Simulation of Fluid Flow Behavior during Co2 Sequestration using COMSOL Multiphysics in Coal Bed

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Abstract— Coal beds are an extremely complicated porous medium with characteristics of heterogeneity, dual porosity and stress sensitivity. In the past decades great achievements have been made to the simulation models of pressure depletion coal bed methane (CBM) recovery process and CO2 sequestration and enhanced coal bed methane (ECBM) recovery process. Due to the assumptions and over simplifications analytical models have limitations or problems in application. In this work, an effort has been made to study the behaviour of fluids i.e. CO2 and 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. Two separate models are developed to understand the fluid flow behaviour in both cleat and porous structure of coal.

Key words: COMSOL Multiphysics, Coal Matrix and Fracture CO_2 Sequestration, Cleat Structure, Darcy's Law, Two-Phase Flow

I. INTRODUCTION

A great deal of research has been conducted and CO_2 sequestration in deep coal seams has been identified as one of the potential ways to reduce CO_2 emission. In addition to the fact that this process can be used to reduce the atmospheric CO_2 level, it may also be used to produce large amount of methane which is a valuable source of clean energy. This is due to the fact that the coal mass shows a higher propensity to adsorb CO_2 rather than CH_4 due to the chemical composition of coal. Therefore, while the CO_2 introduced during the sequestration process is being adsorbed into the coal mass, the CH_4 in the coal mass is displaced by the CO_2 and starts to desorb.

The gas transport within large scale fractures and cleats is driven by pressure gradients and described using Darcy law; while within small scale pore structures in matrix blocks, transport is diffusion dominated. Several kinds of diffusion mechanisms may be present, subject to in-situ pressure conditions and pore sizes (Saulsberry et al. 1996; Shi). For these diffusion processes, the concentration gradient is the primary driving force (Lu and Connell, 2005).To deal with the transport problem of two greatly different spatial scales, dual-porosity models have been developed following the concept proposed by (Barenblatt et al. 1960) and (Warren and Root 1963). The Warren-Root model (Warren and Root, 1963) is a popular approach and most commonly used in a wide variety of commercial reservoir simulation codes. Also in case of coal, there is a strong interplay between adsorption and diffusion. The adsorption processes play a major role since CH_4 is primarily present in an adsorbed phase within coal matrix. Significant gas storage (approximately 95-98%) in the coal seams, through the mechanism of physical adsorption, occurs in coal matrix (Clarkson and Bustin, 1999; Shi and Durucan, 2003).Gas adsorption takes place primarily in the micro pores of the coal matrix. Thus, a detailed modeling of gas transport in the matrix blocks is important for accurate prediction of ECBM recovery. Keeping this fact in mind, in the ensuing modeling task a significant amount of work has been invested to model the complicated gas transport occurring in the pores within the matrix blocks. Once the gas transport within the matrix pores is modeled and verified, we go ahead and model the matrix fracture transfer functions. The matrix-fracture transfer functions couple the diffusive gas transport within the matrix blocks with the bulk flow in cleats and fractures.

II. GAS TRANSPORT MECHANISMS IN COAL RESERVOIRS

In order to produce gas from coal reservoirs, the flow of methane through coal seams experiences three-stage process which are: (a) gas flows from the natural fractures, (b) gas desorbs from the cleat surfaces and, (c) gas diffuses through the coal matrix to the cleats (GRI, 1996).

The majority amount methane is stored in coal basically by adsorption in the matrix. However, as pressure in the coal is lowered, the main fluid that flows in the cleat system is water and small quantities of free gas and some dissolved gas in the water. After the coal is dewatering, the methane is released (desorption stages-process) from the surface of the coal. Desorption is the process by which methane molecules detach from the micro pore surfaces of the coal matrix and enter the cleat system where they exists as free gas (GRI, 1996).

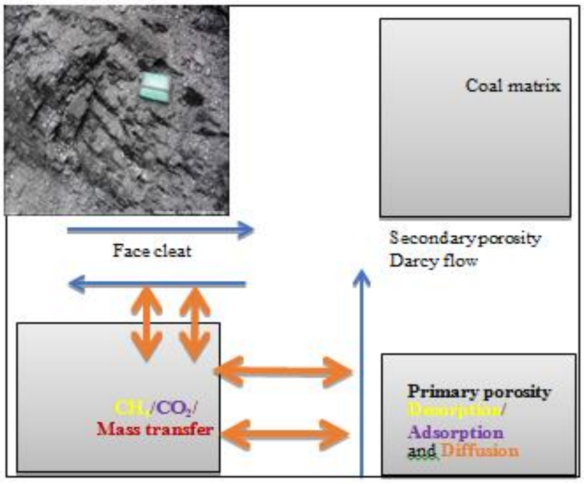

Fig. 1: Schematic view of a coal bed dual porosity system.

After desorbing from the coal surface, the methane flow in the matrix starts moving to the cleat system by different gas concentration gradients in both zones (diffusion). In other words, progressively the cleat system experiments low methane concentration that activates the gas adsorbed in the matrix to move from the higher gas concentration to the lower one. Diffusion is a process in which flow occurs via random molecular motion from an area of high concentration to an area of lower concentration (GRI, 1996).

III. RESULT OF SIMULATING CLEAT STRUCTURE AND POROUS STRUCTURE OF COAL

A. 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 figure.

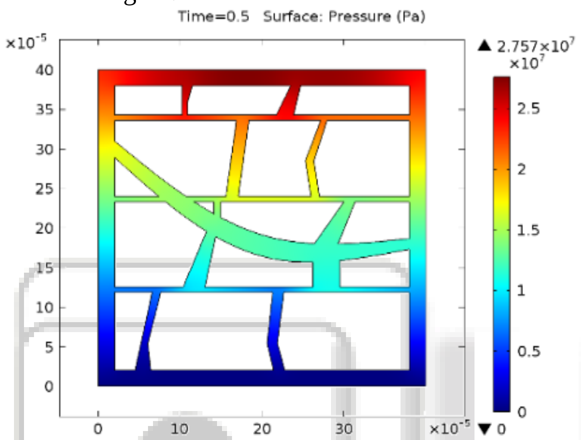

Fig. 2: Pressure profile of the cleat structure (coal)

1) 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.

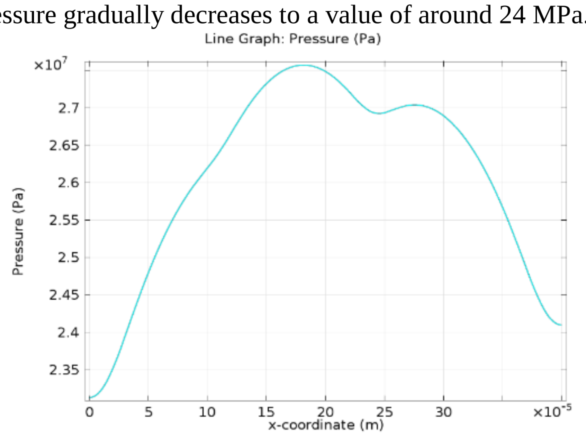

Fig. 3: Pressure vs X-axis at the "Inlet" boundary of the cleat structure (coal)

B. 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,

$$A*V = Constant$$

Where, A is area and V is velocity respectively.

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 figure.

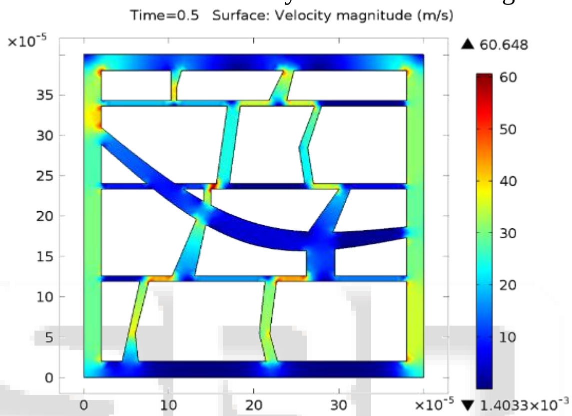

Fig. 4: Velocity profile of the cleat structure (coal)

1) 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.

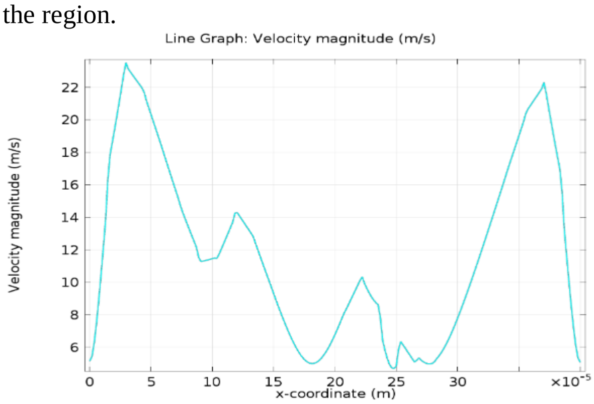

Fig. 5: Velocity vs X-axis at "Inlet" boundary of the cleat structure (coal)

2) 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.

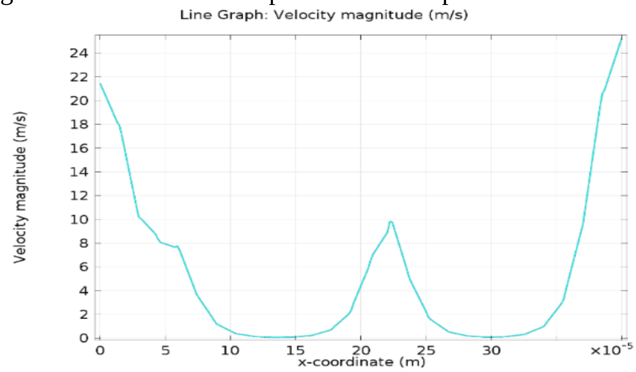

Fig. 6: Velocity vs X-axis at "Outlet" boundary of the cleat structure (coal)

C. Pressure Profile:

After the simulation, it has been found that when the fluid moves with in the porous medium, then the variation of pressure takes place as per the location and size of the pores. As the fluid moves away from the inlet, the pressure gradually decreases in value and the value of pressure at different sections of the porous medium is shown by different colors as depicted in the figure.

The highest pressure is found to be around 14MPa around the inlet area which is highlighted by dark red color in the figure. In the middle portion of the porous structure, the value of pressure becomes average and the value is found to be around 6-8 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 figure. Hence, the pressure varies from around 13 MPa at the inlet boundary up to nearly zero MPa at the outlet boundary.

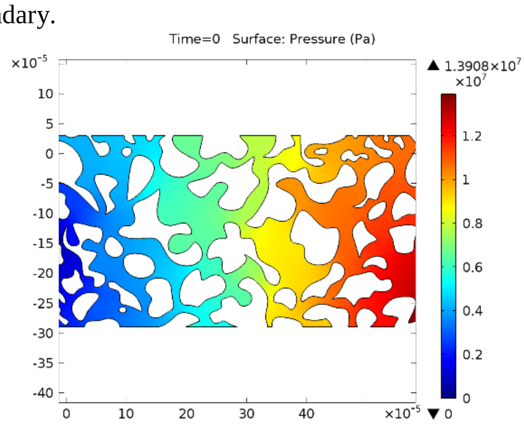

Fig. 7: Pressure profile of porous structure of coal

1) Pressure vs Y-axis at "Inlet" boundary:

The inlet boundary is taken in between the coordinates (500,-280) µm and (500,-170) µm. and the graphical analysis shows that the value of pressure decreases from 13.8 Mpa to 12.9 Mpa at a uniform rate throughout the inlet region. The variation of pressure is due to the presence of nearby pores.

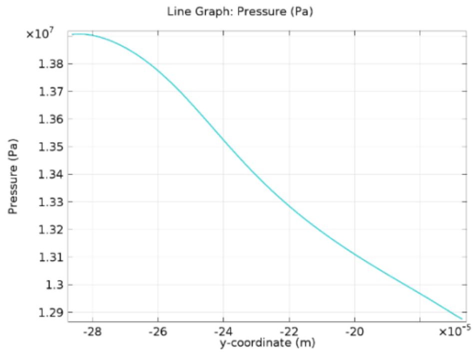

Fig. 8: Pressure vs Y-axis at "Inlet" boundary of porous structure of coal

D. Velocity Profile:

After simulation by COMSOL, it has been found that the velocity varies considerably throughout the whole porous medium as shown in the figure. The velocity varies from 0-90 m/sec throughout the porous medium as per the size of the pores for the flow of fluid.

As per the equation of continuity of fluid flow, 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 very small pores or at intersection of these micro pores within the structure, which is of the order of 90 m/s. and, the velocity is nearly zero in the macro pores or in the wide portions of the porous structure during the fluid flow. On an average the velocity is around 20-30 m/s in the pathways of moderate width. The highest velocity is indicated by red color and the least is shown by very dark blue color in the figure. The highest velocity is found in a particular point in this simulation which is off the order of around 90 m/s and this is shown by zooming in that portion in the figure shown below.

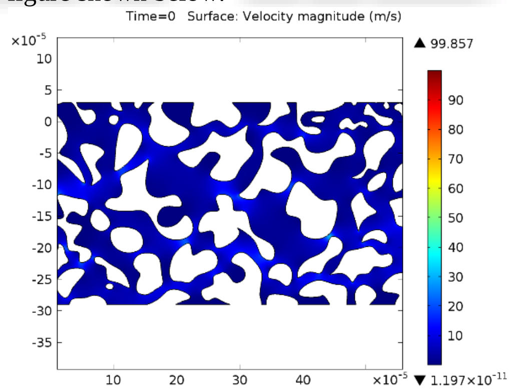

Fig. 9: Velocity profile of porous structure of coal

1) Velocity vs Y-axis at "Inlet" boundary:

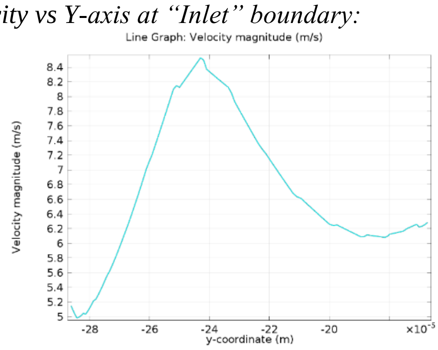

Fig. 10: Velocity vs Y-axis at "Inlet" boundary of porous structure of coal

The initial velocity was give to be of 5 m/sec and after the simulation the graphs shows the variation from 5 to 8.4 m/sec in velocity. And, there is a peak of around 8.4 m/sec corresponding to the Y-axis between (-260 to -240) µm because of a presence of narrow porous media. Hence, the velocity risen up due to the confined porous space.

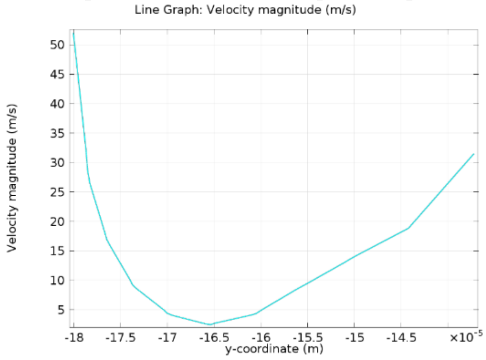

Fig. 11: Velocity vs Y-axis at "Outlet" boundary of porous structure of coal

2) Velocity vs Y-axis at "Outlet" boundary:

The velocity at the outlet boundary decreases first and then increases. The decrease in velocity is due to the open space along the boundary where the fluid gets enough space to move around and the velocity decreases whereas, at the end points of boundary, where fluid doesn't get much space for movement, the velocity goes on increasing.

IV. CONCLUSION

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

In both cleat and porous structure of coal the fluid moves from high pressure to low pressure zone as per Darcy law. Maximum pressure is developed near the injection boundary and the pressure gradually decreases as we move away from it.In both pore and cleat structure the velocity gradually decreases as we move away from the injection boundary. In porous structure the size of pores are extremely small as compared to cleats so the maximum velocity obtained in pore structure is greater than the cleat structure. The value of pressure and velocity is found to be high near the cleats and micro pores.

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