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# Modeling & Simulation of Fluid Flow Behaviour during CO2 Sequestration in Coal Structure using Comsol Multiphysics

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***Abstract— In the present world, Global Warming has been one of the biggest problems regarding environmental aspect and CO2 is held responsible for that. It is an inevitable necessity to mitigate the concentration of CO2 in the atmosphere. CO2 sequestration is one of the best methods to reduce its concentration by trapping it beneath the earth in different geological conditions. The unmined coal seams and thin bands of coal provide a potential storage for CO2 with suitable geological environment. These days it has become necessary to study the relationship between coal structure and flow of fluids inside. In this paper, an effort has been made to study the behaviour of fluids i.e. CO2and methane inside of coal and the analysis has been carried out to study their velocity and pressure variations using COMSOL Multiphysics. Coal contains both cleat and porous structure. Cleats are the natural fractures in coal and pores are the important factors for migration of fluid inside coal. One model is developed to understand the fluid flow behaviour in cleat structure of coal.***

***Index Terms— CO2 sequestration, cleat structure, Darcy's law, two-phase flow***

## I. INTRODUCTION

$CO_2$ comprises nearly 0.04% or 400 ppm of the atmosphere. It has exceeded its concentration of past 80000 years. It is a potent greenhouse gas which is responsible for global warming through radiative forcing. This gas is an integral part for the existence of life on earth and it is a vital part of carbon cycle and biogeochemical cycle in which exchange of carbon takes place between the earth's oceans, soil and biosphere. Plants extract carbon from the atmosphere in the form of $CO_2$ in photosynthesis process and use it as a source of carbon compound for their growth. So, this plays an important role in the biosphere of earth. It is one of the major factors for global warming and its concentration has increased markedly from 280ppm to 400ppm as of 2015. Deforestation and burning of fossil fuels are the major anthropogenic sources behind this. The rising rate is 2ppm per year currently and it's getting accelerated. Atmospheric carbon dioxide and greenhouse effect In greenhouse effect, the thermal radiations of sunlight get absorbed by atmospheric gases which increase their temperature. The heated gases again emit radiations in all directions towards the surface, thereby heating the surface also. Major contributing gases to the greenhouse effect are Water vapor, 36-70%, Carbon dioxide, 9-26%, Methane, 4-9%, Ozone, 3-7%

Carbon dioxide sequestration is a process of minimizing $CO_2$ from the atmosphere or from large scale stationary sources like industries and power plants and putting them into long term storage. This process is significantly used for the mitigation of the level of concentration of carbon occurring in the atmosphere in the form of $CO_2$ and for reducing the release of the gas to atmosphere from various sources. There are various methods which have been scientifically developed for long term storage of $CO_2$.Coal beds are one of the most appropriate places for storage of carbon dioxide. There are a lot of coal beds which are either unmineable due to greater depth or because of very small thickness. At greater depth, conventional mining is not possible in coal seams so they are implemented as the potential storage places for storage of $CO_2$. $CO_2$ can be adsorbed in the coal surface or it may be trapped inside the pore structure of the coal seam and locked up permanently. There is an alternative to $CO_2$ only storage in injection of flue gas, a mixture of $CO_2$ and nitrogen in to coal beds.

There is a possibility of huge cash flow by $CO_2$ sequestration in coal beds by carrying out enhanced coal bed methane process. In this process, $CO_2$ is injected in methane rich coal beds. The disposal of $CO_2$ in these methane rich coal beds increases the drive pressure and the coal bed methane recovery rate. So the gas injection process enables more methane extraction at the same time sequestering $CO_2$.

Both the processes of fracturing of coal and swelling have opposite impacts on the system. The best solution for appropriate rate of $CO_2$ injection is to maintain the near well-gas pressure in the cleat system which will exceed the hydraulic fracturing pressure. But if there is a necessity of repeated hydraulic fracturing for maintaining connectivity between the well bore and the permeable areas of the coal seam, this may result in over or under burden connectivity between the well bore and the permeable areas of coal seam $CO_2$ leakage. In order to ensure the behaviour of fluid flow inside the coal structure, many detailed simulations of gas-coal interaction need to be performed. Such simulations should take into account geological properties such as density, Porosity, permeability and Poisson's ratio etc.

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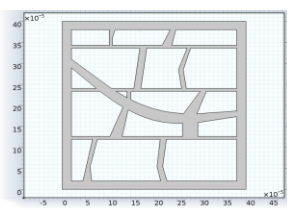
The main objective of this modeling is: To investigate the fluid flow behaviour in coal structure with cleats.

## II. TO INVESTIGATE THE FLUID FLOW BEHAVIOUR IN COAL STRUCTURE WITH CLEATS

The concept that provides the theory behind fluid flow in the subsurface is called Darcy's law. Darcy's law comprises various equations those define the ability of a fluid to flow through a porous media such as rock. This law states that the amount of fluid flow between two points is directly related to the difference in pressure between the points, the distance between the points, and the interconnectivity of flow pathways in the rock between the points. This interconnectivity within the flow pathway is called permeability. Here pressure indicates the excess of local pressure over the normal hydrostatic fluid pressure which increases with depth like in a standing column of water due to gravity. The flow impedance ted during fluid flow is referred to as permeability. Darcy's law gives a simple proportional relationship between the instantaneous discharge rate through a porous medium and the pressure drop over a given distance. The two-phase flow of Darcy law is often referred to as fractional flow formulation. The background for the two-phase flow equations are the general mass balance equations. This approach treats the two-phase flow problem as a total fluid flow of a single mixed fluid, and then describes the individual phases as fractions of the total flow.

## III. Fluid Flow behavior in cleat structure of coal

1. **Geometry:** This is a rectangular 2-Dimensional layer representing a cleat system of dimension 400 µm * 400 µm. The primary zone of interest is the rectangular region with lower left corner at (0, 0) µm and lower right coordinate at (400, 0) µm. The cleat structure of above specification has been developed in AUTOCAD and imported as a dxf file to COMSOL Multiphysics in Fig 1.



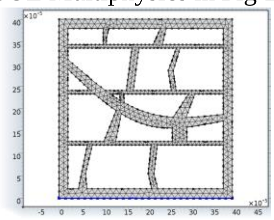
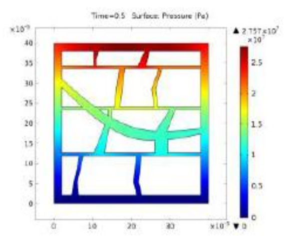


**Fig 1. Geometry of cleat structure Fig 2.Meshing in cleat structure**

2. **Meshing:** iner meshing is done under physics-conrolled condition in Fig.2

3. **Pressure profile:** After the simulation, it has been found that when the fluid moves with in the cleats then the variation of pressure takes place as per the cleat structure. As the fluid moves away from the inlet the pressure gradually decreases in value and the value of pressure at different sections of the cleat is shown by different colors as depicted in the figure. The highest pressure is found to be around 27.5 MPa around the inlet area which is highlighted by dark red color in the figure. In the middle portion of the cleat structure the value of pressure becomes average and the value is found to be around 15 MPa which is shown by yellow and somewhat green color and towards the outlet the pressure decreases to zero as indicated by the dark blue color in the Fig 3.



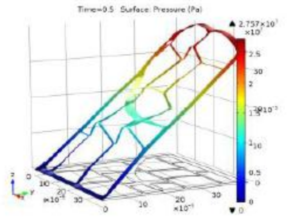


Fig 3.Pressure profile for cleat structure pressure Fig 4. Height expression for Profile of cleat structure

This Fig4 shows height expression and pressure contour. Pressure contour shows variation of gas pressure in coal matrix. Different color line shows different values of pressure in whole coal matrix. These all lines form pressure profile of whole coal matrix.

## IV. Pressure vs X-axis at the "Inlet" boundary

From this graph, it is clear that the pressure at the inlet boundary increases first and then gradually decreases. There are two peaks appearing in the graph one between the coordinates (150, 0) and (200, 0) µm and another peak between the coordinates (250, 0) and (300, 0) µm. This is because of presence of one narrow cleat pathway between the coordinate (150, 0) and (200, 0) µm and another one between the coordinates (250, 0) and (300, 0) µm in the geometry itself. Near these narrow cleats, the inlet the pressure is becoming very high which attains a peak value of 27.5 MPa and 27 MPa respectively. Beyond that zone the pressure gradually decreases to a value of around 24 MPa in Fig 5.

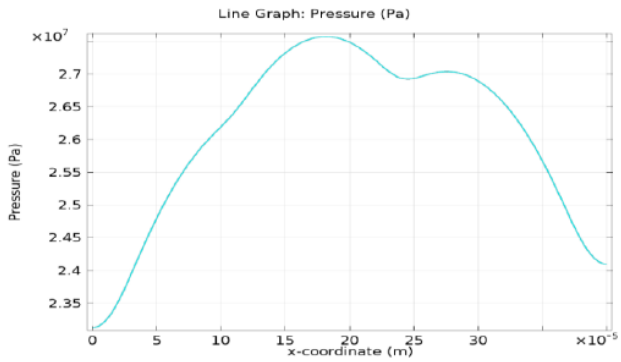



**Fig 5. Plot between Pressure vs X-axis at the "Inlet" boundary**

## V. Velocity Profile

After simulation by COMSOL, it has been found that the velocity varies considerably throughout the whole cleat structure as shown in the figure. The velocity varies from 0-60 m/sec throughout the cleat as per the width of passage for the flow of fluid. As per the equation of continuity of fluid flow,

$$A*V = \text{Constant}$$

Where, A is area and V is velocity respectively.



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As per this law area of passage is inversely proportional to velocity of fluid flow throughout the structure. Where the area of the passage decreases the velocity increases. Hence, the velocity magnitude is very high in the narrowest portions and sharp edges of the cleats structure which is of the order of 60 m/s. and, the velocity is nearly zero in the very wide pathways of fluid flow. On an average the velocity is around 30-40 m/s in the pathways of moderate width. The highest velocity is indicated by red color and the least is shown by blue color in the Fig 6.

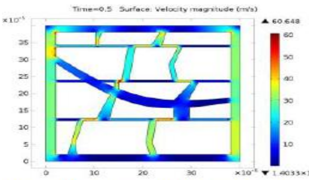

Fig 6.Velocity profile for cleat structure velocity

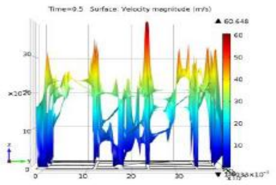

Fig 7. Height expression for profile of cleat structure

This Fig 7 shows the velocity height profile in the cleat structure. Here, the velocity is shown as a projection up on the cleat structure and here we can get the velocity profile quite accurately. The highest velocity is shown by the sharp tip that is shown by the red color in the profile which is around 60.648 m/s in value.

## VI. Velocity vs X-axis at "Inlet" boundary:

The velocity varies along the inlet boundary according to the narrow pathways present near it. The velocity increases from 0 to 25 m/sec between the coordinates (0, 0) and (50, 0) µm because of the presence of sharp corners and narrow pathways within this region. After that it decreases as the flow region is wider and again getting peak of 14 m/sec because of presence of another corner between the coordinates (100,0) and (150,0) µm. Again the velocity decreases due to wider path then increases between (200, 0) and (250, 0) µm and attains a value of around 10 m/sec and then continuously goes on increasing up to 22 m/sec within (350, 0) and (400, 0) µm due to presence of very sharp corner in the region in Fig 8.

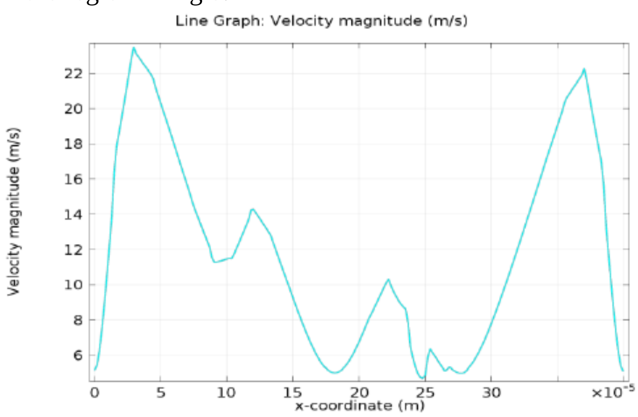


Fig 8.Plot between Velocity vs X-axis at "Inlet" boundary

## VII. Velocity vs X-axis at "Outlet" boundary

This graph shows the variation of velocity of fluid along the outlet boundary and there are three high peaks of velocity of around 22 m/sec initially at the (0, 0) µm and another peak in between (20, 0) and (25, 0) µm of around 10 m/sec and the last peak velocity of around 26 m/sec can be seen at finishing corner of boundary at (40, 0) µm. These peaks are generated because of the presence of sharp corners in Fig 9.

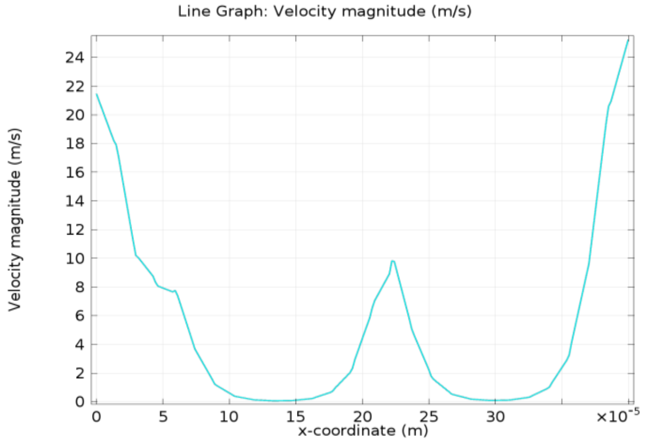


Fig 9.Plot between Velocity vs X-axis at "Outlet" boundary

## VIII. CONCLUSION

From the modeling & simulation we have got the following conclusions:

1. In both cleat and porous structure of coal the fluid moves from high pressure to low pressure zone as per Darcy law.
2. Maximum pressure is developed near the injection boundary and the pressure gradually decreases as we move away from it.
3. In both pore and cleat structure the velocity gradually decreases as we move away from the injection boundary.
4 cleats so the maximum velocity obtained.
5. The value of pressure and velocity is found to be high near the cleats and microspores.

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