

A Critical Review of Methane Trapping Mechanism to Optimize CBM Production

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Abstract: Optimizing Coal Bed Methane (CBM) production depends on the trapping mechanism of methane in the micro pores of coal bed. Methane is trapped in coal beds by adsorption on the free surface. The free surface is mainly available as the micro pores and partly as different cleats. The average percentage of micro pores (1.2×10^{-7} cm diameter) in a coal increases with rank and ranges from 19.3% in lignites to 75% in anthracites. The effective molecular diameter of adsorbed methane is 4.1×10^{-8} cm suggesting a maximum of three molecules can be accommodated in a unit micro pore. The commitment of optimized production of methane depends on the amount adsorbed on the coal surface. Methane in the micro pore can be accommodated either by solution in pore water or adsorption or as free gas under pressure. If it is dissolved in water, then for CBM production it is not useful because the dissolved gas will be expelled during dewatering phase of the well completion. It is only the free gas and the adsorbed gas that need to be evaluated for optimized production. Langmuir assumed a mono-layer of adsorption in selective locales on the adsorbent whereas many of the present day models assumed multi-layers of adsorbates (BET: Stephen Brunauer, Paul Emmett and Edward Teller). Problem arises with the concept of layering during adsorption process whereby it is difficult to think of adsorption of methane over a methane layer. With higher pressure methane can be accommodated as free gas but will not be adsorbed on any methane surface. It is therefore necessary to understand how methane molecule is trapped in the micro pores of the coal bed in order to optimize the CBM production.

Keywords: Adsorption, CBM, methane, trapping

INTRODUCTION

The mechanical properties and permeability of a coal is controlled to a large extent by the network of the natural fractures and cleats in the coal (Laubach *et al.*, 1997). It is therefore necessary to understand the nature and role of the variety of natural fractures to successfully complete a well and produce methane from a coal bed.

Methane is trapped in pores of the coal either as a free gas or as an adsorbate in the pores/micro pores on the coal surface. Dissolved methane in connate water within coal mass is not useful because it will be released during dewatering phase. Coal has a dual pore system consisting of micro pores and macro pores. The size (diameter) of the micro pores in the coal matrix is an essential parameter because the diameter shows the capacity of handling the methane molecules.

The average percentage of micro pores (1.2×10^{-7} cm diameter) in a coal increases with rank and ranges from 19.3% in lignites to 75% in anthracites (Rogers *et al.*, 2007). The effective molecular diameter of adsorbed methane is 4.1×10^{-8} cm suggesting a maximum of three molecules can be accommodated in a unit micro pore. All the three molecules in a pore

cannot remain adsorbed on the coal surface because under such conditions one methane molecule should be adsorbed over another methane molecule which is chemically impossible. Figure 1 shows the assumption of the monolayer and multilayer concepts of the adsorbate on the adsorbent.

A review is therefore made to understand the tectonic and hydrostatic pressures in a basin to evaluate its adsorption/desorption isotherms.

DISCUSSION

Illinois and Raton basins (Rogers *et al.*, 2007) are taken into consideration for evaluation of methane trapping mechanism (monolayer or as a multilayer) in pores.

Illinois basin: Depth of coal = 3000 ft = 914.4 m, coal rank is high volatile bituminous 'B' type (hvBb) and gas content = 30 – 150 scf/ton.

Assuming:

- Density of high volatile bituminous coal (hvBb) is 1.3 g/cc daf (Fig. 2) basis.
- All the gas occupies the pores in coal.

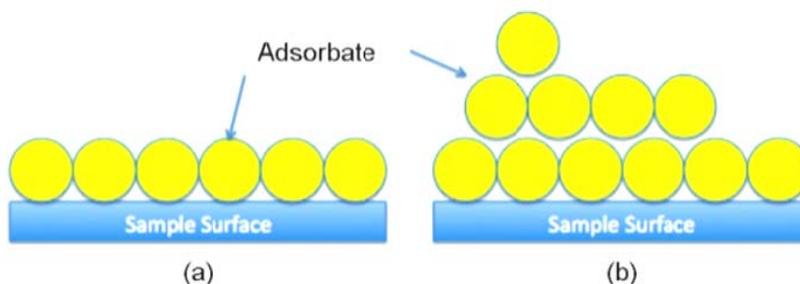


Fig. 1: Adsorbate layers, monolayer (a) and multilayer's (b) (Kazi, 2009)

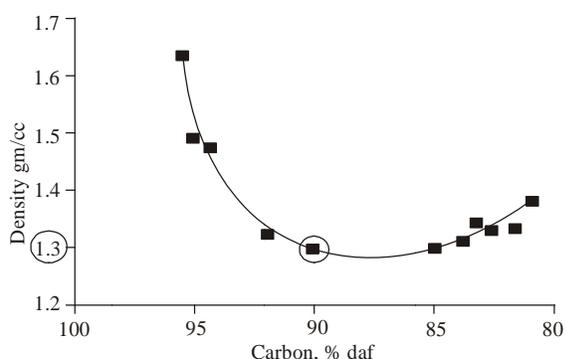


Fig. 2: Apparent density of coal (Franklin Cited in: Rogers *et al.*, 2007)

Gas content is $4.2475 \text{ m}^3/\text{ton} = 5.52 \text{ m}^3/\text{m}^3$ of coal.

If we assume the sample is at a depth of 3000 ft the expected temperature and pressure will be 50°C and 108 atm. The volume 5.52 m^3 at 25°C 1atm. pressure becomes $0.055/1 \text{ m}^3$ of coal. This suggests that the coal has got 5.5% porosity and all the 5.5% pores are completely filled with methane. Further, 0.055 m^3 of methane in the reservoir is equivalent to 5.52 m^3 at surface which is equal to 225.76 moles which is equivalent to $6.02 \times 10^{23} \times 225.76$ (1359.06×10^{23}) molecules.

Let us assume that all the 0.055 m^3 of the pore volume is micro pore of the size $1.27 \times 10^{-7} \text{ cm}$ diameter then the total numbers of pores are 0.051×10^{27} suggesting about 2.66 molecules are adjusted in each pore (assuming all the pores are spherical and uniform in nature). If the micro pore amounts only 30%, which is normal for any high volatile bituminous 'B' coal, the number of gas molecules per pore in the coal should be more than 8.9.

Raton basin: Maximum depth of coal = 4000 ft, coal rank = high volatile 'C' bituminous (hvCb) to low volatile bituminous (lvb) (Accepting an average hvAb).

Gas content = 510 scf/ton at 1192 ft

Based on the earlier assumptions, Gas content is $14.44 \text{ m}^3/\text{ton} = 18.772 \text{ m}^3/\text{m}^3$ at 1192 ft = $18.772 \text{ m}^3/\text{m}^3$ at 363.3 m. Assuming temperature around 30°C and pressure 43 atm, the gas content in the reservoir condition is $0.4439 \text{ m}^3/1 \text{ m}^3$ of coal suggesting 44.39% porosity.

$$18.772 \text{ m}^3 \text{ at } 25^\circ\text{C} = 17.197 \text{ m}^3 \text{ at STP}$$

This is equivalent 767.73 moles = 4621.73×10^{23} molecules. Assuming all the pores are micro in nature then the numbers of micro pores are 4.14×10^{26} . This suggests 0.895 molecules per each micro pore.

Assuming 48.5% of total pores being micro pores, the numbers of micro-pores are 2.008×10^{26} . If all the gas (4621×10^{23} molecules) is filled in micro pore then actually $2301.66 \times 10^{-3} = 2.3$ molecules are allowed per micro pore.

All these calculations suggest there must be huge amount of free gas available in the micro pores out of which more than 90% is released at the surface temperature pressure conditions. In Raton Basin the porosity amounts to 44.39% at a depth of 363.3 m which is difficult to apprehend for coal whereas, for the Illinois Basin the porosity amounts to 5.5% at a depth of 914.4 m. Assuming all the pores are micro in nature, there are 2.3 molecules of methane per each micro pore in Raton Basin and 2.66 molecules in case of Illinois Basin. All these suggest, more than two molecules of methane are there in each micro pore but not exceeding three in any pore. This suggests the gas molecules can be adsorbed in a single layer following Langmuir isotherm pattern.

Further, it is known that coal in general has porosity not exceeding 2.5% but to accommodate the huge gas 5.5 to 44.39% porosity has to be accepted. However, this amount of porosity is not measured by conventional means and it is also not known about the source and mechanism of formation of such porous

nature in a coal. It is possible that these pores being micro in nature are not reflected in the conventional measurements, just because of the same reasons like that of shale. However, shale is known highly porous because of its water content but a coal is filled with gas and therefore cannot reflect high porosity.

More over the amount of micro porosity of a coal is also variable depending on the location. A most possible mechanism of formation of such micro porous nature is possibly associated with genesis of the coal itself. The first stage of coalification process is known a gelification during which wood is converted to gel which ultimately forms vitrinite maceral. During this gelification process if some underground seepage continues through the gel mass then ultimately it will develop micro pores and with further subsidence part of the micro pores may be destroyed but on an average it will remain sufficiently micro porous till seepage continues.

CONCLUSION

It is therefore safe to conclude that single layer Langmuir adsorption isotherm is best suited for

trapping of methane gas in coal micro pores. There is no immediate necessity to think of multi layer adsorbed methane molecules. Further, as to the genesis of micro pores in a coal, it is proposed that local seepage of gas in this area is responsible for generation of micro pores.

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