Potential for CO_2 Storage in Pakistan with Enhanced Coal Bed Methane (ECBM)

Zahid Umer, Beenish[1], Han Chonghan*
Seoul National University Korea, [1]CIIT Pakistan
(chhan@snu.ac.kr*)

1. Introduction:

ECBM is one of the ways among other carbon dioxide geological sequestration techniques to store CO_2 in the coal bed while enhancing the methane production. ECBM is an emerging technology, the first ECBM-CO_2 pilot plant started operation in 1996 in SanJuan basin, USA at Allinson production unit. Pakistan has one of the largest coal reserves in the world accounting to about 185 billion tons (1). Thar is present in the South of Pakistan (Figure 1) with potential coal reserves of about 175.5 billion tons covering area of 9000 km^2 (2). Pakistan's total annual CO_2 emissions are estimated to have been 142.66 million ton in 2006 (3). Figure 1 shows the potential CO_2 storage locations and source of CO_2 in Pakistan. Thar coal reserves were discovered by geological survey of Pakistan and U.S geological survey in 1992. Thar coal beds are divided into six different blocks on the basis of coal seam thickness, coal analysis and depth as shown in Table 1.

There is little literature available on these coal reserves. John (2000) (4) presented a report for the production of coal bed methane from these coal reserves. None of previous studies have considered ECBM production with the simultaneous CO_2 storage. The purpose of this study is to investigate the ECBM potential in these coal reserves and also ascertain the approximate amount of CO_2 that can be stored in these coal reserves.

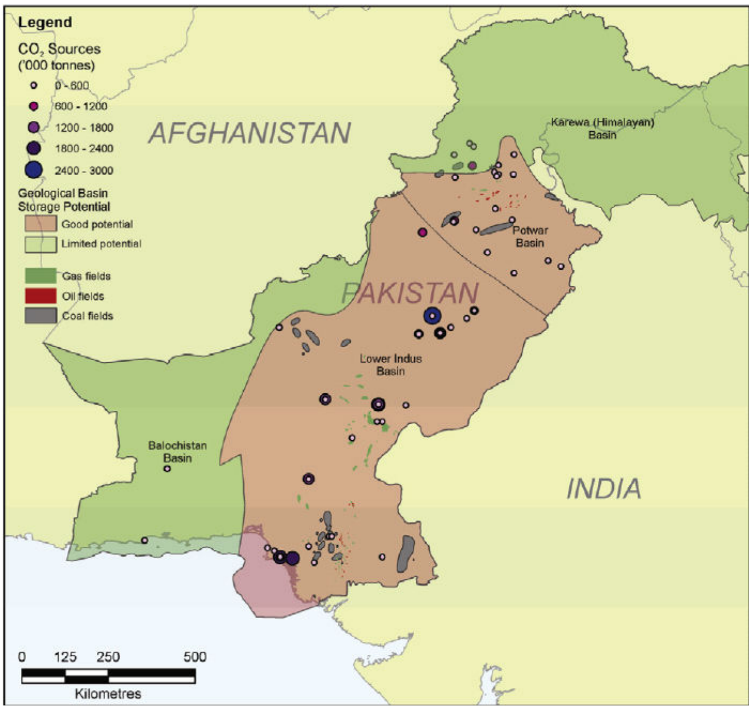

Figure 1: Potential storage and CO_2 sources and in Pakistan (5)

2. Topology and Geology of Thar:

Thar coal field is a part of the Thar desert of Pakistan which is the 9th largest desert of the world.

Block	Area (km^2)	Seam Thickness (m)	Moisture (%)	Ash (%)	Volatile Matter (%)	Fixed Carbon (%)	Sulfur (%)
1	122	8.0-36.0	43.13	6.53	30.11	20.11	0.92
2	55	7.5- 31.0	48.89	5.21	26.55	19.37	1.05
3	99.5	7.2- 25.0	45.41	6.14	28.51	19.56	1.12
4	82	10.7-33.5	43.24	6.56	29.04	21.13	1.20
5	63.5	16.0-30.9	36.82	8.92	38.24	28.22	1.20
6	66.1	9.0- 20.7	38.32	7.62	36.22	20.13	1.52

Table 1: Block wise deposits of Thar Coal Field

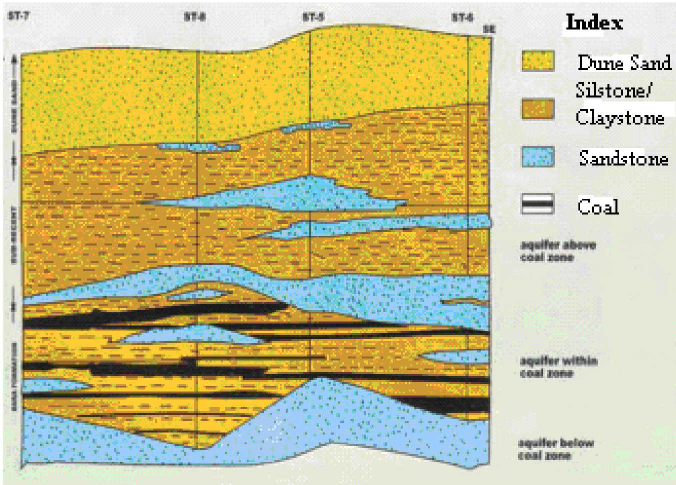

Figure 2: Cross section of Geological formation at Thar Coal Fields (2)

The terrain is sandy and rough with sand dunes forming the topography. Four sub-surface lithostratiographic formations have been identified namely; dune sand, alluvial deposits, bara formation and basement complex. Alluvial deposit comprises of sand stones, silt stones and clay stones. The bara formation consists of carbonaceous clay stone, shale and coal, whereas the basement complex comprises mainly of granitic rocks and quartz diorite (2). There are three saline aquifers located at different depths. One aquifer exists above the coal bed, one exist below the coal bed while the third aquifer lies within the coal zone as shown in figure 2. Salinities in the order of 10,000 ppm total dissolved solids (TDS) with a range of 5,000 to as high as 14,800 ppm is present. In the early stages of dewatering large quantities of saline water is produced, because this water can't be used for any human or industrial purpose due to its high salinity so it must be disposed of carefully.

3. Trapping Mechanism:

In coal bed methane production, large volume of water is pumped-off to lower reservoir pressure causing the desorption of methane from coal while in enhanced coal bed methane, CO_2 gas is used to displace methane from coal. CO_2 adsorbs preferentially on the coal causing the methane to desorb. Coals have higher affinity for CO_2 than for methane as shown in figure 3. Primary coal bed methane recovers only 20 to 60% of original gas in place depending on permeability, gas saturation and operational practices such as well spacing while over 80% of methane in place can be recovered by CO_2 injection which enhances the coal bed methane production (6). CO_2 can be stored in coal as free gas in pore spaces, as gas in solution or as gas directly adsorbed onto internal surfaces of fractures (cleats) in coal. It is a well-established that as gas is released from a coal reservoir, the coal matrix shrinks, and cleats open, creating a significant improvement in coal (cleat) permeability (7). Adsorption is the main CO_2 storage mechanism in coal seams. The mechanism of ECBM and CO_2 sequestration is a complex mix of physical and chemical interaction that must attain equilibrium in the sorbed state and in the gaseous state at the same time. The equilibrium ratio of CH_4 to CO_2 in the sorbed state and in the gaseous state is 1:1 and 3:1 respectively. As

CO_2 is injected it is quickly adsorbed into the coal matrix to achieve sorbed equilibrium, displacing sorbed CH_4 in the process. (8)

4. Estimation of Storage Capacity:

The maximum quantity of gas that can be stored in coal is a function of its adsorption capacity which is sensitive to pressure and temperature. At a given set of P-T conditions, a coal can adsorb higher amounts of CO_2 than CH_4 depending on permeability of seam, permeability of coal matrix, surface area, maceral content, moisture content, rank, grade of coal and pore structure (6, 9). Laboratory isotherm measurement for pure gases have demonstrated that coal can adsorb approximately twice as much CO_2 by volume as methane but sorption capacity of different ranks of United States coal gas shown that this ratio may be as high as 10:1 in some low rank coals (10). In-situ coal contains gas both in micro-pore surfaces in an adsorbed phase and as a free phase within macro-pores given by equations 1 and 2 respectively (9):

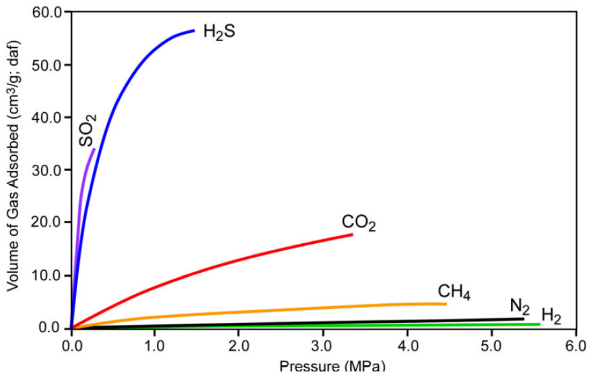

Figure 3: Adsorption of various gases on coal

$c_a = V_L\, p/\, p+P_L$ (1)

where c_a= adsorbed gas content

p= gas pressure

V_L= Langmuir volume coefficient

P_L= Langmuir pressure coefficient

$c_f = \varepsilon\, p/\rho P_a$ (2)

where c_f= free gas content

ε= porosity of coal

ρ= density of coal

p= pressure in coal reservoir

P_a= atmospheric pressure

Department of energy (DOE), US (2007) (11) provided an equation for calculation of CO_2 storage capacity in the coal seams.

$G = A\, h_g\, C\, \rho\, E$ (3)

where G= Estimate of CO_2 storage capacity

A= Area that defines the region begin assessed for CO_2 storage

h_g= Gross thickness of coal seam

C= CO_2 concentration per unit volume of coal

ρ= Density of CO_2 under (Pressure, Temperature) that represents storage conditions

E= CO_2 storage efficiency factor

Powder River Basin of the U.S. and Cambay Basin of India are similar in age and rank to Pakistan's coal (4). Within the range of coal rank for likely targets, methane adsorption capacities in the range of 20 to 30 m^3/ton of coal may be expected at reservoir conditions. The calculated approximate methane production and CO_2 storage capacity is presented in Table 2.

Block Number	Average Seam Thickness (m)	In-Situ Coal (Billion ton)	Methane Production (BCM)		CO_2 Sequestration (Million ton)
			Low	High	
1	22.00	3.566	71.32	106.98	502.4
2	19.25	1.584	31.68	47.52	198.2
3	16.1	2.008	40.16	60.24	299.9
4	22.00	2.471	49.42	74.13	337.7
5	23.82	1.394	27.88	41.82	283.1
6	14.85	1.655	33.10	49.65	183.7
Total		**12.678**	**253.56**	**380.34**	**1805.1**

Table 2: Capacity Estimation of ECBM and CO_2 storage Potential in Thar coal Field

5. Conclusion:

CO_2 injection into the coal seams can be coupled with coal bed methane (CBM) production which is an attractive option for CO_2 storage in coal seams. The results show that approximately 250- 380 billion cubic meters (BCM) of methane can be produced from the coal by the injection of CO_2. The coal reserves of Thar have a potential to store approximately 1800 million tons of CO_2 but there is a need to investigate the specific adsorption isotherms for Thar coal.

6. Reference:

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