

# A Review Paper on CO<sub>2</sub> Separation From Flue Gases In Integrated Gasification Combined Cycle Power Plant

Rahul Srivastava<sup>1</sup> M.K. Chopra<sup>2</sup>

<sup>1</sup>M.E. Student, Department of Mechanical Engineering, RKDF Institute of Science & Technology, Bhopal M.P., India

<sup>2</sup>Assistant Professor, Department of Mechanical Engineering  
RKDF Institute of Science & Technology, Bhopal M.P., India

## Abstract

This paper reviews the different methods that could be used for CO<sub>2</sub> separation from flue gases in IGCC power plant. The concentration of CO<sub>2</sub> gases increases in atmosphere day by day. CO<sub>2</sub> gases are responsible for greenhouse gas emissions which is the greatest environmental challenge in these days. Membrane separation, adsorption, carbon capture and storage (CCS) are some methods to separate CO<sub>2</sub>. Membrane separation include inorganic membrane, polymeric membrane, hollow fiber membrane and novel CO<sub>2</sub> capture technology and these method is clean and easier method. Adsorption process helps to reduce CO<sub>2</sub> gas emission by use of selective adsorbents. Carbon capture and storage (CCS) are another method involves collecting, transporting and then burying.

**Keyword:** membrane gas method, carbon capture and storage (CSS), adsorbents.

## 1. Introduction

Many greenhouse gases present in our atmosphere. There are two ways by which greenhouse gases produce in our atmosphere i.e. First is naturally and second is industrially(i.e; flue gases from IGCC power plant etc.). Some naturally gases are water vapour (H<sub>2</sub>O), carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O) and other gases due to industrial process are Per fluorocarbons (CF<sub>4</sub>, C<sub>2</sub>F<sub>6</sub>), hydro fluorocarbons (CHF<sub>3</sub>, CF<sub>3</sub>CH<sub>2</sub>F, and CH<sub>3</sub>CHF<sub>2</sub>), and sulphur hexafluoride (SF<sub>6</sub>) are only present in the our atmosphere. CO<sub>2</sub> emission is mainly responsible for greenhouse gas emission almost caused by burning of fossil fuels. Water vapour is the most important, dominant and abundant greenhouse gas. Concentration of water vapour depends on temperature and other parameters [1].

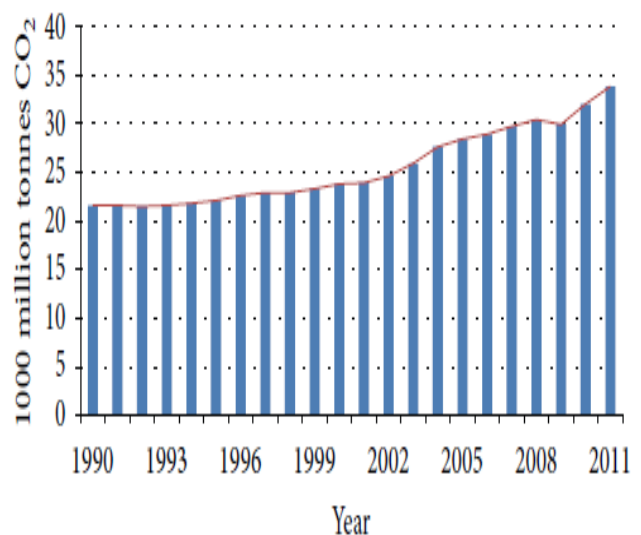


Figure 1: Global CO<sub>2</sub> emission from flue gases [2]

The earth's average temperature continuously increases day by day. Inter-governmental Panel on Climate Change (IPCC) state that Global GHG emissions must be reduced by 30 to 60 percent by 2050 to avoid dramatic consequences of global warming. [2].

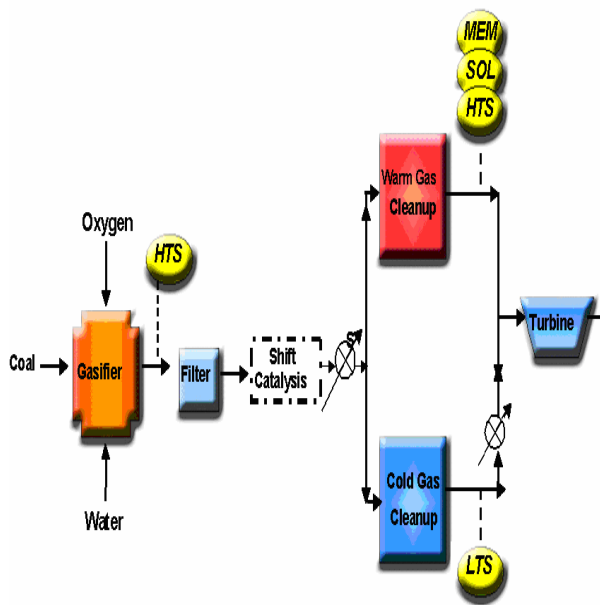


Figure 2: General Case: Advanced Gasification/IGCC – Fuel Gas [3]

Above figure 2 indicates the alternative where acid gas cleaning takes place within a warm gas cleanup system rather than at the previously described cold (lower) temperatures. The benefit in cleaning the gas in an IGCC application at higher temperature is that the thermal plant efficiency will be as much as 2-3% greater as compared to the lower temperature acid gas cleaning scenario. The efficiency improvements are that the heat transfer and latent heat to the more efficient gas turbine cycle are maximized; the capital and operating costs are lowered by reducing the duty on the heat exchangers; and the need for waste water treatment facilities are eliminated.[3]

With respect to CO<sub>2</sub> capture in an IGCC system, post-combustion and pre-combustion technologies can be used. With coal utilization and after the gas turbine, about 9% carbon dioxide exists in the flue gas and partial pressure of the carbon dioxide is low. However, pre-combustion techniques with the IGCC system offer the opportunity to remove CO<sub>2</sub> from the fuel gas before it is combusted in the turbine. The high pressure of the system and the possible shifting of the CO to CO<sub>2</sub> produce a high partial pressure of CO<sub>2</sub> that could be advantageous with certain removal technologies. In a carbon sequestration scenario, the cost of the capture/separation step is much higher than that of the storage step. For IGCC systems, commercial processes for CO<sub>2</sub> removal, such as Selexol, are used as a baseline from which other capture technologies can be compared. The U.S. Department of Energy's National Energy Technology Laboratory (NETL) is conducting in-house research

investigating novel techniques to capture/separate CO<sub>2</sub> from gases from advanced power generation systems. These technologies fall within the process categories of wet scrubbing with physical absorption; chemical absorption or adsorption with solid sorbents; and separation by membranes.

Except for membranes, all capture technique must be re-generable due to the excessive amount of carbon dioxide produced in a power generation plant.

With respect to the first category, physical solvents for CO<sub>2</sub> removal at high temperatures in IGCC applications are being studied. The higher temperature of operation for these solvents enhances the thermal efficacy of the IGCC power generation system.

Depressurization or flashing of the CO<sub>2</sub> from the rich solvent is the means for regeneration.

The use of solid sorbents is another method to remove CO<sub>2</sub> from gas streams. Past work has included alkali and alkaline earth metals as the basic component of sorbent structures. These sorbents could be used in higher temperature absorption processes. More recent work has included lower temperature sorbents for potential use as a substitute for the Selexol process. The regeneration step is crucial for these types of sorbents and either pressure swing and/or temperature swing can be effectively utilized. Whereas re-generable high temperature sorbents "HTS" operate above an arbitrary 300°F level. The 300°F cut off temperature was arbitrary since, in an IGCC application, this temperature typifies the lower end of the warm gas range for obtaining the 2-3% thermal efficiency advantage.[3]

## 2. Membrane gas method for separation of co2 from flue gases

### 2.1 Polymeric membrane

By use of polymeric membrane method we can decrease the amount of CO<sub>2</sub> from our atmosphere. Plasticization effects help us to decrease the flux of CO<sub>2</sub>. By increasing the solubility of CO<sub>2</sub> in polymeric membrane and by increasing the CO<sub>2</sub> diffusion through membrane, we can achieve high performance of CO<sub>2</sub> by this method. Solubility can be increased by change in polymer composition by using selective composition. CO<sub>2</sub> diffusion can be increased by increasing free space volume. By insertion of bulk substitution groups we can increase free volume by annealing conditions and improve membrane casting methods [5].

### 2.2 Inorganic membranes

Inorganic membrane is second method to separate CO<sub>2</sub>, generally porous inorganic membrane are used. In porous inorganic membranes, a porous thin top layer is supported on a porous metal or ceramic support. Zeolite, glass, zirconia, titanium, silicon carbide, carbon and alumina membranes are mainly

used as porous inorganic membranes supported on different substrates, such as alumina, alumina, zirconia, zeolite, or porous stainless steel [6].

### 2.3 Hollow fiber membrane

Hollow fiber is the one which is most industrially important membranes for gas separations. For CO<sub>2</sub> separation, Asymmetric Hollow fiber membranes are more favorable and absorption in gas-liquid membrane by low mass-transfer resistance and high permeability. High adsorption efficiencies can be achieved by this process due to much larger surface area required for gas liquid interface than conventional gas absorption processes [7].

Currently, membrane concept has addressed the limitations of membranes in various ways through fabrication of new type of mixed matrix membranes (MMMs) by incorporation of inorganic particles as fillers into polymer matrices. The performance of MMMs depends on textural properties of fillers, molecular sieving effect and membrane-penetrant interactions. The main challenges in the fabrication of MMMs is selection of fillers, which controls the gas separation characteristics of membranes. In this review, the influences of fillers like zeolite, carbon, and metal organic framework in MMMs fabrication and their CO<sub>2</sub> permeability and CO<sub>2</sub>/CH<sub>4</sub> and CO<sub>2</sub>/N<sub>2</sub> selectivity were compiled from recent reports.

Actually, the interest for commercial CO<sub>2</sub> separation and capture can be strongly find by membrane technology, which has been evolved as a competitive technique in energy production and natural gas industries [8]. In all the separation technique pore diameter is very important for different separation technique so there may have the following figure such as :

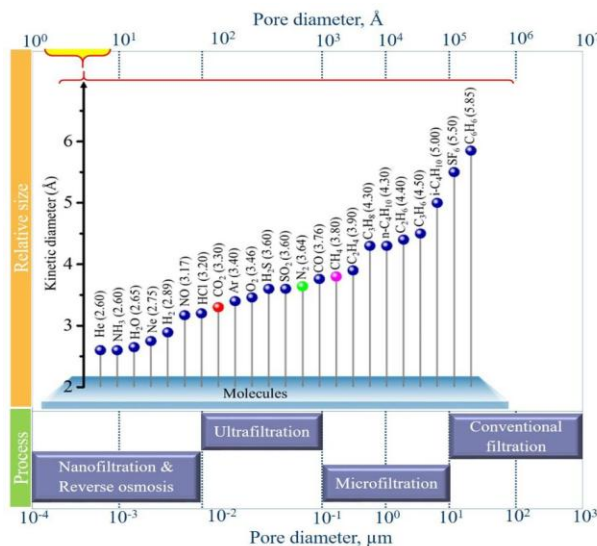


Fig. 3: Cut-offs of pore diameter required for different separation techniques [10]

This figure shows the kinetic diameter of various gas molecules and pore diameter required for their separation. On

The behalf of pore diameter gas separation method may be confined efficiently.

### 2.4 Mixed matrix membranes

Currently, membrane science consist the progress of Nano composite-based membrane for gas separation, which vanishes the task of individual polymeric. And inorganic membrane increases the separation performance. The low surface area, inadequate thermal stability, and chemical properties are the main challenges faced in the development of efficient commercial membranes. In addition to the above-mentioned membrane characteristics, mechanical properties such as crushing, abrasion, and attrition is also important in order to commercialize membrane Technology. Thus to lie on same section some of these aim and to nullify the disadvantages of individual polymeric and inorganic membranes, MMMs or composite membranes are obtained by mixing the inorganic and polymeric phases, which may be linked via van der Waals forces and covalent or hydrogen bonds [11]. Therefore, selective literature has been compiled as a review on the composite membrane, especially focusing on the CO<sub>2</sub> separation by MMMs.

## 3. Carbon Capture And Storage (Ccs)

### 3.1 Pre-combustion capture

Pre combustion capture has a reaction of fuel with air and in some other cases a gas which is mainly composed of carbon monoxide and hydrogen is produced by steam, this produced gas are known as synthesis gas (syngas) or fuel gas. In catalytic reactor produced carbon monoxide is reacted with steam called shift converter, which give CO<sub>2</sub> and more hydrogen gas. After this cryogenic distillation or chemical absorption process used to separate CO<sub>2</sub>, as a result hydrogen-rich fuel produced, which can be used in many applications such as gas turbines, engines, furnaces, and fuel cells [9].

### 3.2 Post-combustion capture

The higher CO<sub>2</sub> concentration and pressure can be achieved in the output stream which is main advantage of post combustion chamber. The main disadvantage of pre-combustion capture is system needs long-term development in a number of enabling technical areas to achieve targeted efficiency towards a hydrogen economy. This disadvantage has limited application approach and it increased investment cost of pre-combustion capture [12].

### 3.3 Oxy-fuel combustion capture

Instead of ambient air nearly pure oxygen is used for combustion in oxy-fuel combustion and as a result, mainly CO<sub>2</sub> and H<sub>2</sub>O are left in the flue gases, which are separated by condensing water. High flame temperature, high CO<sub>2</sub> concentration in output stream and easy separation of exhaust gases are three major advantages of this method. The major disadvantages of oxy-fuel combustion are large electric power requirement to separate oxygen from air and high capital costs [13].

#### 4. Adsorbents

Carbonaceous materials and zeolites are non-reactive adsorbents that help to recover the Carbon dioxide from flue gases. Activated carbons and charcoals (high porous materials) exhibit CO<sub>2</sub> capture capacities ranging from 10 to 15 % by weight. However, the CO<sub>2</sub>/N<sub>2</sub> selectivity is relatively low. Carbon-based systems can be applicable when CO<sub>2</sub> purity is not more than 90 % [14].

##### 4.1 Chemical adsorption

Chemical adsorption is a subclass of adsorption which involves chemical reaction which occurs at the exposed surface. A wide range of metals have been studied including [15]

- (i) hydro talcites and double salts.
- (ii) metal salts from alkali metal compounds: lithium silicate, lithium zirconate to alkaline earth metal compounds (i.e., magnesium oxide and calcium oxide),
- (iii) metal oxides: CaO, MgO

In general, one mole of metal compound can react with one mole of CO<sub>2</sub> with a reversible reaction. The process consists of a series of cycles where metal oxides (such as CaO) at 923K are transformed into metal carbonates form (such as CaCO<sub>3</sub>) at 1123K in a carbonation reactor to regenerate the sorbent and produce a concentrated stream of CO<sub>2</sub> suitable for storage [16].

Considerable attention was paid to calcium oxide (CaO) as it has a high CO<sub>2</sub> adsorption capacity and high raw material availability (e.g., limestone) at a low cost. Lithium salts was recorded a good performance in CO<sub>2</sub> adsorption, but it gained less focus due to its high production cost. Although double salts can be easily regenerated due to low energy requirement, their stability has not been investigated [17].

##### 4.2 Physical adsorption

Activated carbon (AC) has a number of attractive characteristics like as its high Hydrophobicity, low cost, high adsorption capacity, and low energy requirement for re-generation [18]. Activated carbons are insensitive to moisture, inexpensive and easy for

regeneration. These adsorbents have well developed micro and macroscopic structures that are suitable for high CO<sub>2</sub> adsorption capacity at ambient pressure [19].

#### 5. Conclusion

In recent years, post-combustion capture has been the topic of many researches, because it is more flexible and can be easily added to the fossil fuel power plants. Based on above findings, it can be concluded that flue gases properties (mainly concentration of CO<sub>2</sub>, temperature and pressure) are the most effective factors for selection of suitable process for CO<sub>2</sub> separation. Since flue gases have high temperature (about 373 K), low pressure, and low CO<sub>2</sub> concentration (1 atm and 10–15% mol), bulk absorption and adsorption processes may be the best suitable process for CO<sub>2</sub> separation from these streams. Due to simplicity of absorption process, this process has been applied in industrial plants, although many researchers have been focused on preparation of adsorbents with high selectivity and capacity, in recent years. For industrial application, more studies about adsorbents are necessary. Cryogenic distillation and membrane processes are efficient for gas streams with high CO<sub>2</sub> concentration. Therefore, these processes are economically efficient for pre-combustion capture. In recent years, different studies have been performed to optimize cryogenic cycles and preparation of suitable membrane for CO<sub>2</sub> separation from post-combustion flue gases. By the result of this study, future research direction on the scale-up and industrialization of adsorption (with modified adsorbent), and membrane process for CO<sub>2</sub> separation is suggested. Therefore more studies must be focused on modeling and simulation of these processes (membrane and adsorption), although research for finding new adsorbent, suitable membrane (with mixed or modified present membrane) and blending amine solvents can reduce CCS cost. We fabricated mixed matrix membranes demonstrating the ability to enhance the CO<sub>2</sub> permeability of a neat polymer using an inexpensive silica gel filler particle. From all the above explanation regarding CO<sub>2</sub> separation in IGCC Power plant throws a reviewed knowledge in such a way that the mixed membrane method play an important role in the way to remove CO<sub>2</sub> from flue gases.

#### References

- [1] T. J. Blasing, Recent Greenhouse Gas Concentrations, US Department of Energy, 32 edition, 2012.
- [2] Powell C, Qiao G (2006) Polymeric CO<sub>2</sub>/N<sub>2</sub> gas separation membranes for the capture of carbon dioxide from power plant flue gases. *J Membrane Sci* 279: 1-49.



- [3] Intergovernmental Panel on Climate Change (IPCC) 2007. Climate Change 2007: Mitigation of Climate Change. Summary for Policymakers.
- [4] Henry W. Pennline, David R. Luebke, Carbon Dioxide Capture And Separation Techniques For advanced Power Generation Point Sources, DOE-NETL-IR-2006-202
- [5] Macheras JT (1997) Fluid separation membranes prepared from blends of polyimide polymers. US5635067.
- [6] H. Yang, Z. Xu, M. Fan et al., "Progress in carbon dioxide separation and capture: a review," *Journal of Environmental Sciences*, vol.20,no.1,pp.14–27,2008.
- [7] L. Liu, A. Chakma, and X. Feng, "Preparation of hollow fiber poly(ether block amide)/polysulfone composite membranes for separation of carbon dioxide from nitrogen," *Chemical Engineering Journal*, vol. 105, no. 1-2, pp. 43–51, 2004.
- [8] V. R. Choudhary, S. Mayadevi, and A. P. Singh, "Sorption isotherms of methane, ethane, ethene and carbon dioxide on NaX, NaY and Na-mordenite zeolites," *Journal of the Chemical Society, Faraday Transactions*, vol. 91, no. 17, pp. 2935–2944, 1995.
- [9] T. F. Wall, "Combustion processes for carbon capture," *Proceedings of the Combustion Institute*, vol. 31, pp. 31–47, 2007.
- [10] M. Vinoba, M. Bhagiyalakshmi, Y. Aiqaheem, Recent progress of filters in mixed matrix membrane for CO<sub>2</sub> separation : a review, *Separation and purification technology* (2017)
- [11] H. Siddique, E. Rundquist, Y. Bhole, L.G. Peeva, A.G. Livingston, Mixed matrix membranes for organic solvent nanofiltration, *J. Membr. Sci.* 452 (2014) 354-366.
- [12] M. Rezakazemi, A. E. Amooghin, M.M. Montazer-Rahmati, A.F. Ismail, T. Matsuura, State-of-the-art membrane based CO<sub>2</sub> separation using mixed matrix membranes(MMMs): An overview on current status and future directions, *Prog. Polym. Sci.* 39(2014) 817-861.
- [13] M. Glazer, C. Bertrand, L. Fryda, and W. de Jong, "EOSLT consortium biomass co-firing, WP4—biomass co-firing in oxyfuel combustion Part II: ash deposition modelling of coal and biomass blends under air and oxygen combustion conditions," *Tech. Rep.*, Energy research Center of the Netherland, 2010.
- [14] M. Radosz, X. Hu, K. Krutkramelis, Y. Shen, Flue-gas carbon capture on carbonaceous sorbents: towards a low-cost multifunctional carbon filter for "green" energy producers, *Ind. Eng. Chem. Res.*, 47, 2008, 3783- 3794.
- [15] M. Martunus, Z. Helwani, A. D. Wiheeb, J. Kim, and M. R. Othman, "Improved carbon dioxide capture using metal reinforced hydrotalcite under wet conditions," *International Journal of Greenhouse Gas Control*, vol. 7, pp. 127–136, 2012.
- [16] B. Dou, Y. Song, Y. Liu, and C. Feng, "High temperature CO<sub>2</sub> capture using calcium oxide sorbent in a fixed-bed reactor," *Journal of Hazardous Materials*, vol. 183, no. 1–3, pp. 759–765, 2010.
- [17] Z. H. Lee, K. T. Lee, S. Bhatia, and A. R. Mohamed, "Postcombustion carbon dioxide capture: evolution towards utilization of nanomaterials," *Renewable and Sustainable Energy Reviews*, vol. 16, no. 5, pp. 2599–2609, 2012.
- [18] T. C. Drage, J. M. Blackman, C. Pevida, and C. E. Snape, "Evaluation of activated carbon adsorbents for CO<sub>2</sub> capture in gasification," *Energy and Fuels*, vol. 23, no. 5, pp. 2790–2796, 2009.
- [19] C. Pevida, M. G. Plaza, B. Arias, J. Feroso, F. Rubiera, and J. J. Pis, "Surface modification of activated carbons for CO<sub>2</sub> capture," *Applied Surface Science*, vol. 254, no. 22, pp. 7165–7172, 2008.