# The Effect of Some Coalbed Methane Properties on Deep Thick and Shallow Thin Coalbed Methane Reservoirs

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**Abstract**

Recently, the industry has moved toward unconventional gas reservoirs to supply their demand of the energy. The unconventional gas reservoirs are new source of the energy in the world and especially in the United State of America (USA). The unconventional gas reservoirs are trapped in impermeable rock which cannot migrate. These gas reservoirs can be classify into Tight Gas, Coal Bed Methane, Shale Gas and, Methane Hydrates. Among these types of reservoirs the CoalBed Methane (CBM) covers the largest area in the USA. Some areas have been discovered and others not yet. Each area has different reservoir characteristics start with reservoir rock properties such as coal thickness and end with reservoir fluid properties such as gas content. As a result of discovering coalbed methane reservoirs (CBMs), many studies of understanding reservoir properties have been covered fairly. However, each study covers specific area of CBMs and specific reservoir characteristic. Moreover, the most challenging task for reservoir engineers is to understand of how the fluids flow in the porous media and how each reservoir parameter effects on the flow. This can be achieve by using reservoir engineering tools which provide a great view to engineers of how the fluid flow through the coal porous media. Some studies focused on deep CBMs but not thick or thin CBMs but not shallow. As a result, this study has been chosen to covers the effect of some reservoir properties on the gas production of deep thick and shallow thin CBMs. This can be accomplishing by building two reservoir simulation models for deep thick and shallow thin CBMs, to study the effect of some reservoir parameters. Four reservoir properties have been chosen in this study. These reservoir parameters are; Coal Permeability, Coal Porosity, Gas Content, and Desorption Time. The chosen of these reservoir parameters is because they have the most effect on the gas production of CBMs. Each reservoir parameter will be investigated individually when coal is deep thick and when coal is shallow thin. In the end, comparison between the obtained results will illustrate whither the deep thick CBMs has more influence on the gas production than shallow thin CBMs or not.

**Keywords:** *Induction machine, diagnostics, current spectrum, harmonics.*

## 1. Introduction

Coalbed methane reservoirs are typically reservoirs that have low permeability and porosity and have some difficulty to produce gas due to shrinkage in the porous media. The productions processes from CBMs are different from any other reservoirs, this is return to the difference between the coal rock and any other reservoir rock. Furthermore, the coal is a sedimentary rock which is different than other reservoir rock in the way of holding gas and releases it. The coal is formed from organic materials after they have been buried and compressed over period of time under suitable condition [1]. As the number of the deposition layers increase, it leads to an increase in the temperature under the ground. This increase in temperature will decrease the amount of oxygen and hydrogen but will increase the carbon content. At the same time, the buried peat is affected by pressure and temperature which will convert (peat) into lignite or sub-bituminous coal or anthracite and form the coal rock as shown in figure 1.


**Figure 1**. Illustrates the steps of the coal deposition[1].

After the process of deposition is repeated many times in different areas, it forms basins. The major CBM resources in the USA are located in twelve basins "San Juan, Warrior, Wind River, Greater Green River, Illinois, Piceance, Arkoma, Central Appalachian, Northern Appalachian, Uinta, Power River, and Raton [2]. These basins have different reservoir characterizations such as depth and the thickness. The deepest CBM basins in the USA are located in the western part of the USA. The depth and thickness of the coal seams have great influence on production system and drilling system. Also as the coal depth increases some reservoir properties are affected such as permeability and gas content which will discussed later. Table1 shows the distribution of CBM basins with their depth and formation thickness in the US.

**Table 1**. Formation depth and thickness of CMB basins in USA [2].

| **Basin** | **San Juan Basin** | **Arkoma Basin** | **Cahaba Basin** | **Central Appalachian Basin** |
|---|---|---|---|---|
| Minimum depth (ft) | 500 | 2500 | 2500 | 100 |
| Maximum depth (ft) | 5000 | 9000 | 9000 | 3500 |
| Minimum thickness of coal formation (ft) | - | 7 | 2 | 1 |
| Maximum thickness of coal formation (ft) | - | 45 | 20 | 10 |
| **Basin** | **Cherokee** | **Uinta** | **Forest City** | **North Appalachian** |

| | Basin | Basin | Basin | Basin |
|---|---|---|---|---|
| Minimum depth (ft) | 611 | 1200 | 400 | 1030 |
| Maximum depth (ft) | 2300 | 4400 | 1350 | 6570 |
| Minimum thickness of coal formation (ft) | 3 | 4 | 2 | 2 |
| Maximum thickness of coal formation (ft) | 7 | 48 | 25 | 12 |
| **Basin** | **Raton Basin** | **Warrior Basin** | **Piceance Basin** | **Powder River Basin** |
| Minimum depth (ft) | 1500 | 800 | 2300 | 720 |
| Maximum depth (ft) | 2500 | 3500 | 6500 | 2096 |
| Minimum thickness of coal formation (ft) | 2 | 10 | 80 | 2.1 |
| Maximum thickness of coal formation (ft) | 35 | 66 | 150 | 22 |

## 2. Reservoir Simulation Models Description

The overall goal of this study is to illustrate the influence of some reservoir properties on the gas production of deep thick and shallow thin CBMs. In order to accomplish that, two syntactic CBMs models have been built by using Computer Modeling Group (CMG) software. First model is for deep thick CBMs and Second model for shallow thin CBMs. The data for these models were collected from some experience and literature review as listed in table 2. The main focus in the data is the coal thickness, depth, and any other parameters can be affected by thickness and depth. The differences in the data between the two models are highlighted. After collecting data and building models, two points are focused in this study. First, the two models should be capable of producing methane (natural gas) from deep thick and shallow thin CBMs. Second, is performing sensitivity analysis to address the impact of the several reservoir properties of deep thick and shallow thin CBMs "Fracture Permeability ($K_f$), Fracture Porosity ($\varphi_f$), Gas Content ($G_c$) and, Desorption Time ($\tau$)". In the end, the result will help to understand the effect of each reservoir parameter individually, and identify which one has more effect than others.

**Table 2**. Reservoir simulation input data for deep thick and shallow thin CBMs.

| Input Parameters | Deep Thick Value | Shallow Thin Value | | Input Parameters | Deep Thick Value | Shallow Thin Value |
|---|---|---|---|---|---|---|
| Grid top depth, ft | 8000 | 1000 | | Fracture spacing, i , ft | 0.02 | 0.02 |
| Total thickness, ft | 150 | 10 | | Fracture spacing, j , ft | 0.02 | 0.02 |
| Number of layers | 3 | 4 | | Fracture spacing, k , ft | 0.02 | 0.02 |
| Porosity, matrix, fraction | 0.005 | 0.005 | | Coal desorption time, days | 300 | 200 |
| Porosity, fracture, fraction | 0.03 | 0.07 | | Langmuir pressure $P_L$ , psi | 1900 | 158.34 |

| | | | | | |
|---|---|---|---|---|---|
| Permeability matrix, i , md | 0.001 | 0.001 | Langmuir volume $V_L$ , scf/ton | 600 | 400 |
| Permeability matrix, j , md | 0.001 | 0.001 | Gas content, scf/ton | 400 | 300 |
| Permeability matrix, k , md | 0.001 | 0.001 | Temperature, ºF | 200 | 80 |
| Permeability fracture, i , md | 6 | 8 | Reservoir pressure, psi | 3800 | 475 |
| Permeability fracture, j , md | 6 | 8 | Bottom hole pressure, psi | 750 | 50 |
| Permeability fracture, k ,md | 3 | 4 | Production time, years | 10 | 10 |

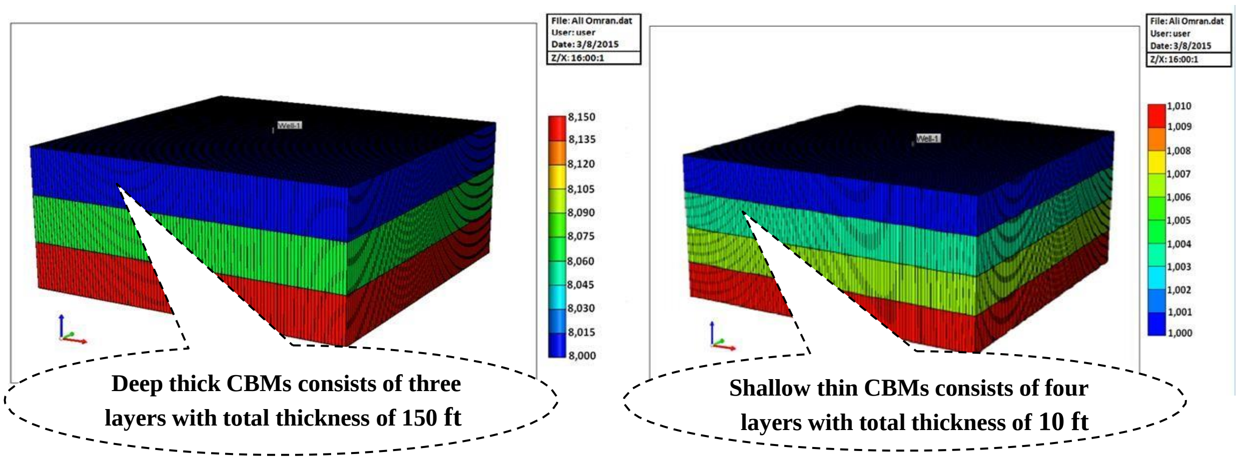


**Figure 2**. Reservoir simulation models of deep thick and shallow thin CBMs.

## 3. Coalbed Methane Reservoir Characteristics

As mentioned before several reservoir parameters will be investigated. The table below illustrates the reservoir properties with their investigated values. Each scenario includes different value start with smallest value in first scenario until reach highest value in fourth scenario. The parameters will be change individually while others keep constant. This process will be done when the coal is deep thick, and also when the coal is shallow thin respectively.

**Table 3**. Shows the change in the reservoir parameters for sensitivity analysis.

| Parameters | Base Scenario | | First Scenario | | Second Scenario | | Third Scenario | | Fourth Scenario | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Deep Thick | Shallow Thin | Deep Thick | Shallow Thin | Deep Thick | Shallow Thin | Deep Thick | Shallow Thin | Deep Thick | Shallow Thin |
| **Fracture Permeability** | 6 | 8 | 3 | 2 | 9 | 6 | 12 | 10 | 15 | 14 |
| **Fracture Porosity** | 0.03 | 0.07 | 0.02 | 0.03 | 0.04 | 0.04 | 0.05 | 0.05 | 0.06 | 0.06 |
| **Desorption Time** | 300 | 200 | 50 | 1 | 150 | 50 | 200 | 100 | 250 | 150 |
| **Gas Content** | 400 | 300 | 200 | 100 | 300 | 200 | 500 | 400 | 600 | 500 |

**Coal Permeability**: The permeability is the most critical reservoir parameter that has an obvious effect on the gas production from coal. The coal formations are considered to be dual-permeability system. These two systems are presented by the matrix and the cleats as shown in figure 3. The matrix stores the gas by adsorption and flow of gas in the matrix is by diffusion into the cleats. In CBM production, permeability refers to the permeability of the cleats and not the matrix. The permeability of the cleats is always higher than the permeability in the matrix, and it is around eight times of the matrix permeability [3].

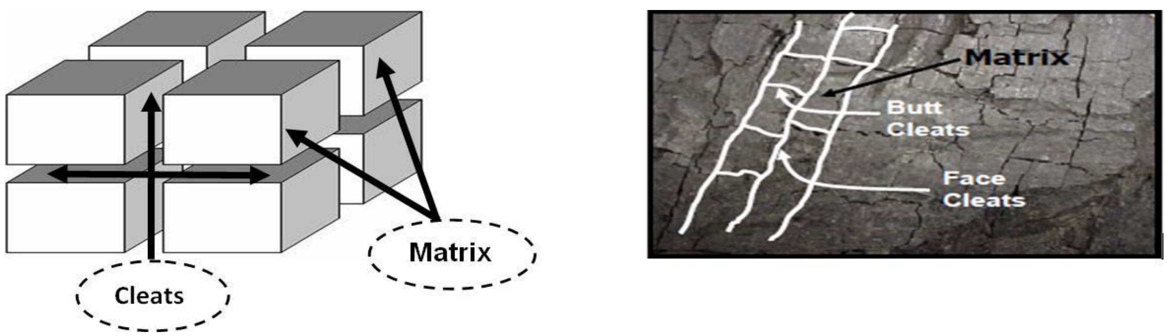


**Figure 3**. CBMs model and actual CBMs model[3].

Four values of coal permeability are signed to be investigated as listed in table 3.The results of reservoir simulation of deep thick and shallow thin CBMs show increasing in the gas production as the permeability increase which is expected. This increase in the gas production returns to the increasing in the ability of fluids (gases) to flow through the porous medial of the coal rock (cleats). The results of the reservoir simulation of coal permeability are shown in figure 4 and 5.

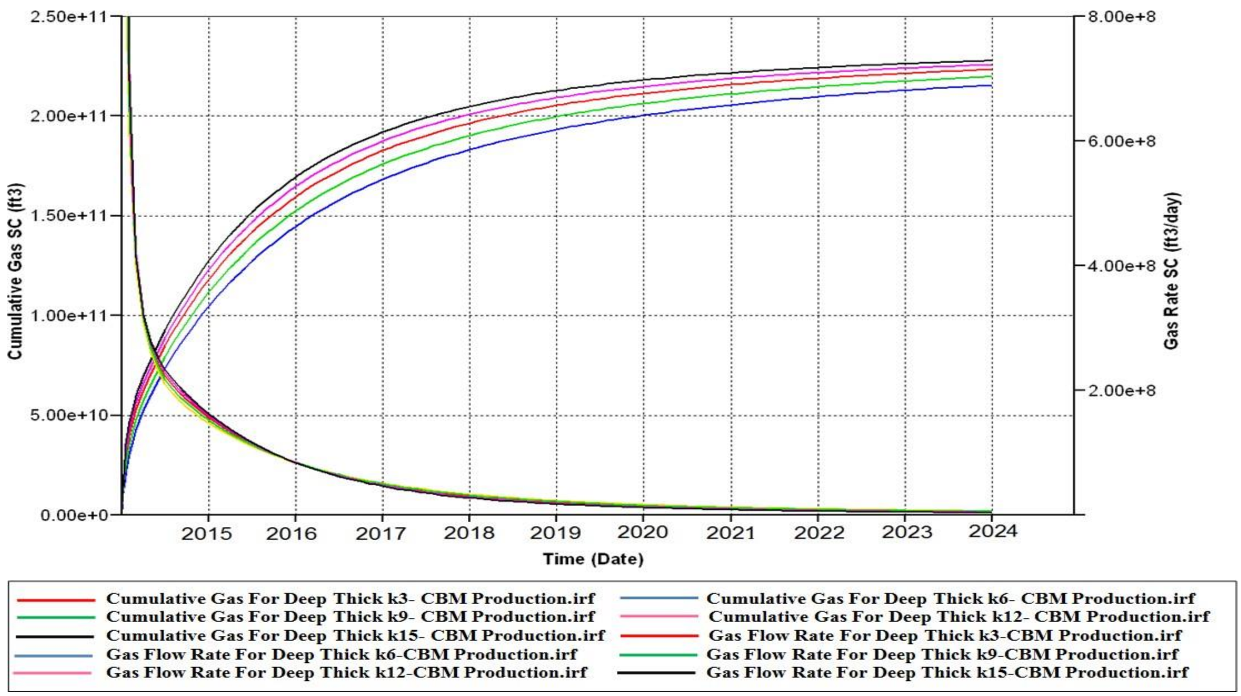


**Figure 4**. Effect of fracture permeability ($K_f$) on cumulative gas and gas rate for deep thick CBMs.

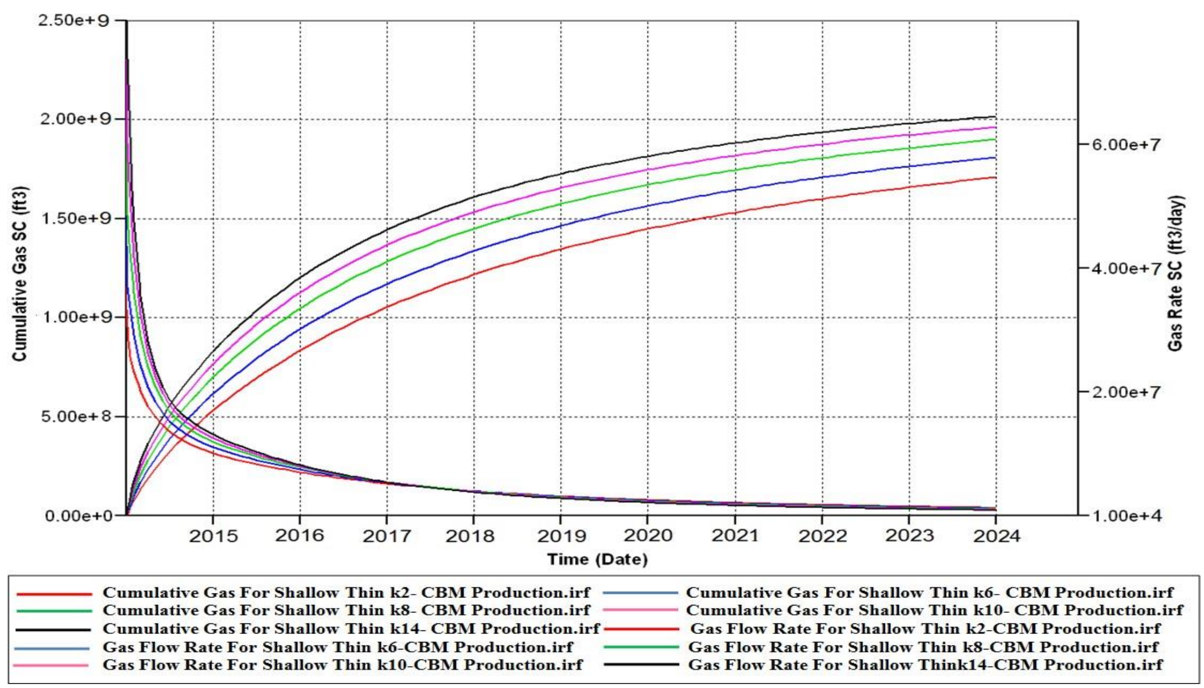


**Figure 5**. Effect of fracture permeability ($K_f$) on cumulative gas and gas rate for shallow thin CBMs.

**Coal Porosity:** Essentially, the coal has two different types of porosities which are called the primary porosity and the secondary porosity. The primary porosity is the porosity of the matrix which is composed of fine pores, which called Micropores, with extremely low permeability [4]. The secondary porosity refers to the cleats porosity. This type of porosity is also called the Macropores, which consists of the natural fracture of cracks and fissures inherent in all coal [4]. These Macropores which are bigger than Micropores, provides a place for the fluid to flow from the matrix. The coal cleats are composed of two types of the components which are face cleats and butt cleats as they are shown in figure 6.

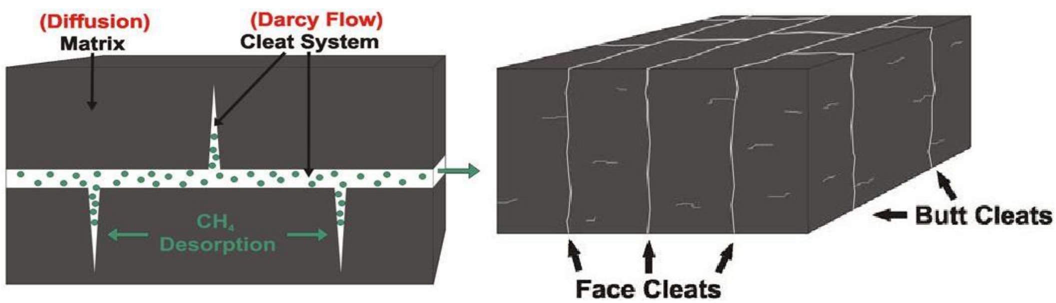


**Figure 6**. Shows the coal matrix and cleats system[4].

The change in porosity values will be in the secondary porosity. Different values of the porosity have been investigated as shown in table 3. The simulation results show the increasing in porosity will decrease in gas production for both deep thick and shallow thin CBMs as shown in figure 7 and 8. The decreasing in the gas production when the porosity increased returns to deceasing in the matrix size, which is place for the gas to adsorb.

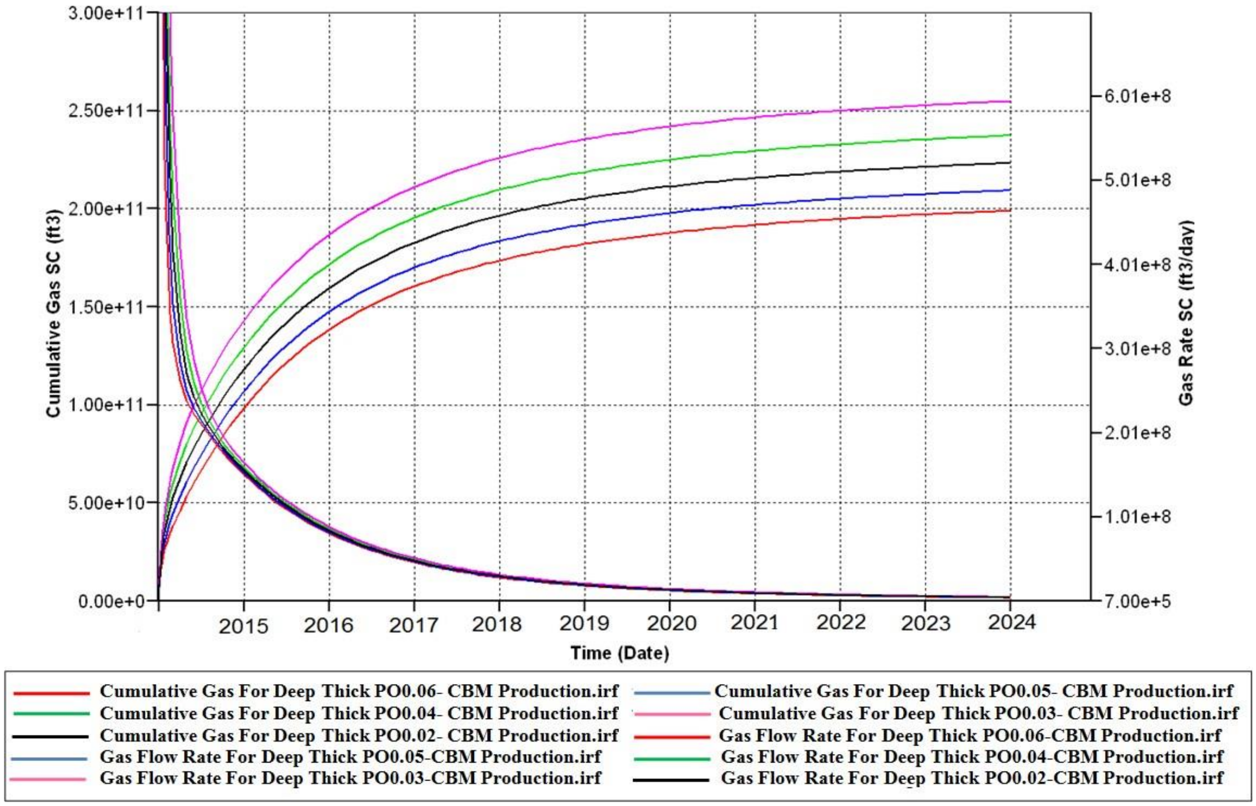


**Figure 7**. Effect of fracture porosity ($\varphi_f$) on cumulative gas and gas rate for deep thick CBMs.

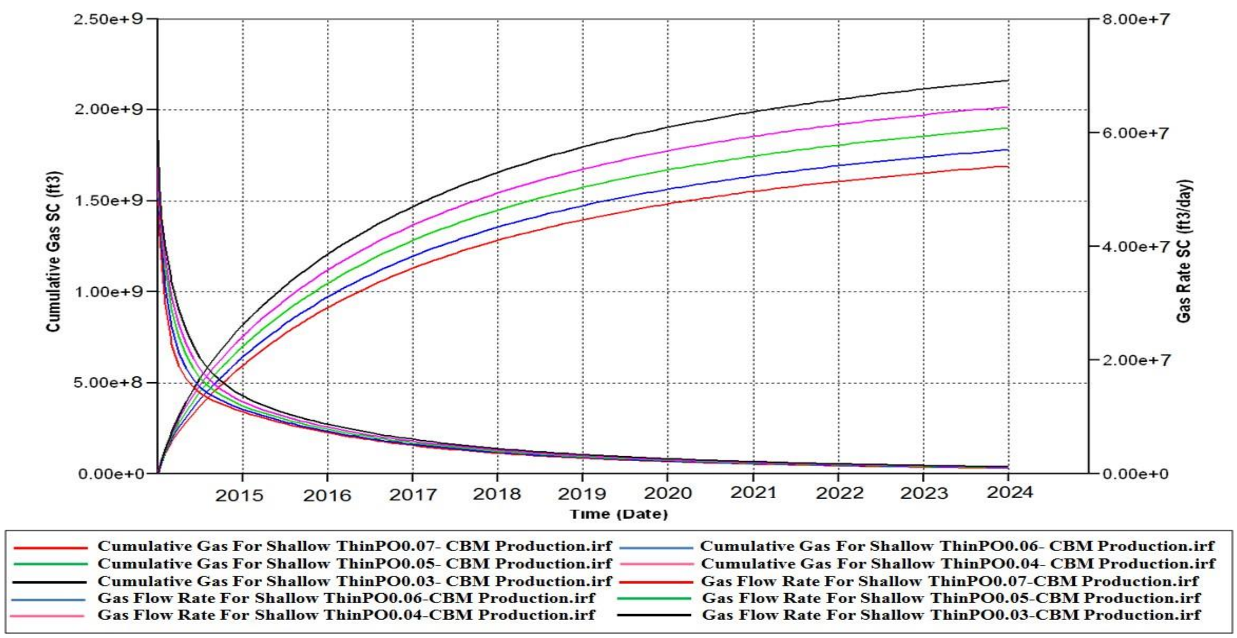


**Figure 8**. Effect of fracture porosity ($\varphi_f$) on cumulative gas and gas rate for shallow thin CBMs.

**Gas Content:** The gas content in the coal refers to the amount of gas that exists as adsorbed gas. The gas content of coal seam is dependent on depth and rank of the coal. Deeper coal beds are associated with increased methane adsorption due to higher pressures, and also it has a higher probability of gas containment [5]. Figure 9 illustrates the relationship between gas content and coal depth.

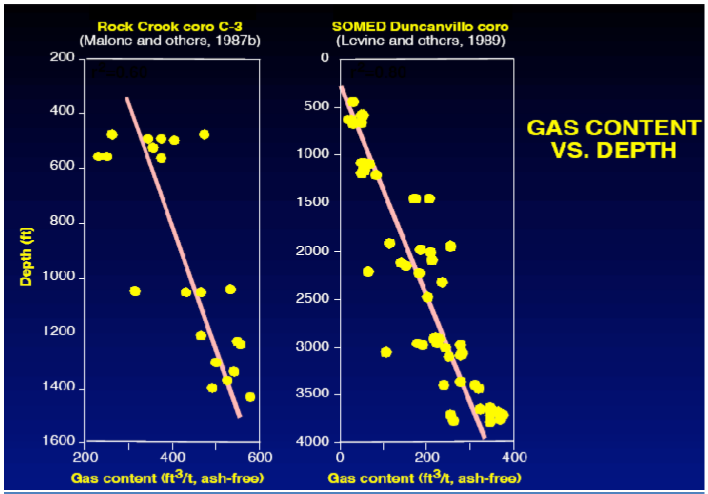


**Figure 9**. Plots of gas content versus depth for coalbed methane reservoir in the Black Warrior basin[5].

The same system has been simulated with four different values of gas content as shown in table 3 or 4. These values have been generated by changing in the Langmuir volume and Langmuir pressure carefully in order to have saturated CBMs. The saturated reservoir is different from the under saturated reservoir. If the initial reservoir pressure is significantly greater than the pressure required to initiate desorption that means the coal is under-saturated, and if initial reservoir pressure is equal to the critical desorption pressure, the coal is saturated [5]. In the under-saturated CBMs, the water is initially present in the cleat system, and the initial production is water and sometimes with a small amount of free gas. The period of producing water in this type of reservoirs may take a few months to couple years without producing gas [5]. This can significantly affect the economics of the project. In the saturated CBMs the gas production will start as soon as reservoir pressure begins to decrease. Please refer to figure 10 for illustration.

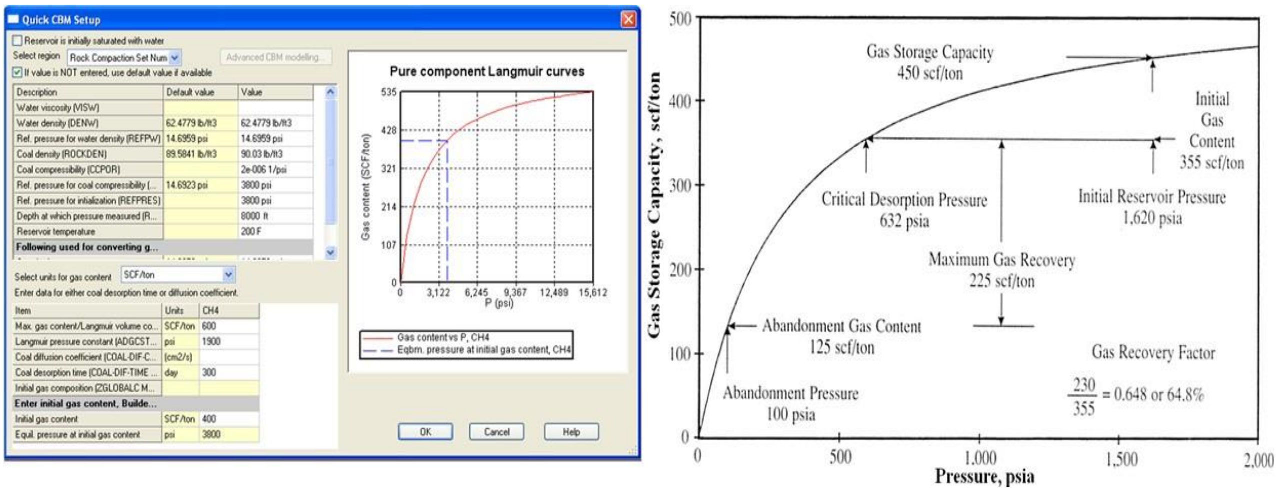


**Figure 10**. Input data in CMG software and example of Langmuir isotherm relationship.

After understanding of saturated and under-saturated coal reservoirs, it is clear based on what the values in table 4 have been shown. Four scenarios will clarify influence of gas content on gas production.

**Table 4**. Effect of gas content with change in the Langmuir pressure and Langmuir volume.

| Parameters | Gas content, scf/ton | | Langmuir volume ($V_L$), scf/ton | | Langmuir pressure ($P_L$), psi | |
|---|---|---|---|---|---|---|
| | Deep Thick | Shallow Thin | Deep Thick | Shallow Thin | Deep Thick | Shallow Thin |
| **Base scenario** | 400 | 300 | 600 | 400 | 1900 | 158.34 |
| **First scenario** | 200 | 100 | 400 | 200 | 3800 | 475 |
| **Second scenario** | 300 | 200 | 540 | 336 | 3040 | 323 |
| **Third scenario** | 500 | 400 | 740 | 512 | 1824 | 133 |
| **Fourth scenario** | 600 | 500 | 870 | 600 | 1710 | 95 |

The simulation results show that gas production increases for both deep thick and shallow thin CBMs when the gas content is increased, this because the increase in the amount of original gas in place in the coal matrix.

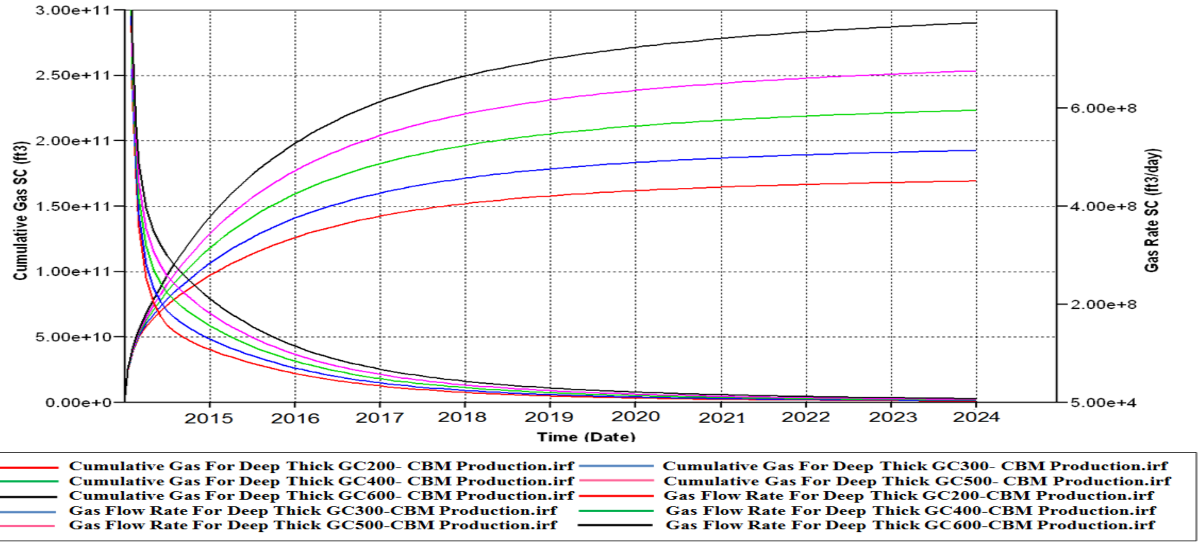


**Figure 11**. Effect of gas content ($G_c$) on cumulative gas and gas rate for deep thick CBMs.

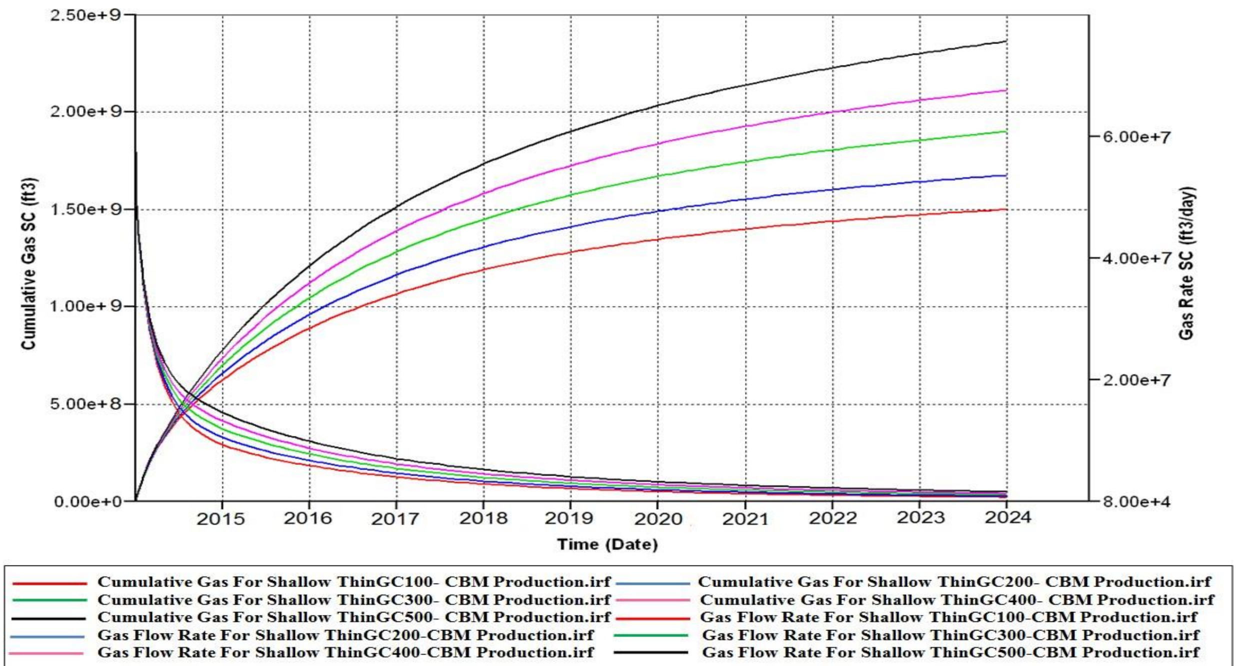


**Figure 12**. Effect of gas content ($G_c$) on cumulative gas and gas rate for shallow thin CBMs.

**Desorption Time:** By definition, desorption time is the time taken for a methane molecule to desorb from matrix into the fracture, and as long as this time is small as soon as the gas is released from matrix. It is found that between 90-98 percent of the gas which is produced from CBMs is desorbed gas [6]. Again different values of the desorption time have been investigated, the results show the increasing in the desorption time will increase the production for both deep thick and shallow thin CBMs. The effect of desorption time is usually clear in first years, because after a period of time all the gases will be desorbed.

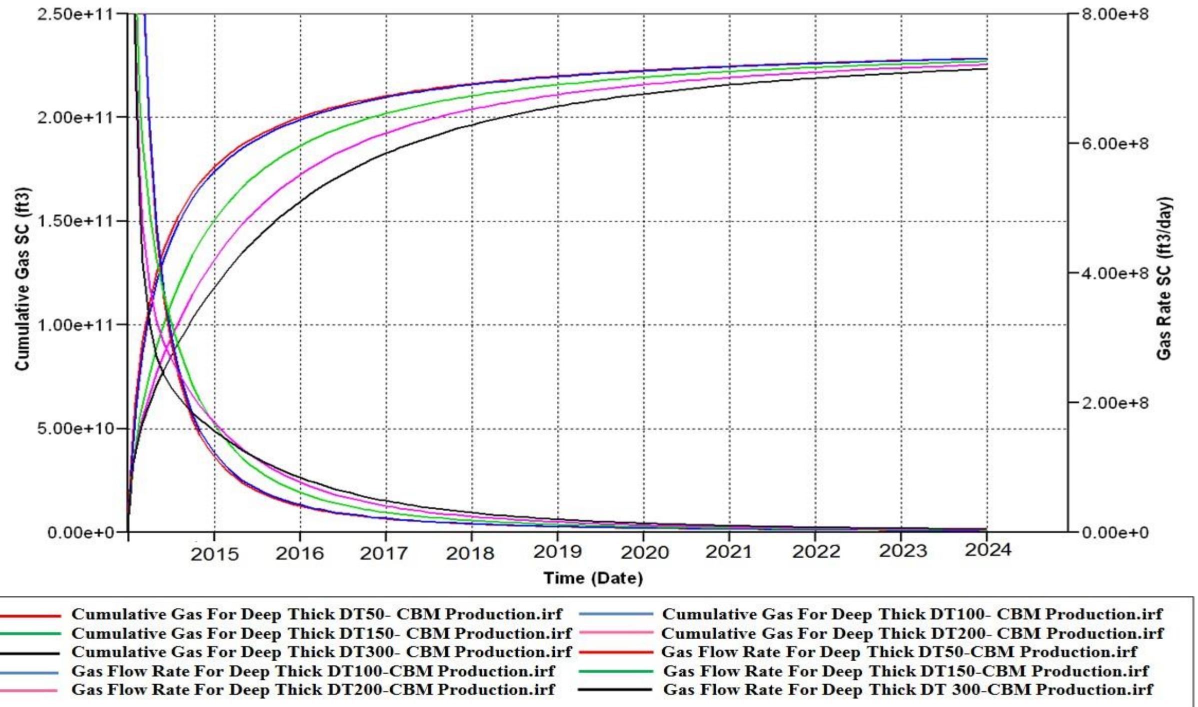


**Figure 13**. Effect of desorption time (τ) on cumulative gas and gas rate for deep thick CBMs.

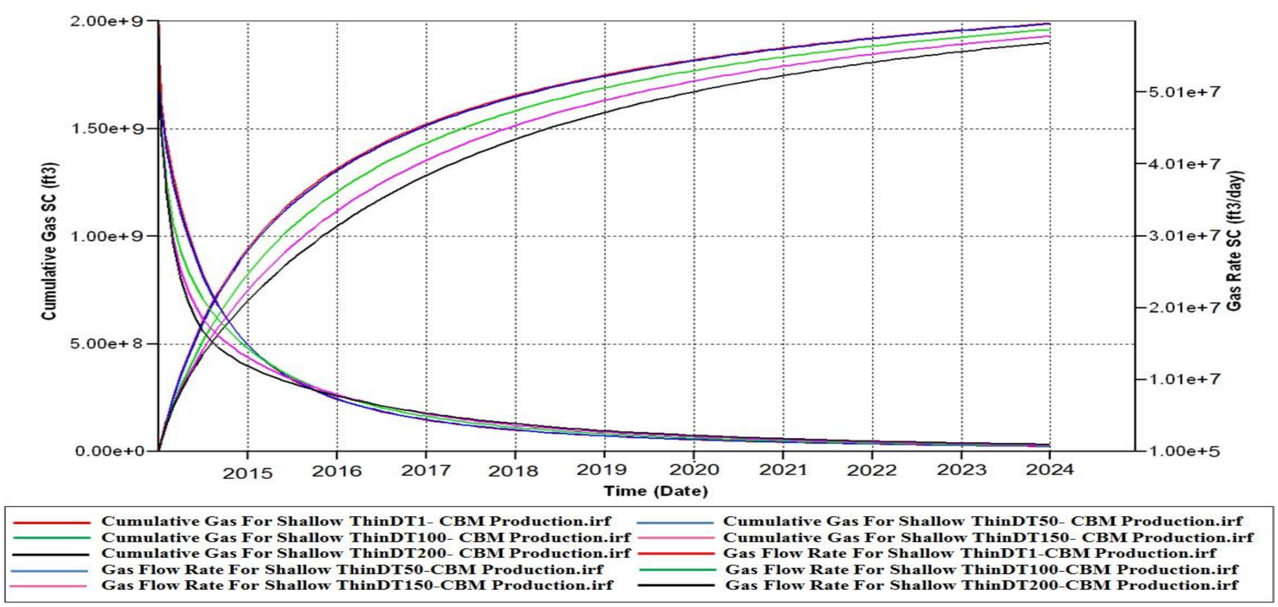


**Figure 14**. Effect of desorption time (τ) on cumulative gas and gas rate for shallow thin CBM.

## 4. Conclusion

The literature reviews and simulation results indicate that the deep thick CBMs are better than shallow thin CBMs to storage gas and produce it. The reservoir parameters that have been investigated for the both deep thick and shallow thin CBMs show in general the same effect which can be summarized as:

**1.** Increasing in the fracture permeability will increase in the gas production, this is due to the ability of gases to move through the porous media when the permeability is increased.

**2.** The fracture porosity has different influence on gas production, where increasing the porosity will limited the surface of the coal matrix which is the place for the gas to be exist.

**3.** Increasing the gas content will increase the amount of original gas in place according to gas equation ($G=1359.7Ah\rho Gc$). The gas content is the most effected parameter on gas production.

**4.** The desorption time plays good role on gas production, where increasing desorption time will increase gas production. usually the effect of desorption time is clear in first years of the production

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