbon dioxide capture. Chemical Absorption, Physical Absorption, Adsorption, Membrane Separation, and Cryogenic Fractionation are some of them. The chemical absorption method is globally used and broadly use in gas and oil-related industries. The membrane separation method is also a cost-effective and environmentally friendly method that use Permeable or semi-permeable materials in the membranes that allow for the selective particulates and removing them from CO_2. Despite the adverse effects of fossil fuel use, fossil fuels are still widely used to generate energy. Therefore the release of carbon dioxide to the atmosphere has increased drastically since the industrial revolution. As climate change has become a major threat to living beings' existence, the reduction of these emissions is really important to control the ongoing adverse impacts. Further, there are a lot of standards and policies that have been established and implemented to find solutions for this matter. The carbon Dioxide Capture & Storage method is a technically feasible method that can address this issue as it can reduce emitted CO_2 to a large extent.

When discussing the application of the Post carbon-capturing method, it has both advantages as well as disadvantages. The main advantage of the post-combustion carbon capture is the reduction of CO_2 emission to the environment. Also, this method has a higher maturity than other technologies, which is an advantage in fitting easily to the existing plants. Apart from that, the captured carbon can be utilized for different purposes. For example, captured CO_2 could be injected into the depleted layers, where the oil and gas reservoirs are located. The pressure inside the reservoirs becomes higher by this injection and provides the driving force that makes it easier to extract the oil and gas while CO_2 will be stored permanently underground.

Typically, the post-combustion carbon capture system consumes a lot of electricity for the operation. Studies have shown an increase in electricity cost when using post-combustion carbon capture units in gas and coal power plants. Also, accidents can occur due to CO_2 transporting pipelines. If the water concentration increased above 50 ppm, the formation of carbonic acid leads to the corrosion inside the pipeline, and with the time, the accidents could occur. Another drawback of this method is the cost of installing a post-combustion carbon capture unit, and maintenance costs are higher. Therefore most of the companies are not interested in this technology.

The use of a post-combustion carbon-capturing system can minimize the release of carbon dioxide due to several industrial processes to a large extent. This will help to reduce the carbon footprint of the industries and achieve their sustainability goals. Furthermore, it will reduce the greenhouse gas concentration of the earth's atmosphere and ultimately help mitigate the impacts of climate change. Therefore, industries should give their concern on this matter and should try their best to implement such a carbon-capturing technique into their operation.

References

[1] Niveta Jain, Arti Bhatia, Himanshu Pathak, Navindu Gupta, D.K. Sharma, and Rajeev Kaushik, Greenhouse Gas Emission and Global Warming," in Introduction to Environmental Sciences, TERI Press, 2015, pp. 379-411.

[2] Darkwah Williams Kweku, Odum Bismark, Addae Maxwell, Koomson Ato Desmond, Kwakye Benjamin Danso, Greenhouse Effect: Greenhouse Gases and Their Impact on Global Warming," Journal of Scientific Research and Reports, vol. 17, no. 6, pp. 1-9 , 2018.

[3] A. Stangeland, "Why CO2 capture and Storage is an important strategy to reduce global warming," bellona, 2007.

[4] U.S.P.R. Arachchige, Rasenthiran Kohilan, M.A.L. Lakshan, M.K. Lakshitha Madalagama, Prabhath Pathirana, P.W. Sakuna Sandupama, "Simulation of carbon dioxide capture for industrial applications," Energy Reports, vol. 6, pp. 659-663, 2019.

[5] Yuan Wang, "A Review of Post-combustion CO2 Capture Technologies from Coal-fired Power Plants," Energy Procedia, vol. 114, pp. 650-665, 2017.

[6] A. Kothandaraman, "Carbon Dioxide Capture by Chemical Absorption: A Solvent Comparison Study," MASSACHUSETTS INSTITUTE OF TECHNOLOGY , 2010.

[7] U. S. P. R. Arachchige and M. C. Melaaen, "Aspen plus simulation of CO2 removal from coal and gas fired power plants," Energy Procedia, vol. 23, no. 1876, pp. 391–399, 2012, doi: 10.1016/j.egypro.2012.06.060.

[8] U. S. P. R. Arachchige, Carbon Dioxide Capture by Chemical Absorption: Energy Optimization and Analysis of Dynamic Viscosity of Solvents, Ph D thesis, University of South-Eastern Norway, ISBN: 978-82-7206-516-3. 2019.

[9] M. Abu-Zahra, "Commercial liquid absorbent-based PCC processes," Absorption-Based Post-combustion Capture of Carbon Dioxide, pp. 757-778, 2016.

[10] J. M. A. H. Howard Herzog, Advanced Post-Combustion CO2 Capture, Clean Air Task Force, 2009.

[11] U.S.P.R. Arachchige, N. Aryal, M.C. Melaaen, Case study for flue gas separation of a coal fired power plant and parameters' effect on removal efficiency, Proceedings, APCRE'11 chemical engineering symposium, Beijing, China; 2011.

[12] U.S.P.R. Arachchige, M. Muhammed, M.C. Melaaen, Optimization of post combustion carbon capture process-solvent selection. International Journal of Energy and Environment, 3, No. 6: 861-870, 2012.

[13] He, X. A review of material development in the field of carbon capture and the application of membrane-based processes in power plants and energy-intensive industries. Energy Sustain Soc 8, 34, 2018.

[14] M. Zhao, "Membrane Separation Technology in Carbon Capture," in Recent Advances in Carbon Capture and Storage, Beijing, Intech open, 55-90, 2017.

[15] U.S.P.R. Arachchige, M. Muhammed, M.C. Melaaen, "Optimized Carbon Dioxide Removal Model for Gas Fired Power Plant". European Journal of Scientific Research, 86, No. 3: 348-359, 2012.

[16] Intergovernmental Panel on Climate Change, "Carbon dioxide capturing and storage," United States of America by Cambridge University Press, New York, 2005.

[17] M.-V. Dennis Y.C. Leung, "An overview of current status of carbon dioxide capture and storage technologies," Renewable and sustainable energy reviews, vol. 39, pp. 426-443, 2014.

[18] Mahamud R., Khan M.M.K, Rasul M.G. and Leinster M.G, "Post combustion carbon capture and storage in existing coal power plant: importance and recent development," in 8th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics, Central Queensland University , 2011.

[19] U S. P. R. Arachchige, Dinesh K., and Morten C. M, Simulation of carbon dioxide capture for aluminium production process. International Journal of Modeling and Optimization (4-1), 43-50, 2014.

[20] U.S.P.R. Arachchige, Aryal, N., Melaaen, M.C., "CO2-flue gas separation for a gas-fired power plant", Proceedings, 10th Annual Conference on Carbon Capture and Sequestration, Pittsburgh, USA, 2-5 May, 2011.