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Computation Modelling of a Carbon Capturing Membrane in the power plant Using ANSYS

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Abstract:

The term "thermal power plant" refers to a facility where coal is gasified before the energy is used to power both gas and steam turbines. Capturing the carbon dioxide that is released from sources like power plants is of utmost importance because as the industrial revolution advances, more and more carbon dioxide is being added to the environment every single day. This is causing the world to face the biggest environmental hazards we have ever faced, with global warming being the leading consequence. This study paper's major goal is to propose a novel technique for removing carbon dioxide emissions from coal-fired power plants. Additionally, the modelling and design of a carbon collecting membrane employed in TPP. The simulations have been run in the workbench ANSYS Fluent to explain the mechanism of the carbon capture through membrane from Thermal power plant.text.

Keywords **—power plant, carbon, membrane, ANSYS**

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I. INTRODUCTION

The primary issue for the environment is climate change. The earth's temperature is steadily increasing like a warning. The global temperature will rise by 1.4–5.8 degrees Celsius by 2100 if initiatives to combat climate change are not implemented. According the report from the Intergovernmental Panel on Climate Change (IPCC), people are the primary cause of climate change, aside from CO_2. The earth's climate system is undoubtedly heated. The increase in atmospheric CO_2 is primarily attributable to the industrial sector. The globe is currently dealing with a number of issues and difficulties as a result of the emission of fuel gases from businesses and power plants, which mostly consists of CO_2 and NO_x.The primary contributors to global warming are flue gases, which are produced when fossil fuels and coal are used in factories, homes, farms, and transportation. Flue gases, commonly referred to as greenhouse gases, include CO_2, NOx, CH_4, ozone, and chlorofluorocarbon (GHG). The most important greenhouse gas for global warming is thought to be carbon dioxide. Since there is a significant amount of CO_2 in the atmosphere, it might be regarded as the most important GHG. As the earth's temperature rises and glaciers and ice caps melt, sea levels rise, and other severe atmospheric issues are brought about, such as changes in the length and timing of seasons and the occurrence of extreme weather events like flooding, draughts, and wildfires.At the starting of the 19th century,the level of CO_2 in the atmosphere was around 280 ppm but it is today over 400 ppm. With 409.8 ppm, the average atmospheric CO_2 reached a new highest record. The level of CO_2 is now higher than it has been for millennia. The need for carbon capture systems is required since the earth's temperature is increasing. The carbon capture technique is seen as offering the best chance to slow the increase in CO_2 emissions in the environment. Solar energy, carbon capture and sequestration,laser fusion, among other

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effective and cutting-edge technologies, have all been developed to lessen the amount of CO_2 in the atmosphere. Most experts agree that carbon capture, storage, and utilization (CCSU) is considered as the most significant technology for reducing CO_2 emissions in the industrial sector. Pre-combustion carbon capture, combustion carbon capture (oxy-fuel combustion), and post-combustion carbon capture are three important methods for reducing carbon dioxide emissions from industrial processes.

II. LITERATURE REVIEW

The research in the area of carbon dioxide capture has attracted so much concentration from the researchers. Brief description of the study conducted in the field of carbon capture in recent years and the future trends of this technology are presented in this chapter.

Yang Han et al. in their paper, discuss the evolution of polymeric membranes for carbon dioxide separation as well as the development, design and formation of membrane materials. Comparing membrane separation technology to other CO2 capture separation technologies, it is acknowledged that it is the most promising technology for capturing carbon dioxide from fossil fuels because of its properties like, low operational cost, energy consumption is less, easy to operate, process simplicity etc. It is reviewed that another method is employ to capability of processing of polymers is mixed matrix membrane (MMMS) because of its particular pore size and the geometry of material. There are two types of polymers used which are rubbery polymers and glassy polymers.

Ali Kargari et althe study evaluates the alteration of polymeric membranes with the help of poly (ethylene oxide) and poly (ethylene glycol) for capturing the carbon dioxide. PEO and PEG, sometimes known as Poly (ethylene oxide) and Poly (ethylene glycol), are created when ethylene is oxidized through a reaction with water. Poly (ethylene glycol) is the name given to the substance when its molecular weight is less than 20,000 g/mol, and when its molecular weight is greater than 20,000 g/mol then poly (ethylene oxide) is the name given to the substance. The existence of an oxygen polar group in the structure of the material signified a significant achievement for gas separation. The substance is categorized into three classes, liquid form, semi-solid form, and solid form, based on its molecular weight. PEOs with a lower molecular weight are in a liquid state, whereas those with a greater molecular weight are solids. The molecular weight of PEOs and the material's crystallinity are directly inversely correlated; as molecular weight increases, so does crystallinity. The molecular weight of PEOs affects the glass transition temperature, which ranges from -15 to -95 degrees centigrade.

Varghese et al. reported about the climate change and the effects of climate change, how it can be controlled by different methods. To control climate changes many researchers has specified different technologies one of them is absorption process amine based. Absorption process based on amines is regarded the best alternative method for capturing the carbon dioxide in power plants from acid gases. This technique attracted many researchers interest because of its properties such as demand of energy is less, efficiency of process is high. This research mainly focused on the advancement on the polymeric amine based solid adsorbents and their capability to capture carbon dioxide or performance of the process

Magda karaszova et al. evaluated the membrane technique during post-combustion systemfor carbon capture. The average temperature of global has reached 1˚C by 2017. So the importance of effective technologies for carbon capture and to store it and reuse of captured carbon dioxide is very much. According to the research of last few years the emission of GHG_s should be decrease by 21% in 2020 and 41% upto 2030 if compared to 2005.This industry, which involves the generation ofelectricityand heat, is protected by the European

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Union Emissions Trading System (EU ETS). They reduce their overall GHS output by 43% between 2005 and 2030. The European Union Emission Trading System is regarded as the world's first and biggest system for trading carbon. It also regulates the emissions of greenhouse gases from industry and power plants (Emission Trading System, 2020).Membrane separation is regarded as the best favorable approach because of its characteristics that go beyond those of present methods, such as its frequent low energy usage, cheap operating costs, and ease of operation.

Roussananly et al. According to their study, a coal-fired power station that produced 4.6 Mt of carbon dioxide annually was used as the basis for their numerical model. The two methods of carbon capture, membrane separation and MEA absorption, have been compared by Roussanaly et al. They also discussed the best uses for membrane separation of carbon dioxide in several plants. Roussananly himself specify about 70 materials for membrane among them few materials are capable to challenge MEA absorption. PolyActive^{TM} and Polaris^{TM} appear as the most favorable materials which are commercially present. They discussed about the implementation of membrane separation technology for capturing the carbon dioxide in power plants and the cost of process in which these consist the materialcost, cooling cost and energy consumption cost for process.

Moussa et al. address two major problems of environmental which are hydrogen storage and CO2 capture to control emission of flue gas. Two ACs (Activated carbons) developed by the help of KOH and K2CO3 and chemical reaction of olive stones. CO2 can be absorbed by the prepared activated carbons at atmospheric pressure and 0°C. The research compared the outcomes of KOH and K2CO3 activated carbons for CO2 capture. The result is depending on the carbon pore size under post-combustion condition, the activated carbon K2CO3 presented the highest carbon dioxide capture or highest CO2 recovery. The activated carbons can be developed by the physically or chemically activation with the help of any materials which have high carbon. The benefits of CO2 and H2 absorption through activated carbons are significantly improved by factors including low process cost, material availability, and thermal stability.

III. GEOMETRY SETUP AND MODELLING

3.1 Math metical model

It is mainly depending on the selection of right polymeric membrane material. There are many factors which are important to consider in the gas separation process that are gas composition in the permeate sideandfeed side, high permeability and high selectivity. To create a membrane with high performance for carbon capture process other factors also considered like process ability, cost, mechanical and thermal stability and availability of material. This process worked on the solution-diffusion (SD) model.

By 'Fick's law

The gas flux represents as (J) along a dense polymeric membrane which is directly proportional to the driving force (dc/dx) which is a concentration gradient through the thickness (L) of dense film and the gas Diffusivity (D),

$$J = -D \times (dc/dx) \quad (1)$$

The equation may be integrated while taking the limits into account under steady-state conditions Caf and Cap (concentration of gas 'a' on the feed or permeate side) for C, and x=0 and x=l for x, thereby equation becomes;

$$J_a = D_a \times (C_{af} - C_{ap}) / L \quad (2)$$

According to Henry's law, the concentrations $C_{af}$and C_{ap} of gas 'a' can be displaced by its partial pressure (Pa)

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$$C_a = S_a \times P_a \quad (3)$$

Where S_a is the coefficient for solubility of gas 'a'. By combining the equation (3.3) into the equation (3.2), the gas flux (J) changes into;

$$J_a = D_a \times S_a \left(P_{af} - P_{ap}\right) / L \quad (4)$$

Theterm $D_a \times S_a$ in equation (3.4) refers as the gaspermeability (P).

The product of diffusion co-efficient and solubility may be defined as the gas permeability (P) for the given membrane material of any gas according to the Solution-diffusion (SD) model,

$$P_a = D_a \times S_a \quad (5) \quad P_b = D_b \times S_b \quad (6)$$

Where, D_a refers as the diffusion co-efficient and S_a refers as the solubility selectivity of gas 'a' and similarly D_b and S_b are diffusion co-efficient and solubility respectively for gas 'b'.

Theratio of permeability for two gases represented as the selectivity of a membrane,

$$A_{a/b} = \frac{P_a}{P_b} \quad (7)$$

From equation (3.5) and (3.6),

$$A_{a/b} = \frac{D_a}{D_b} \times \frac{S_a}{S_b} \quad (8)$$

Where $\frac{D_a}{D_b}$ presented as diffusivity selectivity and $\frac{S_a}{S_b}$ as solubility selectivity.

3.2 Geometry of membrane

The computer-aided design-based approach is employed in this study for membrane modeling and design. The design and model of the membrane are simulated using Ansys Fluent. As seen in Figure 1, the first stage is to construct the membrane's geometry. The membrane is made in middle part of the geometry, or in between the inlet and outflow part. Because of its wide surface area and straightforward construction, this design was chosen for its great efficiency. The input segment, membrane zone, and output section make up geometry. The dimension of inlet and outlet section is equal in diameter and length and the dimension of membrane structure is twice the length of inlet and outlet section. Membrane has the large surface area which is best for absorbing the molecules of carbon dioxide in the membrane zone. In this paper, the simulation of the design and structure of the membrane and also the simulation for the membrane material has been shown. The simulation for the polymeric membrane's performance in process of carbon capture has been performed.

TABLE I
GEOMETRY PARAMETERS

S.N.	Parameters	Dimension in meter
1	Inlet length of the pipe (Lin)	1 m
2	Membrane pipe length (Lm)	2 m
3	Inlet length of the pipe (Lout)	1 m
4	Inlet pipe diameter (Din)	0.3 m
5	Membrane pipe diameter (Din)	0.6 m
6	Inlet pipe diameter (Din)	0.3 m

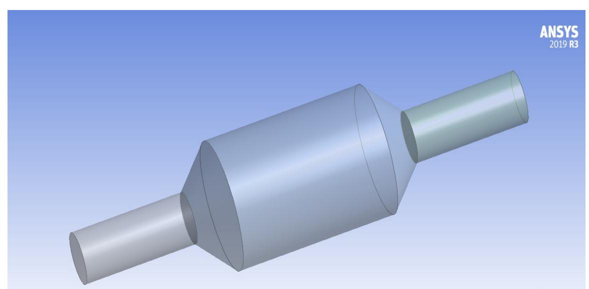

Fig. 1 Membrane's geometry

3.3 Meshing of geometry

After developing the membrane's basic geometry, the next step is meshing. ANSYS fluent (workbench) is used to create design modeling and meshing of geometry. The parameters for meshing operation are same for both conditions. For mesh generation, curvature is used as size function in the meshing operation.

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The meshing has 63586 nodes and 58480 elements in this process.

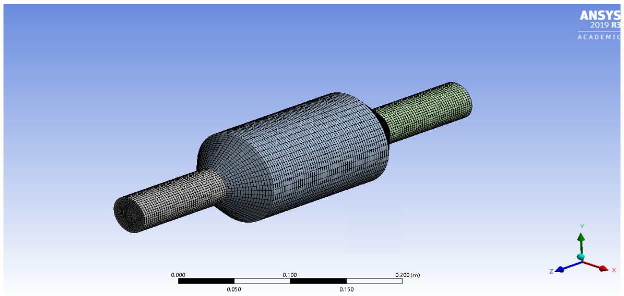

Fig. 2 Mesh of the Membrane

3.4 Technique

After geometry and meshing are successfully finished, setup comes next. This design is simulated using a velocity formulation-absolute, pressure-based and steady model. We employed the standard, viscous-k, and e models in this. CO2 is employed as a substance for fluid. Aluminum is employed as the material for the membrane's entrance and exit sections, while ash-solid graphite, which is made of carbon, is applied for the membrane zone. After the computation was successfully finished, we discovered a pressure difference at the membrane's intake and outflow, and we also used the solution to acquire velocity fluctuated from the inlet to the exit. With the use of this method, additional parameters can be calculated as well, such as mass flow rate.

IV. RESULTS AND DISCUSSIONS

4.1 Contour Pressure profile

The results achieved by the computation defined the value of pressure at the entrance and exit of membrane in fig.3. Following figure makes it clearly visible that the membrane's pressure value is largest at the input part which is 7.549e^{05} Pascal, and lowest at the outflow region which is -4.067e^{05} Pascal. As a result, the pressure profile showed that membrane zone's carbon dioxide has a required pressure decrease due to the membrane's form and size. The pressure inside the membrane zone is continuously dropping.

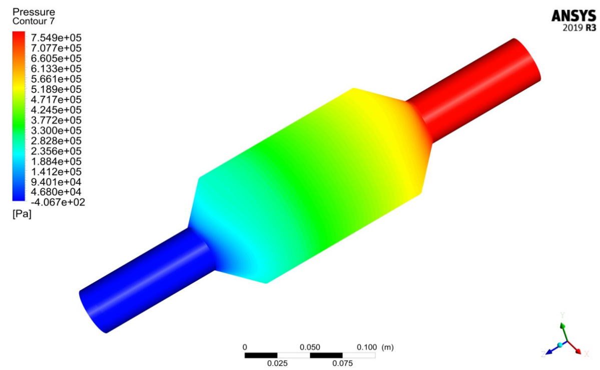

Fig. 3 Pressure variation contour

TABLE III
VARIATION OF THE PRESSURE IN THE MEMBRANE DURING CARBON CAPTURE

Location (m)	Pressure
0	621942.7
0.5	586676.53
0.1	465956.99
0.15	356366.12
0.20	311883.71
0.25	271078.60
0.30	176441.16
0.35	100374.53
0.40	48394.67

4.2 Contour Velocity profile

The velocity profile is shown in fig. 4. The velocity is constantly minimizing inside of membrane zone as evidenced by the velocity profile, which shows the velocity value inside of membrane zone is at its lowest. This is the indication of that the molecules of carbon dioxide absorbed by membrane and that this has an impact on the speed at which molecules move through the membrane. According to the graph, the velocity value is 4.246e^{01} m/s near the outflow and 2.654e^{00} m/s inside the membrane zone (fig.4).

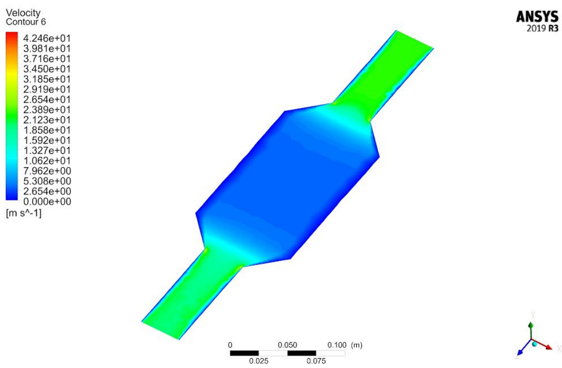

Fig.4. Velocity variation contour

TABLE IIIII
VARIATION OF THE VELOCITY IN THE MEMBRANE DURING CARBON CAPTURE

Location (m)	Velocity
0	30
0.5	28.26
0.1	22.40
0.15	11.60
0.20	8.14
0.25	11.40
0.30	8.35
0.35	28.46
0.40	35.23

4.3 *Variation of mass flow rate*

The graph distinctively shows that under both conditions, the mass flow rateis constantly decreasing in the membrane zone from the inside of the membrane's intake to its exit. The mass flow rate is constant in the input section until the membrane zone starts, and there is a required drop in the MFR inside of membrane zone, which indicates that the MFR is reduced just after the membrane zone and hencethe carbon dioxide particles has absorbed by membrane inside it. According to fig. 8, the mass flow rate drops w.r.t the iterations and exhibits fluctuation at the beginning of the process before developing a linear graph and uniformly declining through time.The result from the study cases shows thatMFR has minimum value as well as it is required. The membrane is therefore particularly effective in capturing carbon.

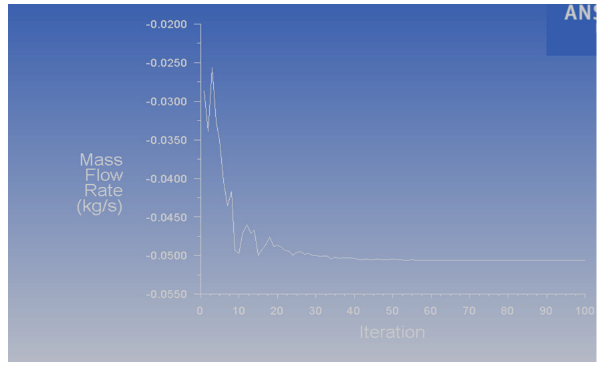

Fig.5. mass flow rate v/s iteration

V. CONCLUSIONS

The effectiveness of the membrane in this study's post-combustion separation procedure for separating $CO_2$from a mixture of the gases has been examined. The goal of this study is to demonstrate the effectiveness of membranes in the separation of CO_2. To that end, a model or membrane design was constructed using ANSYS Workbench, and its effectiveness in achieving the necessary working conditions was confirmed. Additionally, ANSYS may be used to simulate how a membrane can separate $CO_2$from other gases, not just in power plants but also in a wide range of industries to capture carbon dioxide emissions. In diverse industrial uses, the membrane's material will change, but the design will stay the same. Polymeric membrane was used as the simulation's medium. The most effective method to stop climate changes is to use a membrane as a mechanism to absorb carbon dioxide emissions. These studies' results demonstrate that pressure and velocity are decreasing inside the membrane zone, indicating that the membrane had an impact on molecular velocity.

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