Coalbed Methane Potential of Pakistan-A Review

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Abstract

The continuous decrease in gas reserves and increase in natural gas demand forces Pakistan to explore new reserves. Coalfields in the country offer potential availability of gas reserves in the form of coalbed methane (CBM). These coalfields can accommodate gas demand of the country in long-terms. CBM is a clean energy source and shows a complex storage mechanism as compared to conventional gas reserves. Hence, modern techniques are required for its exploitation.

This paper provides a review and analysis of literature for CBM and CO_2-ECBM production from the largest coalfield. Based on available data, similarity among different coalfields assist in calculating potentiality of CBM. The study investigates production potential of CBM and CO_2-ECBM in Thar coalfields. The CO_2 injection can enhance CBM production, and a significant amount of CO_2 can be stored because of process. Being largest coal reserves in the country, the investigation concludes that Thar coalfield can accommodate the country's gas demand. This study proposes technical recommendations for practical implications of large-scale development of CBM and CO_2-ECBM subjected to the in-depth calculation of gas adsorption, gas content, and optimum depth for CO_2 injection.

Introduction

Oil and coal, being major energy contributors for decades, indicate their reliable energy sources (EIA 2015). Lower emissions give natural gas an edge over oil. Since the last few decades, there has been no significant gas discovery found in Pakistan. Hence, the reserves are declining over time. In recent times, the country is facing a shortage of gas supply, which becomes worst during winter. The southern part has been faced with gas shortage despite the presence of huge coal reserves in the region. These coalfields can be the potential source to reduce the imbalance between gas supply and its demand, in terms of coalbed methane (CBM).

Coal bed methane (CBM) contributes around 6% to 9% of natural gas production around the world (EIA 2016). The coalification process generates CBM, which remains trapped in the coal matrix. CBM consists mainly of methane (i.e., > 90%). When coal does not anticipate the release of methane following dewatering, CO_2 and/or N_2 are injected to enhance production of methane, and this process is called enhanced coal bed methane recovery (ECBM). ECBM appears to be an economical coalbed methane production procedure. It offers the ability of environmental mitigation by sequestrating a considerable amount of CO_2 in coalbed.

A few studies have addressed CBM and ECBM recovery from the Thar coalfields of Pakistan. Thar Coalfield has importance for being the largest coal reserve in the country. The literature studies estimated the potential recovery of billions of cubic feet of natural gas from Thar coalfields. However, CBM and ECBM recovery are not discussed as distinct features of recovery in the literature. This study provides a review of the literature, and the ability of Thar coal reserves to meet gas demand using CBM and ECBM mechanisms for the country based on available data.

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Coalbed Methane

In CBM, gas is adsorbed onto coal surface, which makes it different from conventional natural gas in terms of occurrence. This feature allows coal surface area to accommodate greater volumes of gas, in comparison to equivalent conventional reservoirs. The gas is held within the coal matrix and fractures surrounding it. This gas tends to flow away from the coal surface, water presence restricts this movement of gas. Due to this, gas remains trapped between the water and coal matrix as shown in **Figure 1**.

CBM sites vary in properties depending on geological history, burial depth, coal type, and gas content. Hence, the geometrical structure across the coal matrix and the arrangement of cleats (natural fractures) were found to be dissimilar. All these properties combined for the projection of the estimated ultimate recovery of gas.

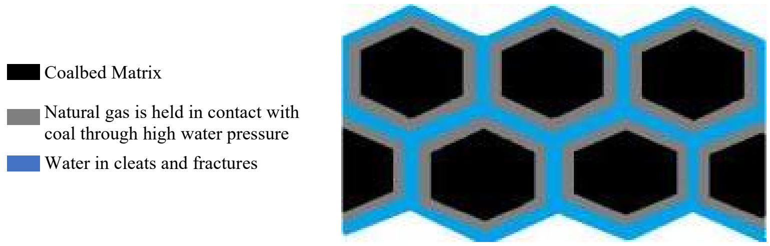

Figure 1—Coalbed matrix illustrating gas surrounding the coal bounded by water and rock.

Gas Trapping Mechanism. Dual or two porosity are mostly found in coals: macro-porosity and micro-porosity, where the average porosity of matrix is less than 1% (Gunter et al. 1997). Coals of the Thar field show dual nature of porosity, with presence of cleats (Siddiqui et al. 2011). Whereas, micro-porosity determines matrix porosity. Therefore, gas could show presence in the following possible ways:

a. Adsorbed condition (gas is adsorbed on the surface of the coal matrix)
b. Free gas (when gas is present in the micro-pores and macro-pores)
c. Mixture form (when gas is dissolved in the water present in coal matrix)

Adsorbed state of gas shares higher fractions of storage, this leaves dissolved or free gas to share less amount for storage.

Production Scenario. Conventional reservoir starts producing by simply drilling a wellbore to the target zone. In contrast, penetrating coal seam does not cause CBM to flow out of the well. The natural pressure of the system must be decreased using either means, in order to encourage gas to flow. CBM is conventionally produced by reversing the physical adsorption process. This is done by means of reducing the partial pressure of adsorbed material into coal mass (Metcalfe et al. 1991). As shown in **Figure 2**, the typical stages of production for CBM wells are (Godec et al. 2014):

a) Dewatering stage: CBM wells produce water initially. This water production is higher in the beginning, which decreases when pressure depression accelerates gas desorption. The gas desorbs and becomes part of producing fluid. The production of gas increases with the decrease in water production.
b) Stable production stage: Gas production reaches the maximum while water production moves to its minimum value. After this stage, gas production decreases slowly.
c) Decline stage: Water production is negligible during this stage, whereas gas production continuously declines. Eventually, a stage comes when gas is uneconomical to produce.

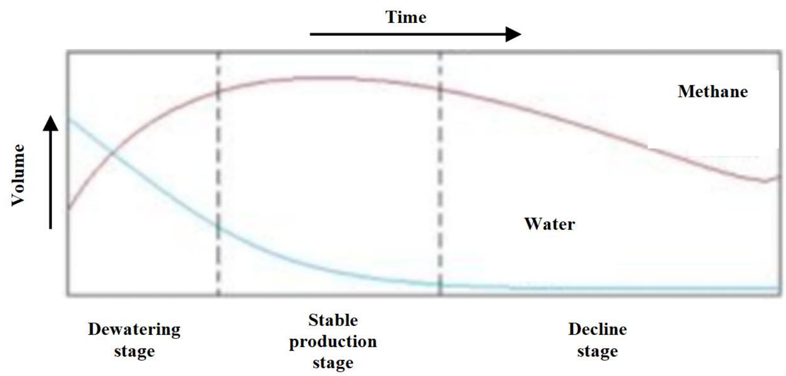

Figure 2—volumes of methane and water during stages of CBM production (Reproduced from Rice 2000).

In conventional gas reservoirs, decreasing pressure causes gas to expand. However, in CBM reservoir threshold value of pressure is needed to initiate desorption. The cleat system remains saturated with water until the initial reservoir pressure is higher than the desorption pressure (Sloss 2015). This condition is under-saturated. During water production, no gas is produced under this condition. During water production, a stage comes when pressure declines and reaches to desorption point, where the gas production starts, as shown in **Figure 3**. The gas follows the Darcy flow through the cleat network to the wellbore (Sloss 2015). The coal releases CH_4 in three main stages:

a) Desorption of the gas from the internal micropores on the surface of the coal.
b) Diffusion of the gas through the matrix of the coal
c) The fluid flow of the gas through the fracture network within the seam to the production well.

The good orientation type depends upon coal rank. Vertical wells are recommended for lower- rank coal, whereas high-rank coals are produced through horizontal wells (Godec et al. 2014). Hence, vertical wells are recommended for CBM production from Thar Coalfield.

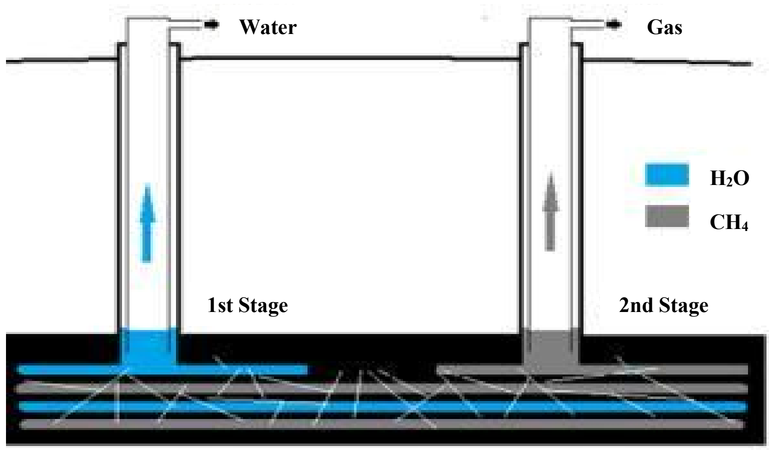

Figure 3—Vertical well showing stages of CBM production.

Similitude among CBM Coalfields

Coalfields show their presence in almost every region of the country. However, Thar Coalfield, having lignite reserves, shares higher deposits than the rest. Besides this, Lakhra and Sondha-Jerruk show a significant amount of coal as well (report). These coal deposits are included in the study based on their presence of greater amounts and availability of data.

The data available in **Table 1** shows the properties of Tharcoal and other coalfields in the world. The data is analyzed to draw an analogy with deposits in other countries. The limited available data on the world's developing CBM fields are used to draw an analogy and project the potential of the Thar coal field for producing gas.

Table 1—Similitude among Pakistan's largest coalfields with world's CBM coalfields.

Country	Pakistan (Talapatra and Karim 2020)			India (Altowilib et al. 2020)	China (Zhou 2013)	Malaysia (Rao and Phadke 2017)	Indonesia (Ranathunga et al. 2014)	Australia (Clarkson and Bustin 2011)	Brazil (Sinayuc et al. 2011)	United States (Primer 2009)	
Project	**Thar coalfield**	**Lakhra**	**Sondha-Jerruk**	**Jharia, Jharkhand**	**Guhan-shan**	**Sarawak**	**South Sumatra Basin**	**Sydney Basin**	**Paran Basin**	**Illinois**	**Wyoming**
Ash content, %	2.90-11.50	4.30-49.00	2.70-52.00	9.01	7.99	20	5.2	35.5	41.99	17.4	6.6
Moisture content, %	29.60-55.50	9.70-38.10	9.00-48.00	1.4	2.68	2.74	10	0.9	0.93	3.1	23.8
Fixed carbon, %	14.20-34.00	9.80-38.20	8.90-58.80	60.7	93.2	N/A	N/A	42	29.91	N/A	N/A
Depth, m	120-200	80-450	1-85	450 m-500 m	530 (avg.)	N/A	516.3 (avg.)	N/A	620 (avg)	N/A	N/A
Gas content m^3/t	N/A	N/A	N/A	N/A	N/A	N/A	51.6	12.9	2.18	N/A	N/A
Recoverable gas, BCM	25.35	N/A	N/A	N/A	31.2	N/A	N/A	N/A	N/A	N/A	N/A

Ash Content. Methane adsorption capacity is correlated with ash content. Increasing ash content reduces the adsorption capacity of methane. However, a higher range of ash content seems to decrease adsorption capacity (Feng et al. 2014). Considering this phenomenon, the adsorption of gas in Tharcoals would be less than that of Lakhra and Sondhajherruk. Furthermore, ash content of Thar coalfield shows similarity with Jharia coal deposits, shown in **Figure 4**.

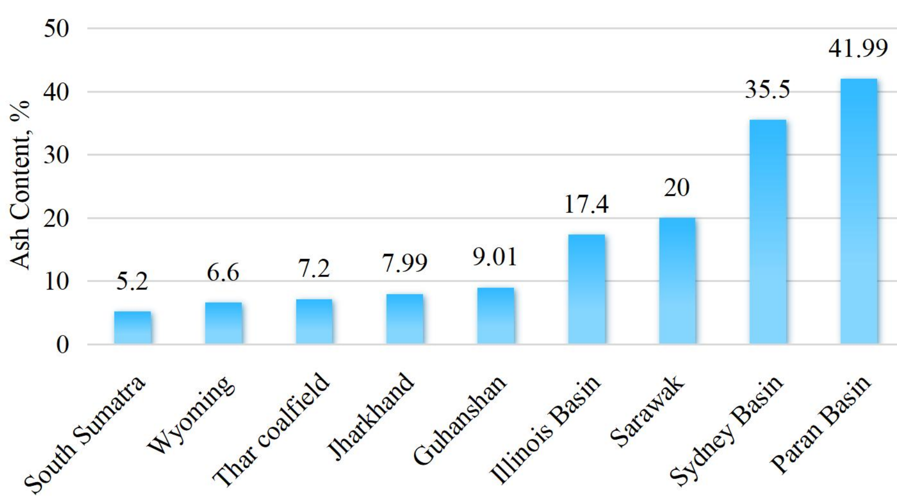

Figure 4—Ash content of different coalfields.

Moisture Content. For accurate calculation of gas production and recovery, the moisture content effect is incorporated in different directions of reservoir properties. Sorption rate, gas diffusivity, and gas adsorption decrease with an increase in moisture content (Cao et al. 2020). This is because water molecules occupy large spaces, leaving less volume for gas residence (Pan et al. 2010; Li and Zhang 2014). The higher moisture content implies lower gas residence in coal seams (Talapatra and Karim 2020). Even though higher moisture contents (**Figure 5**) in coals of Thar indicate lower gas storage in the spaces. Thar coal has the advantage of more gas storage due to its great amount as compared to the other regional deposits.

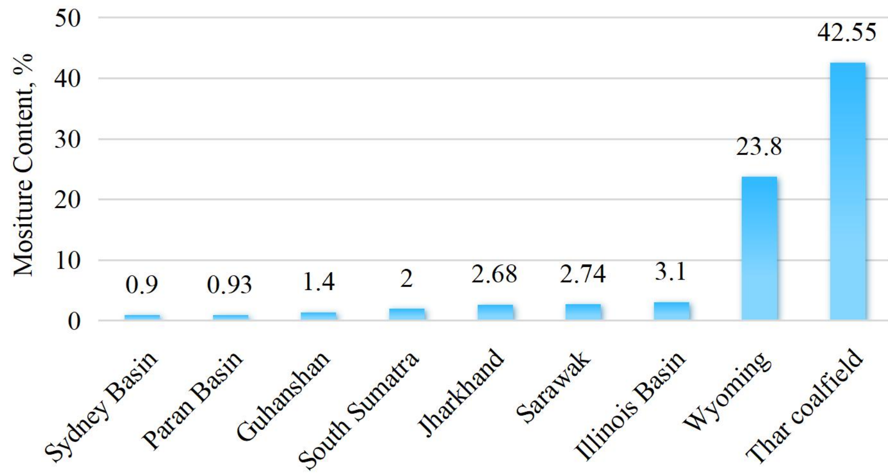

Figure 5—Moisture content of different coalfields.

Fixed Carbon. Carbon and energy content decides coal ranks. The lower coal ranks have lower carbon contents (Tunio and Ismail 2014) . Coals in Thar, being lignite, have lower carbon content. Paran basins show similarity with Thar coalfields in terms of carbon content (**Figure 6**). Gas content in Paran basin is lower as compared to others in Table 1, whereas gas content in coals of Thar is still to be determined.

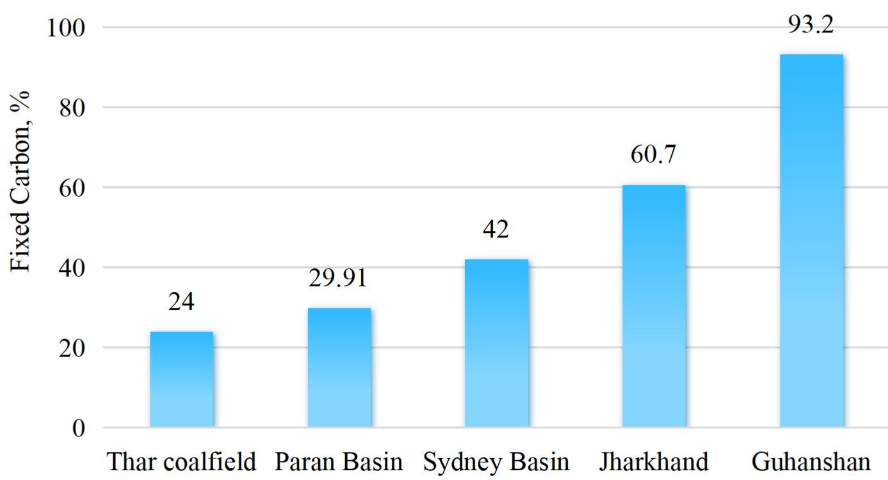

Figure 6—Carbon content of different coalfields.

Enhanced Coal Bed Methane (ECBM) Recovery

The reservoir pressure method can recover around 50% of gas-in-place (Gale et al. 2001). This method is simple but inefficient. Hence, a considerable amount of gas is left behind, which cannot be recovered by the depletion method. The remaining gas can be recovered by displacement desorption, in which another gas having a higher adsorption capacity is injected. The injected gas displaces the gas in the coal seam. Any such method used to recover CH_4 is regarded as ECBM, shown in **Figure 7**. Several recovery agents such as N_2, CO_2, and flue gas are used for this purpose. However, CO_2 has gathered attention due to its sequestration ability and promising environmental mitigating effect.

CO_2 shows a greater affinity to coal than CH_4. Early laboratory measurements concluded that coals can absorb twice as much CO_2 as methane by volume. How recent research on coals of different ranks in the United States claimed this ratio could be as high as 10:1 in low coal ranks (Stanton et al. 2001). Therefore, there is a large potential for CO_2 storage in unmineable coal seams of the world. Since Thar coalfield has low-rank coal so it offers higher CO_2 storage against CH_4 production.

CO_2 injection in coal seams causes a reduction in strength and permeability. This reduction in strength affects ECBM and the long-term safety of CO_2 sequestration, as CO_2 may migrate back to the atmosphere after sometime of injection. This makes it a great challenge to produce methane against the best bargain of CO_2 storage. However, hydraulic fracturing can increase seam permeability so that CO_2 can provide maximum penetration in the formation.

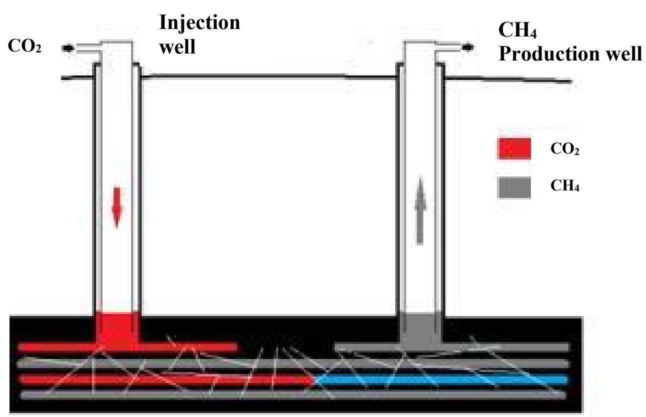

Figure 7—Vertical well showing CO_2-ECBM recovery.

Coal seams should be deep enough to ensure enough reservoir pressure. This parameter serves as a key control on the amount of gas adsorbed to coal. The permeability decreases with an increase in depth. Hence, the effective optimal depth window for CO_2-ECBM is between 300 and 1500m (Laenen et al. 2005). Since the depth of Tharcoals ranges from 120-200m, it could offer less efficiency.

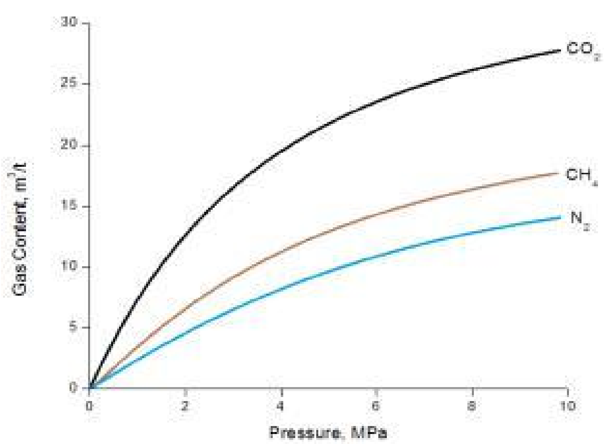

Figure 8—Measured CH_4, N_2 and CO_2 Langmuir isotherms (Data Source: Sinayuc et al. 2011).

Experiment test showing the adsorption of CO_2 is twice that of methane, shown in **Figure 8**. This makes CO_2 displace methane efficiently and remain stored in a coalbed (Sinayuc et al. 2011). Geology is also one of the most important parameters to be considered to store CO_2. The Bara formation of the Thar area containing coal seems to provide a good geology structure for CO_2 storage, but more study is required in this regard.

Effect of Rank on ECBM. Thar coalfield can offer around 20% efficiency due to the presence of lignite reserves, shown in **Figure 9**. However, a great amount of gas storage in a coal seam is a function of its adsorption capacity, and other geological factors: stratigraphy, structural geology, and hydrology. Whereas coal sorption capacity is a function of pressure, temperature, the permeability of the coal seam, rank, moisture content, surface area, and macerals composition of coal.

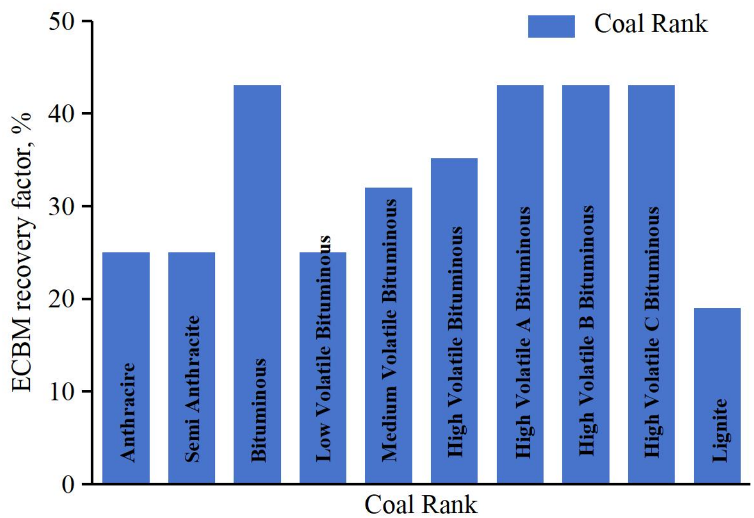

Figure 9—ECBM percentage recovery against each coal rank (Data Source: Godec et al. 2014).

CO_2-ECBM Projects. Four CO_2-ECBM field projects have been completed in China (Zhou et al. 2013), three in the Qinshui Basin and one at the eastern margin of the Ordos Basin. Being environmentally friendly in nature, CBM is being exploited across many parts of the world. **Table 2** shows injecting amount of CO_2 at various location of the world.

Table 2—CO_2-ECBM projects around the world (Leung et al. 2014).

Project Name	Location	Year	CO_2 Inj. Rate (Mt/yr)
San Juan Basin	New Mexico, USA	1996	0.1
Fenn Big Valley	Alberta, Canada	1998	0.02
Recopol	Poland	2003	0.0004
Qinshui Basin	China	2003	0.01
Yubari	Japan	2004	0.004
Permian Basin	Texas, USA	2005	0.3
Pamham Dome/Uinta Basin	Utah, USA	2005	0.9
Hokkaido	Japan	2015	0.01

Thar Coal Potential and Gas Demand

The rapid decline in gas reserves leaves Pakistan facing a shortage of energy. In recent years, natural gas demand has risen to 6 BCFD across the country, with a supply of 4 BCFD (Pakistan's Inevitable Demand for Energy 2018). This shortage becomes worst during the winter season when a rise in demand is observed. The

CBM or ECBM from Thar Coalfield can accommodate regional demand and beyond. Since Thar coal seams have lignite coal so it offers suitability for CO_2 sequestration along with CH_4 production. Lignite coals contribute to 99.7% of coal reserves in Pakistan, as shown in **Figure 10**, **Table 3** in appendix-Ishows the distribution of types of coal reserves in the country. The country has lignite reserves in great amounts that could accommodate methane gas even with lower gas content per ton.

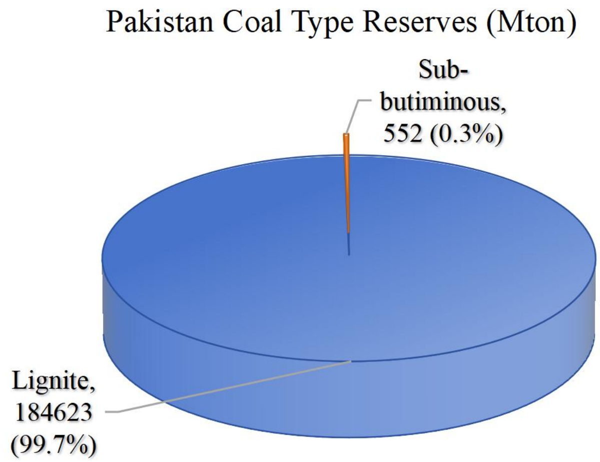

Figure 10—Coal type reserves in Pakistan.

Figure 11 shows a simulation of the production capacity of a different block at Thar Coalfield (Zahid 2018). The studies discussed are based on a limited amount of data available. However, detailed data and studies can further estimate the amount of CH_4 production and CO_2 storage in Thar coalfields. Block 1 appears to be the most promising candidate for CBM and ECBM production. Further detailed data could indicate right candidate block for the long-term.

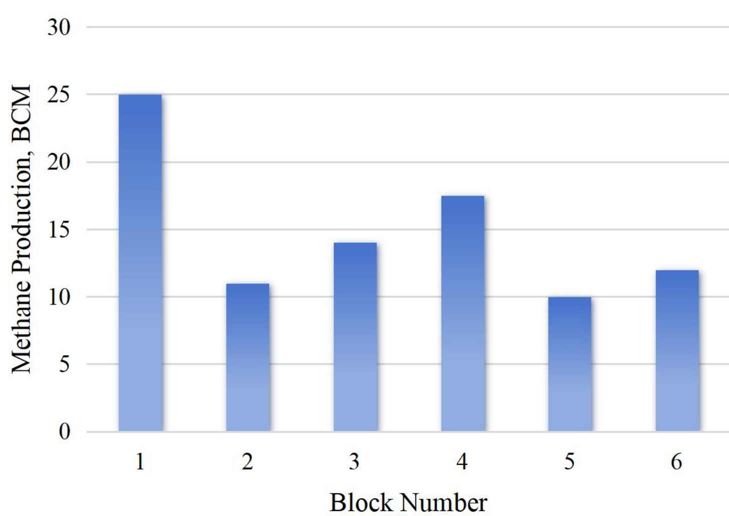

Figure 11—Simulation CH_4 production capacity for each block of Thar coalfield (Data sources: Zahid 2018).

Conclusion and Suggestions

CBM is promising unconventional reserves held in an absorbed state. Many factors contribute to its large-scale production. The study evaluated CBM and ECBM from potential coalfields in Pakistan and conclude following findings:

1. Properties of coals present in Thar, Lakhra, and Sonda Jherruk show the potential of CBM presence. Thar coalfield, being great in quantity, gathered preference for studies present in literature.
2. The high amount of moisture present in Thar coals implies a long dewatering time before CBM development for production.
3. Gas content and gas adsorption need to be studied to calculate the exact recoverable methane.
4. After CBM recovery, CO_2-assisted CBM production could be calculated. More studies need to be carried out for enhanced methane recovery and sorption behavior of coal.
5. Lignite reserves have lower exchange efficiency for CO_2 and CH_4, hence CO_2 injection offer CO_2 sequestration as well.

Open pit mining in Thar Coalfield causes methane emissions directly into the atmosphere. This gas could accommodate areas suffering from energy shortages. Whereas the pilot project can reflect its wide-scale applicability to meet domestic gas needs. Since the administrative proposition is beyond the scope of this study. Therefore, the technical implication of CBM production from Thar coalfield is as under:

1. Gas adsorption capacity at different depths and seams is to be determined.
2. The average volume of gas content per ton in coals of Thar is still to be determined.
3. The product of coal seam available and gas content will simulate CBM reserves in an absorbed state.
4. The deposition depth of coal is shallower than the optimal depth for CO_2-ECBM. Hence, maximum efficient depth for Thar coalfield is to be carried out for safe storage of CO_2.

Conflicting Interests

The author(s) declare that they have no conflicting interests.

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