International Journal of Emerging Engineering Research and Technology
Volume 3, Issue 1, January 2015, PP 79-85
ISSN 2349-4395 (Print) & ISSN 2349-4409 (Online)

Development of A 2d Model to Study the Co_2 Sequestration in Coal Seams

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Abstract: *With the World' expanding use of fossil fuel and implementation of advanced industrialization techniques; contribute emissions of greenhouse gases into the atmosphere. CO_2 is the main component in greenhouse gas As per United States Department of Energy's Carbon Dioxide Information Analysis Center (CDIAC), the total amount of CO_2 emission in the world is around 3010 thousand tons and out of this China, USA, European Union and India 60% of the world total (CDIAC, 2012). CO_2 not only generates heat globally, but also makes the planet gradually unsuitable for the sustenance of human beings. It is therefore essential to limit the amount of CO_2 in the atmosphere. Various CO_2 sequestration options have been proposed, a numerical simulation model was developed to simulate flow profiles and fluid flow in COMSOL Multiphysics. The COMSOL Multiphysics model closely predicts the gas flow through the porous coal matrix sample for the range of confining and gas injection pressures studied in low gas flow rates. COMSOL Multiphysics model uses two phase Darcy's law and heat transfer in porous media for flow simulations.*

Keywords: *COMSOL Multiphysics, coal matrix andfracture, numerical model, flow behavior,Darcy's law*

1. Introduction

The atmospheric CO_2 concentration can be controlled either by reducing its production and release into the atmosphere, or by sequestrating the CO_2. Since, it is not possible to reducing the production of CO_2, the sequestration of CO_2 is one of the ideal alternatives for reducing the amount of CO_2 in environment. Various CO_2 sequestration options have been proposed, including placement in the deep oceans; placement in geologic formations (deep saline aquifers, abandoned oil or gas reservoirs, and unmineable coal seams). These options are under investigation to determine their feasibility in terms of their storage capacity, safety, and costs.

CO_2 sequestration in deep unmineable coal seams is one of the best alternatives for sequestrating in geological media. The attractiveness of Coal seam sequestration of CO_2 is attractive due to two major reasons: (a) in some coal seam, the CO_2 can be stored in an adsorbed state that is expected to be stable for geologically significant periods, and (b) the injection of CO_2 can enhance the production of the coalbed methane (CBM).

A schematic diagram the coal seam sequestration of CO_2 is presented in Figure 1. Coal is a naturally fractured porous solid with a dual porosity consisting of both micropores and macropores (Kolesar et al, 1990). The microporosity of coal is contained within the macromolecular network of the coal matrix. The macroporosity of a coal seam consists of the naturally occurring fractures called cleats (Meyers, 1982). Coals also contain a range of microstructures of various shapes and sizes between the micropores and the cleats (Gamson et al, 1993). The storage of gas is dominated by adsorption within micropores; whereas, the cleat system provides the medium for mass transfer through the formation (Shi and Durucan 2008).

The primary goal before performing CO_2 sequestration is to understand the behavior of CO_2 when stored in geological formations. Also how CO_2 moves within the geological formation, and what physical changes occur in the formation when CO_2 is injected. These questions can be answered by an effective modeling of the sequestration process. It is essential for the understanding of the complex interactions occurring during the CO_2 storage and for predicting the economic viability of the sequestration.

The sequestration of CO_2 in coal bed has focused mainly on two areas: the transport in the coal seam and the storage within the coal matrix. The transport in the coal seam usually includes the flow of CO_2

through the naturally fractured porous network i.e. cleats, diffusion into the organic coal matrix, and storage within the micropores in an adsorbed state. Different parameters like properties of coal (rank, type) (Laxminarayana and Crosdale 1990), depth of coal (Peter et al. 1998), fractures and structure of coal (Clarkson and Bustin 1999; Gamson et al. 1993), porosity and permeability of coal and surrounding rocks (Lin et al. 2007; Ross 2007), temperature of coal beds (Perk et al 2011), swelling and shrinkage properties of coal (Perk et al 2011; Zhongwei et al. 2011), and adsorption and desorption property (Dutta 2009; Fathi and Akkutlu 2008) of coal significantly influences the CO_2 sequestration in coal bed as well as the enhancement of methane recovery. Apart from that, the location of the injection and production wells made significant impact on the gas recovery (Abukhamsin 2009). Therefore, in this thesis an attempted has been made to simulate the CO_2 sequestration in coal bed to maximize the CO_2 storage as well as methane recovery. It is noted that the flow of gas is significantly affected by the porosity and permeability of face and butt cleats. Most of the literature, the value of porosity and permeability is considered as constant throughout the reservoir. However, Ross (2007) reported that for heterogeneous gas reservoir these values are varying spatially. In this thesis, the porosity and permeability is considered spatially varying parameters and modeled accordingly.

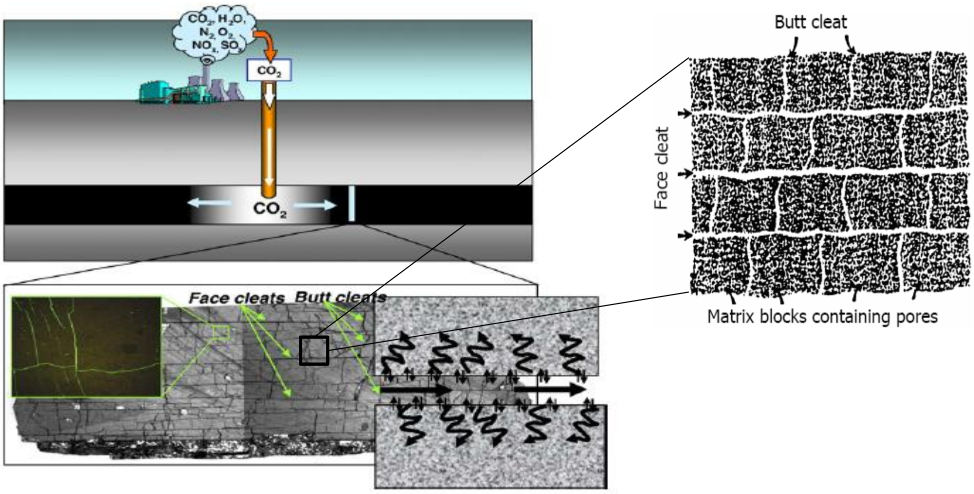

Fig1. *Schematic representation of coal seam CO_2 sequestration (modified after Ozdemir 2004)*

2. SIMULATION OF 2 PHASES FLOW (CO_2& CH_4) FOR IMPROVING METHANE RECOVERY

The flow and transportation of CO_2 in coal bed is affected by different properties of coal and its surrounding rock masses. With carbon dioxide injection, the porosity, relative permeability, and saturation of the gaseous CO_2 phase were shown to increase, which contributes to the storage capacity of the coal seam, because of decreasing of residual methane in the coal matrix. Thus, increasing the CO_2 injection pressure and the consequent reduction in the amount of residual methane contributes to the increase in the CO2 storage capacity of the reservoir and thus increase the recovery. The complete equation system consists of the following set of equations found in literature (Ross 2007).

Coal bed is having heterogeneous pore structure. Gas flow in coal bed is involves two different set of transport process. One is related to flow with in fracture and cleats and other is in matrix block. When co2 injection occurs ch4 is desorbed from the matrix blocks and migrate through inter connected micro pores to the cleats and fracture.

The gas (CO2+CH4) transport with in large scale in fractures and cleats using two phase Darcy's law. Darcy's law states that the velocity field is determined by the pressure gradient, the fluid viscosity, and the structure of the porous medium. According to Darcy's law

$$u = -\frac{K}{\mu}\nabla P \qquad (1)$$

Where,

- **u** (SI unit: m/s) is the Darcy velocity
- κ (SI unit: m^2) is the permeability

- μ (SI unit: Pa·s) is the fluid's dynamic viscosity
- p (SI unit: Pa) is the fluid's pressure

The average density and average viscosity are calculated from the fluids properties and the saturation of each fluid

$$S1 + S2 = 1 \tag{2}$$

$$\rho = S1\rho1 + S2\rho2$$

$$\frac{1}{\mu} = S1\frac{Kr1}{\mu1} + S2\frac{Kr2}{\mu2} \tag{3}$$

Where,

$\rho1$Is the density (kg/m3)

$\mu1$Is the dynamic viscosity (pa.s)

$Kr1$Relative permeability (dimensionless)

The Two-Phase Darcy's Law interface combines Darcy's law with the continuity equation

$$\frac{\partial \varepsilon p\ \rho}{\partial t} + \nabla\rho u = 0 \tag{4}$$

with the transport of the fluid content

$$C1 = S1\rho1$$

$$\frac{\partial \varepsilon p C1}{\partial t} + \nabla C1u = \nabla Dc \nabla C1 \tag{5}$$

Where,

ρ (SI unit: kg/m^3) is its density

ε_p is the porosity, defined as the fraction of the control volume that is occupied by pores, and

D_c (SI unit: m^2/s) is the capillary diffusion.

$C1$Concentration of fluid.

In a porous medium gas (CO2) attach to (adsorb) and (CH4) detach (desorb) and transport through the matrix to cleat and cleat to matrix. In a coal there is a strong interplay between adsorption and diffusion. The adsorption process having major role since CH4 is primarily present in adsorbed phase within the coal matrix.

$$Cp = Kp\ C$$

$$\frac{\partial Cp}{\partial C} = \frac{\partial (Kp\ C)}{\partial C}$$

$$CP = \frac{KLCPmaxC}{1 + KLC}$$

$$KP = \frac{\partial CP}{\partial C} = \frac{KL\ CPmax}{(1+KL\ C)2} \tag{6}$$

Where,

Concentration of porous media CP

User defined isotherm K_P (unitless)

Langmuir constant K_L (SI unit m^3/mol).

$CPmaxC$Is adsorption maximum

CConcentration at liquid phase

Diffusion involves the transport of molecule from the coal matrix to cleats through the matrix well

$$De = \in\ \tau F\ DF \tag{7}$$

Where,

De = effective diffusion (m2/s)

ε = porosity

τ_F= tortuosity factor < 1

D_F = diffusion (m2/s)

in case of CO 2 sequestration, The free flow adds concentrations variables the governing equation used here is

$$\frac{\partial Ci}{\partial t} + \nabla(Ci\ u) = \nabla(DFi\ \nabla Ci) + Ri + Si$$

Where,

c_i is the concentration (SI unit: mol/m^3) of species *i*,

$D_{F,i}$ is the fluid phase diffusion coefficient (SI unit: m^2/s),

R_i denotes a reaction rate expression (SI unit: mol/(m^3·s)), and

S_i an arbitrary source term for species *i* (SI unit: mol/(m^3·s)).

u The Velocity field (SI unit: m/s)

heat equation in the mathematical model

$$\rho Cp \frac{\partial T}{\partial t} + \rho Cpu.\nabla T = \nabla.(k\ \nabla T) + Q$$

Where,

The density (ρ)

The fluid heat capacity at constant pressure (C_p)—describes the amount of heat energy required to produce a unit temperature change in a unit mass

The fluid thermal conductivity (k)

The fluid velocity field (**u**)

The heat source (or sink) (Q)

The equation for this condition is $T = T_0$ where T_0 is the prescribed temperature on the boundary. Enter the value or expression for the temperatureT_0 (SI unit: K). The default is 293.15 K.

3. RESULTS AND DISCUSSION

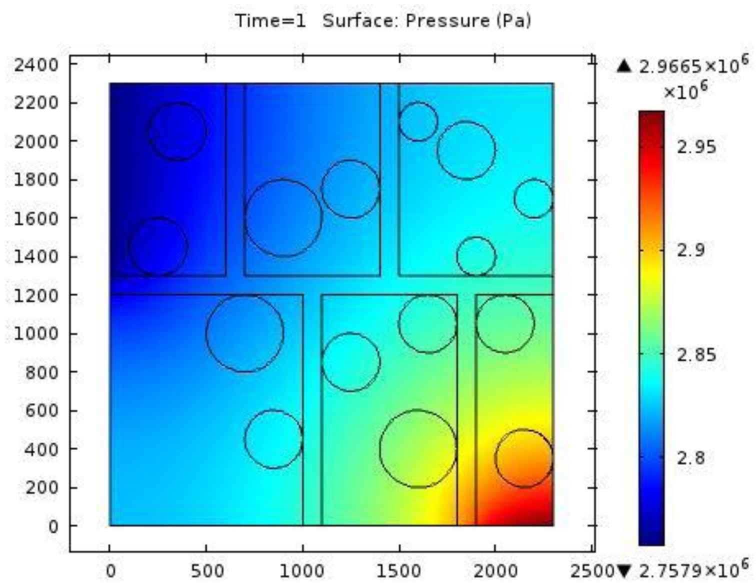

Fig2. *2D Plot Group*

According to Fig.2, the maximum storage capacity is obtained by having right lower injection wellsand the addition of further production wells of CH4 into the coal seam does not increase the CO2 storagecapacity by a significant amount. This may be due to the fact that further increasing the number ofwells after the injecting well condition causes pressure contours to coincide, resulting inincreased pore pressure and consequently reduced storage capacity. This arises because, when theinjecting wells is increased from right lower corner to left upper corner, In order to check this, the spread of CO2 concentration contours was checkedafter some years of CO2 injection for one injecting well conditions. The results are shown inFig3.in middle concentration is high and it reduces to the outer surface of the porous media.

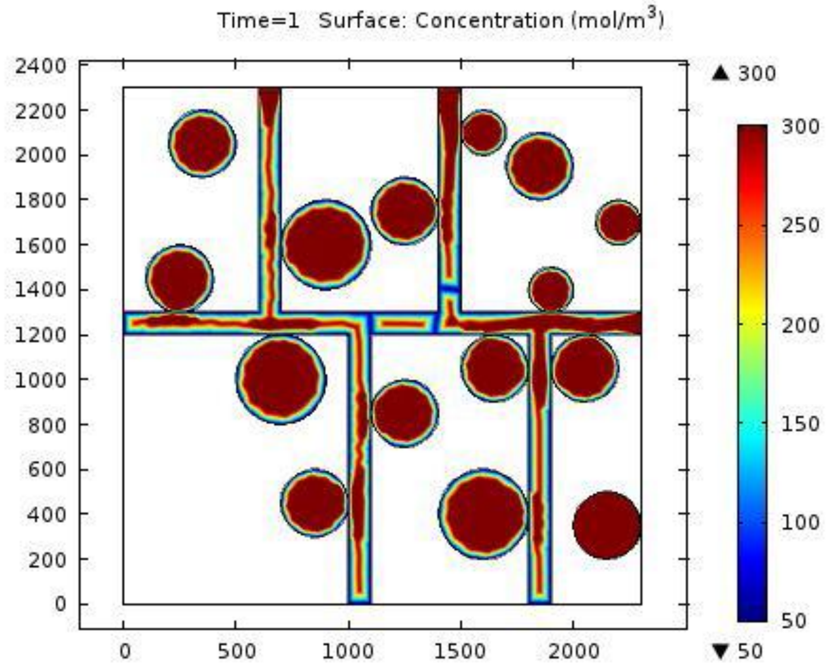

Fig3. *Concentration*

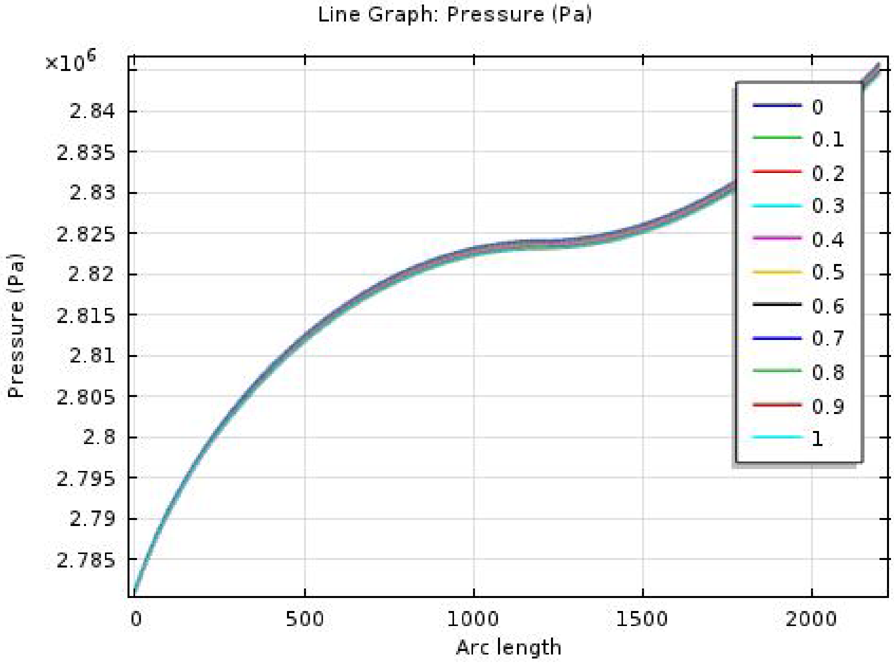

Fig4. *1D Plot Group*

Induced swelling. In contrast, at higher temperatures Permeability increases with increasing injecting pressures. This is due to the due to the fact that coal permeability for CO2 increases with increasing temperature at higher injection pressures and this increment increases with increasing injection pressure in fig 5 and fig 6.

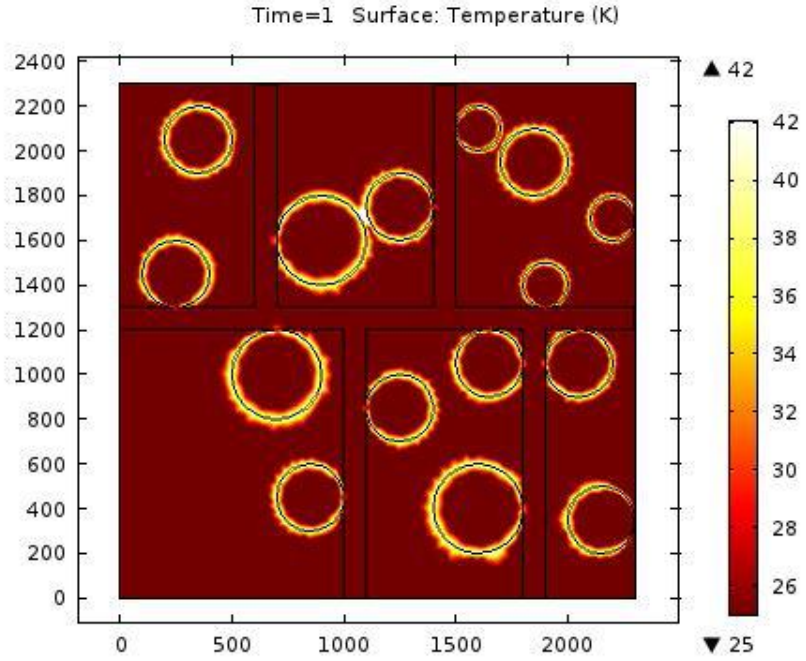

Fig5. *Temperature*

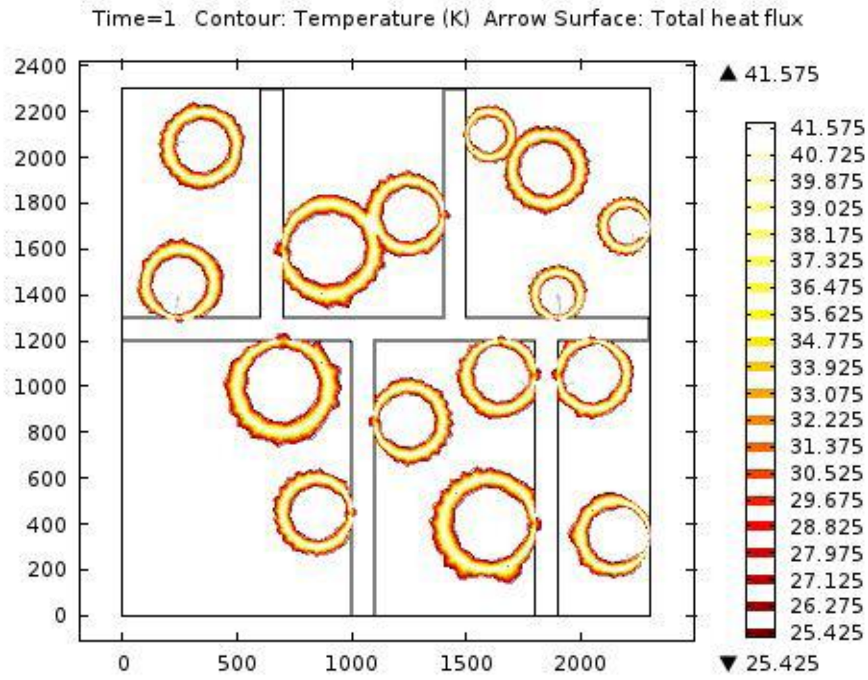

Fig6. *Isothermal Contours*

4. CONCLUSIONS

It was clear from the model that the extraction rate from a coal block can be increased by widening up the existing cleats. More widened cleats reflect enhanced permeability. if pressure of the CO2 gas can be increased inside the coal unit (in turn at the cleat boundary) it will enhance the extraction rate (increased velocity) as seen in the breakthrough profile. Net change of coal permeability accompanying binary gas dispersion is controlled competitively by the influence of effective stresses and differential swelling of coal. There is a clear increase in the permeability of naturally fractured black coal with increasing temperature for CO2 injection at higher injection pressures for any confinement, and the permeability increment increases with increasing injection pressure. However, temperature has no much effect on permeability for low injection pressures. In addition, at low temperatures CO2 permeability decreases with increasing injecting pressures due to CO2 adsorption-Since, no values can be found in literature for such a model, it became quite complicated to arrive at the real time situation with this model and hence model is in developing stage. Also, the program routinely crashes/takes longer time to solve for small size geometries and varied ranges of data. Allocated memory in the systems won't allow for fine mesh sizes.

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