



## Study on CO<sub>2</sub> Sorption Capacity of Coal – An Experimental Approach

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**Abstract:** In the present situation of global warming, the percentage of CO<sub>2</sub> in atmospheric air is increasing very rapidly, which will create major problem for the future generation. Storage of CO<sub>2</sub> is gaining widespread interest as a potential method of controlling greenhouse gas emissions as suggested by Intergovernmental Panel on Climate Change (IPCC). This study includes methane desorption mechanism from coal bed, and suggests that the desorbed methane can be used as a pure fuel for many purposes. It is generally acknowledged that coal beds are an important rock medium with regard to their capacity to act as a reservoir for CO<sub>2</sub> gas. In this paper, CO<sub>2</sub> sorption capacity of coal under different temperatures has been investigated by experimental approach and also explains the effect of cracks on coal surface in its sorption capacity. As temperature and pressure increases, with the depth of seam from surface level, the mathematical relation derived from this experiment will be helpful in determination of total amount of CO<sub>2</sub> that can be stored in a coal seam at various reservoir temperature. The results will be helpful to use enhanced production of methane as additional benefit and also to use coal seam as a permanent sink for anthropogenic CO<sub>2</sub> emission.

**Keywords:** Coal, Methane Desorption, CBM, CO<sub>2</sub> Sequestration

### 1. Introduction

The control of greenhouse gases is arguably the most challenging environmental policy issue facing India and other countries. Carbon dioxide is one of the major greenhouse gases of which emissions need to be reduced. An approach that gives a solution to control CO<sub>2</sub> emissions by capturing and sequestering CO<sub>2</sub> in non-minable coalbeds. The key attraction of this option is that it gives desorbed methane, as an alternative to compressed natural gas (CNG) without producing more greenhouse warming. [1] Depletion of conventional resources, and increasing demand for clean energy, forces India to hunt for alternatives to conventional energy resources. Intense importance has been given for finding out more and more energy resources; specifically non-conventional ones like CBM, shale gas & gas hydrates, as gas is less polluting compared to oil or coal. CBM is considered to be one of the most viable alternatives to combat the situation [2]. With growing demand and rising oil and gas prices, CBM is definitely a feasible alternative supplementary energy source. It is of pipe line quality; hence can be fed directly to national pipeline grid without much treatment. Production of methane gas from coalbed would lead to de-methanation of coal beds and therefore would lead to no emissions of methane into the atmosphere, thus turning an environmental hazard into a clean energy resource.

As the third largest coal producer in the world, India has good prospects for commercial production of coal bed methane. In 2006 it was estimated that of global resources totaling 143 trillion cubic meters, only 1

trillion cubic meters was actually recovered from reserves (CIMFR 2006 report).

This method consists of injecting CO<sub>2</sub> into deep coal seams to sequester the carbon and enhance the recovery of coal-bed methane (CBM). Wasted CO<sub>2</sub> from CBM-fueled power plants could be injected into CBM reservoirs to produce more methane (CH<sub>4</sub>) for the power plant. 2:1 is the coal-sorption selectivity for CO<sub>2</sub> over CH<sub>4</sub>, which supports the feasibility of operating fossil-fueled power plants without atmospheric CO<sub>2</sub> emissions. [4] It is possible to enhance the recovery of methane by injecting CO<sub>2</sub> in the coal Seam. The coal Seam exhibited the commonly perceived (ad/de)sorption behavior preferential adsorption of CO<sub>2</sub> and preferential desorption of methane following CO<sub>2</sub> injection. Up to 80% of the gas-in place could be recovered by two rounds of CO<sub>2</sub> injections. [4] An improved understanding of these processes from the macroscopic to the microscopic scale is important for the accurate prediction of gas and water production as well as CO<sub>2</sub> injection rates. Flow through the cleat system is pressure-driven and may be described using Darcy's law, whereas flow through the matrix is assumed to be concentration-driven and is modeled using Fick's law of diffusion. [5]

In this context, this paper summarizes gas sorption on coal and specifically addresses the following issues: understanding of CO<sub>2</sub> gas sorption on coal, changes in sorption capacity according to the nature of the coal body surface and temperature dependent isotherms. Production strategy of methane from CBM is very much different from conventional gas reservoir. It is

strongly recommended to work further on the effects of coal type, rank, volatile matter and fixed carbon on coal sorption capacity.

**2. Experiment and Methodology**

**2.1. Experimental Setup**

The manometric apparatus consists of two reference cells and a sample cell of approximately  $3.72905 \times 10^{-4} m^3$  volume; sample cellis contained within a temperature-controlled oven box. The pressure within eachcell was monitored using a pressure transducer, accurate to  $\pm 0.25\%$  full scale. The temperature inside the oven was monitored. Load up to 10tonne can be applied on the sample with the help of hydraulic ram. The whole system is connected to a computer and all 4 data (3 of pressure and 1 of temperature) were automatically recorded by the software.

Gaseous  $CO_2$ sorption isotherms were obtained using the manometric gas adsorption apparatus as shown schematically in Figure 1.

**2.2. Methodology**

The experiment for sorption capacity has been performed to obtain the isotherms for different temperatures. Initially the experiment has been performed and the data has been collected at room temperature (298K) for an initial pressure of 140 Psi inside the reference cell. The pressure fall for the sample cell and the reference cell with respect to time is noted for every 1 min interval. Then, the gas inside the sample cell is released using release valve and the sample is kept at particular high temperature for 24 hrs. Subsequently, the data is collected using same procedure as described above.

*Calculation for sorption capacity of coal sample:*

Using real gas equation, moles of carbon dioxide gas absorbed and adsorbed can be calculated.

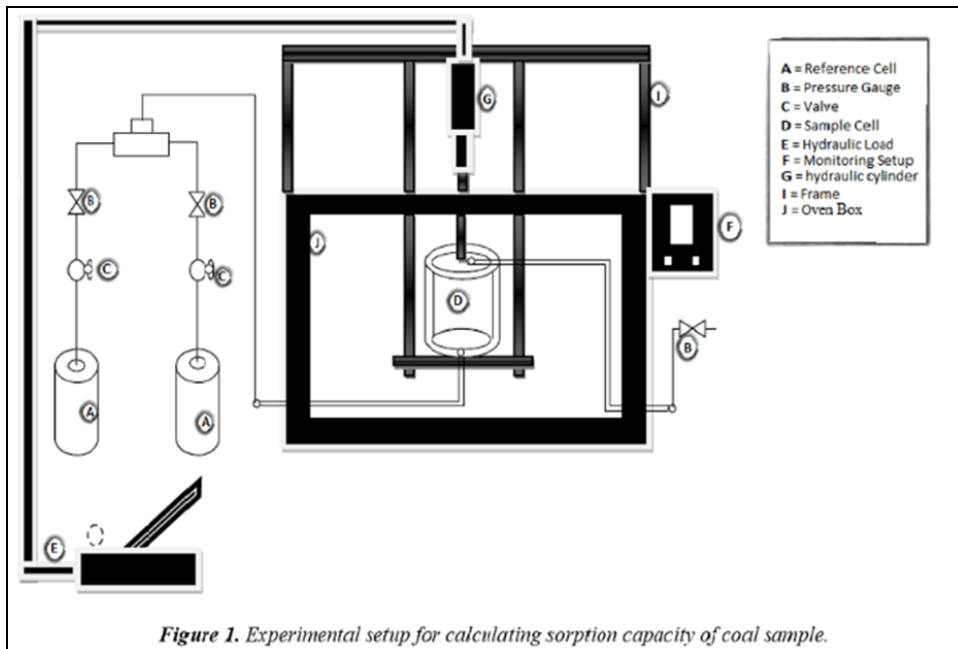


Figure 1. Experimental setup for calculating sorption capacity of coal sample.

$$\Delta n = \frac{1}{wRT} \left\{ \frac{P_1 V}{Z_1} - \frac{P_2 (V - V_s)}{Z_2} \right\} \dots \dots \dots [Eq 1]$$

Where,

$\Delta n$ = adsorbed and absorbed mole of carbon dioxide (mmole/gm)

$P_1$ = initial pressure of reference cell (Psi)

$P_2$  = final pressure of sample cell (Psi)

$Z_1$  = value of constant at pressure  $P_1$

$Z_2$  = value of constant at pressure  $P_2$

V = volume of sample cell = volume of reference cell( $m^3$ )

$V_s$  = volume of sample( $m^3$ )

w=weight of sample (gm)

R=gas constant =  $1.2059 \times 10^{-3} (m^3 Psi K^{-1} mol^{-1})$

T = temperature of sample cell (K)

**2.3. Sample Collection**

Samples were collected from BLOCK II, JHARIA COALFIELD, Jharkhand, India. These samples from the coalfield were collected from freshly exposed faces of coal mines. The coal block was drilled in 50mm diameter with 100mm length. By initial proximate analysis, the basic coal properties (ash%, density, volatile matter) were calculated.

Table 1: sample specifications used for the experiment

	Sample Type	Weight (gm)	Diameter (mm)	Length (mm)
1	Coal (Intact)	305	50	107
2	Coal (With Visible Crack)	305	50	105

**Table 2:** Proximate analysis of the coal samples

Coal Sample	Ash content (%)	Moisture content (%)	Volatile matter (%)
Sample 1	18.06	1.54	13.87
Sample 2	16.61	1.8	15.66



**Fig. 2** (a) Sample 1 (Intact) Fig. 2(b) Sample 2 (Visible Crack)

**3. Results and Discussion**

**3.1. Analysis of Sample 1**

The study presented here provided experimental data for sorption of carbon dioxide on a well-characterized Indian coal. The single component experiments were conducted over a period of few days with the same experimental set-up under identical conditions. Therefore, the resulting data-sets are considered to provide a good basis for comparison of the sorption properties of coal at different temperatures. With the increase in temperature, moles of CO<sub>2</sub> increases as shown in fig. 2b. Also, it can be concluded that with the rise of temperature, the porosity and permeability of coal increases, through which molecules of CO<sub>2</sub> reaches to the unexposed parts of the coal. The first coal sample used was an intact piece of coal. It has been found that with the rise of 173K in temperature, moles of CO<sub>2</sub> sorb by intact coal sample increases by 0.0671 moles per gm of coal. After placing the coal sample for 24 hours inside the heater at a constant temperature, the permeability of coal increased because of micro cracks generated inside the coal which therefore lead to connect more pores internally and as a result the absorption capacity of coal increases. [6]

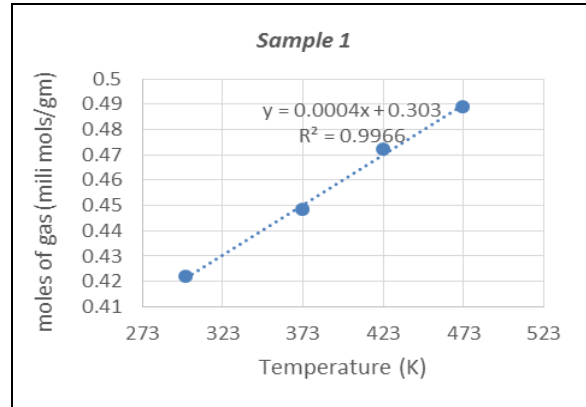
**Table 3:** Pressure variation and CO<sub>2</sub> sorped for sample 1 at different temperatures

Temperature	Initial Pressure of reference cell	final Pressure of sample cell	mole sorb of CO <sub>2</sub>
K	psi	psi	milimoles/gm
300	140	55	0.4219
373	140	37	0.4483
423	140	23	0.4720
473	140	12	0.4890

Fig. 3 shows the linear variation of temperature and sorb moles of CO<sub>2</sub> gas for the sample of coal. Extensive regression analysis has been done to obtain the linear relationship between number of millimoles sorbed and temperature.

**Equation:**

$$\text{moles of gas (mili moles/gm)} = 0.0004 * \text{temperature (K)} + 0.303$$



**Fig. 3:** Sorption capacity of sample 1 at different temperature

**3.2. Analysis of Sample 2**

The second experiment is carried out on a sample of coal which has visible cracks on its surface. It is found that with the rise of 173K in temperature, moles of CO<sub>2</sub> sorb by intact coal sample increases by 0.0777 moles per gm of coal. It is also found that coal sample with crack sorb 15.7% more moles of CO<sub>2</sub> as compared to intact coal sample. This is because of the crack which increases the surface area of coal sample and hence more portion of unexposed area comes in with contact with the CO<sub>2</sub> molecules. [7]

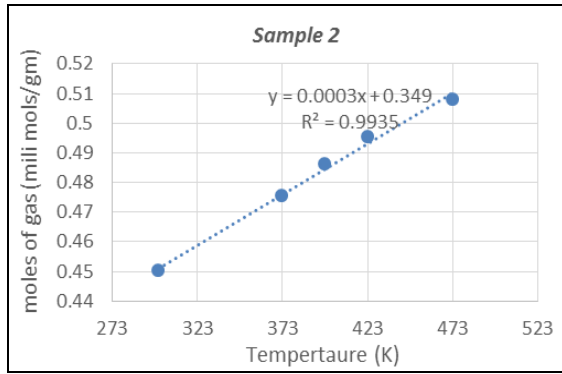
**Table 4:** Pressure variation and CO<sub>2</sub> sorped for sample 2 at different temperature

Temperature	Initial Pressure of reference cell	Final Pressure of sample cell	mole sorb of CO <sub>2</sub>
K	psi	psi	milimoles/gm
300	140	37	0.4503
373	140	21	0.4753
398	140	14	0.4860
423	140	8	0.4952
473	140	4	0.5280

The pattern in which the sorption capacity of cracked coal sample increases, it is same as that of the intact coal sample. It is linear and the equation of that line represents the relation between temperature and sorb mole of CO<sub>2</sub> gas for crack sample of coal (Fig.4).

**Equation:**

$$\text{moles of gas (mili moles/gm)} = 0.0003 * \text{temperature (K)} + 0.349$$



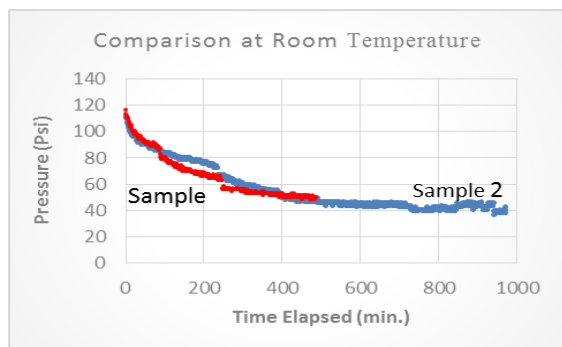
**Fig.4:** Sorption capacity of sample 2 at different temperature.

The millimoles absorbed and adsorbed has been calculated using equation 1

**Inference 1:** mili moles sorped by coal sample increases with the increase in temperature.

### 3.3. Comparison of Intact and Cracked coal

This paper presents the results of the laboratory experiments which investigated the effect of cracks on the surface of the coal sample and its effect on the sorption capacity of coal. In the graph, the pressure of  $CO_2$  molecules is represented with time in x and y axis respectively. From the experiment, two important conclusions can be made, the first is that the sample which has cracks on their surface absorbs and adsorbs faster than the intact coal sample. At the temperature of  $27^\circ C$  and pressure of 140 psi, the amount of  $CO_2$  absorbed and adsorbed for sample 1 and 2 are respectively 0.4219 millimols/gm and 0.4503 millimols/gm which concludes that the sample with cracks absorb 0.0284 millimols/gm more. The second conclusion is that with the increase of the surface area due cracks, the amount of sorb  $CO_2$  increases (Fig.5). The  $CO_2$  and  $CH_4$  sorption capacity using a high-pressure adsorption isotherm technique can be increased. At the temperature of  $17^\circ C$  and to 400 psi, Indiana coals (high volatile C bituminous rank) can sorb (on dry ash-free basis) from 4 to 6.3 m<sup>3</sup>/ton of  $CH_4$  and 19.5–24.6 m<sup>3</sup>/ton of  $CO_2$ . The ratio of  $CO_2/CH_4$  at these conditions ranges from 3.5 to 5.3. [8][9]



**Fig. 5:** Comparison of millimolesorped by sample 1 and sample 2 at room temperature.

**Inference 2:** At particular temperature (room temp. in this case) difference between initial and final pressure of sample cell is more for coal sample with visible crack

### 4. Conclusion

- Experimental Sorption capacity of coal is influenced by numerous factors such as temperature, presence of discontinuities in sample, external stress, initial pressure of gas in reference cell etc.
- With the increase in reservoir temperature, the millimoles of gas sorped by the coal sample increases (fig 3& fig 4).
- Due to presence of crack in the coal sample the pressure change in reference cell is more as compared to that in case of coal sample without crack, which may be because of sorption of more quantity of gas due to presence of more voids (fig 5).
- It can also be concluded that the coal seam should be fractured before injecting  $CO_2$  into the seam for storage. This relates the geo engineering significance of the work.
- The result obtained in this study confirms the number of millimolesorped by Indian coal as studied by other researchers. [8].
- This study is useful for Indian coal industry as a means to enhance production of methane and financial benefit to the industry.

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