SYNOPSIS

**Background:**

Conventional hydrocarbon reserves are declining very fast to keep pace with the global energy demand for economic growth. Even presently produced natural hydrocarbons are insufficient to fulfill the increasing global energy demand. To meet the challenges of this situation, all concerned with energy sectors all over the world are working hard to find out other sustainable, economic energy resources, besides the conventional one. Coalbed methane (CBM), which was considered to be uneconomical and non-conventional only a few years back, has now become very much attractive as a new energy resource. Specifically, for the countries like India where more than 75% of the total energy demand is accomplished from imported oil & gas, CBM can play the most important role to sustain its rapid pace of development.

Methane which is found in coal seams is named as coalbed methane. Large amounts of gases like methane, ethane, CO₂, water vapor, H₂S etc. are produced during coalification, and a part of them is held both in the coal seams and adjacent rocks [Kim and Kissel, 1988; Patching, 1970]. Methane is the principal gas in this mixture. Methane, which is 23 times more potent green house gas (GHG) than CO₂ leads to mining hazard if not ventilated prior to coal mining operations. Thus, presence of CBM in underground mines not only makes works difficult and risky, but also makes it costly. On the other hand, CBM is a remarkably clean fuel with a heating value of approximately 8500 KCal/kg compared to 9000 KCal/kg of natural gas of power grid quality. Thus, CBM production not only can provide additional energy to fulfill more demand, but also help to reduce global warming to great extent. Enhanced recovery of CBM by CO₂ sequestration can improve the situation.

The Directorate General of Hydrocarbons (DGH) of India estimates that the major Indian coal fields (in twelve states of India covering an area of 35,400 km²) contain 4.6 TCM of CBM [Prasad, 2006] against global reserve of 120 to 150 TCM. In terms of CBM potential, India is the fifth largest country in the world.
Exploration activity of CBM in India was started in 1995. The four major Damodar valley Gondwana coalfields viz. Jharia, Bokaro, North Karanpura and Raniganj indicate the prospective CBM basins; exploration and field development activities have been going on since 1997 and a few fields have started producing commercially.

The essential aspect of efficient and economic coalbed methane production is the clear understanding of sorption characteristics of methane on coal seams, gas transport mechanism through the cleats and efficient water production from formation. The main factors, which determine the efficient recovery from coalbeds are: the gas content of the coals [Diamond and Schatzel, 1998; Levine, 1993], the permeability or flow characteristics of the coals and the thickness of the coal beds. Total volume of gas reserve and recoverable amount immensely depend on these parameters. On the other hand, origin of coal, its petrographic & chemical characteristics and geology of the reservoir are the key parameters controlling the gas content and permeability of the coal.

Though natural gas recovered from CBM reservoir is sold and used in the same manner as that from gas reservoir, CBM production is more complex due to its heterogeneity, pressure dependent properties and friable nature. Moreover, unlike conventional reservoir production rate is enhanced at lower pressure in CBM reservoir. Coal reservoirs are mostly water saturated and requires long dewatering to deplete the pressure for free gas generation. Injection of CO$_2$ into reservoir may improve the recovery. When CO$_2$ is injected under high pressure through injection wells, it flushes the gaseous CH$_4$ because of its preferential adsorptivity on coal. The partial pressure of CH$_4$ in the gaseous phase is reduced, resulting in a non-equilibrium condition in a system containing both CH$_4$ and CO$_2$. As a result, CH$_4$ is pulled into the gaseous phase to achieve partial-pressure equilibrium and release methane to cleat system. However, detailed investigations are required for effective implementation of efficient technologies for economic production of CBM from Indian fields. Only a few countries like Canada, China and USA have started pilot scale CO$_2$ sequestration projects to enhance CBM production (E-CBM). More intensive investigation is necessary for fruitful application of this technology. So far, only a very limited investigation has been reported on detailed study of Indian CBM fields.
Keeping these prospects and difficulties of CBM in mind, the present research work addresses various issues of Indian CBM reservoirs starting from geological aspect to enhanced methane recovery, and its future prediction using commercial simulators.

Jharia and Raniganj, the two most prospective Indian CBM fields, and another less prospective Singareni Coalfield were selected as the study area. Another reason for selection of Singareni coalfield is geological prospect for CO\textsubscript{2} injection. A good number of coal samples were collected from the wells of these fields and experiments were carried out.

The present research work describes a systematic approach for coalbed methane evaluation and is arranged into six main sections: 1) Selection of study area and its geology 2) Petrographic study of the collected samples, 3) Evaluation of gas content, adsorption capacity and gas saturation, 4) Primary recovery of methane, 5) Enhanced recovery of methane by CO\textsubscript{2} sequestration and 6) Prediction of water production in CBM wells.

**The objectives in a nutshell:**

I. Collection of coal samples and reservoir core samples from three coalfields in India.
II. Chemical and petrographic study of the collected samples and evaluated CBM potential zone.
III. In-situ gas content measurement and isotherm study for evaluation of CBM potential
IV. Determination of primary recovery of methane from experimental study & future prediction using Fekete CBM software based on Material Balance equation
V. Laboratory investigation on recovery of CBM by CO\textsubscript{2} injection
VI. Data analysis & Optimization of the primary and enhanced CBM recovery using Eclipse simulator based on Black-Oil model.
VII. Prediction of water production in CBM wells
Brief descriptions of the chapters of the thesis are as follows:

**Chapter 1** emphasises with the introductory contents, in which importance of coalbed methane and CO\textsubscript{2} sequestration are explained in detail. The present, global and Indian scenario of CBM and its distribution are also discussed. A brief overview of the different important parameters which affect CBM reserve and its recovery are also discussed.

**Chapter 2** mainly deals with the different geological aspects like lithology, stratigraphic succession, and geological structure, i.e., fault, joint, fractures etc. Effects of these parameters on occurrence of coal in CBM basin, generation of methane and its retention capacity of the coal have been explained in detail. This chapter also incorporates the feasibility study of CO\textsubscript{2} sequestration techniques based on the geology of the areas under investigation. From this study, it could be concluded that only small parts of Jharia and Raniganj coalfield which contain favorable thickness, cap rock and CO\textsubscript{2} capacity, are suitable for prospective CO\textsubscript{2} sequestration. In Raniganj coal basin the average seam thickness is about 5m-20m and seal/cap rocks are mainly sandstone, shale. So this formation is suitable for storage of CO\textsubscript{2} because of seam thickness and cap rock integrity. However, many areas are geologically disturbed in presence of fault/fracture/etc. and should not be considered for geologic storage of CO\textsubscript{2} instead of having good adsorption capacity.

**Chapter 3** describes the procedure for sample collection from the CBM field, preparation of sample for analysis, experimental setup and methods for the present investigation. Procedures for the determination of rank of coal from proximate, elemental and from petrographic studies have been discussed. Proximate analysis, chemical analysis, and petrographic study were carried out on samples collected from different fields because these are the key parameters in identifying the prospective coalbeds for economic amount of methane content. The analysis show the variation of ash content from 10.26% to 40.06%, moisture content from 0.13% to 3.82%, variation of volatile matter from 6.92% to 40.26% with remaining fixed carbon. Jharia coalfield shows maximum carbon content whereas Singareni shows minimum carbon content.

Correlations are made for variation of the above parameters with depth for the studied areas which will be helpful in identification in the suitable seams for CBM exploration. From the
results, it can be inferred that fixed carbon percentage show an increasing trend with depth whereas moisture and volatile matter indicate decreasing trend with depth. Elemental analyses showed a variation of elemental carbon content 59.93% to 90.23% on dry-ash-free basis (daf). Lowest ‘C’ content was observed for Singareni coals. Results of elemental analysis are used for determination of type of kerogen present in the respective field using van-Krevelin diagram. The plots obtained from present investigation show that the studied coal samples from Jharia and Raniganj coalfields belong to type III kerogen and bituminous in rank, whereas those from Singareni coalfield are of type III kerogen and coals are belonging to lignite to sub-bituminous in rank. Petrographic analysis of coal shows the variation of vitrinite reflectance from 1.23% to 2.03%. Correlation has been made for mean vitrinite reflectance with depth and shows an increasing trend of vitrinite reflectance with depth of coal seam. The Jharia and Raniganj coalfields where from the samples were collected may be the suitable zone for CBM production because of bituminous rank of coal and presence of type III kerogen whereas for Singareni coalfield although this field shows type III kerogen but it is less favorable for CBM prospect due to presence of low rank coal.

Chapter 4 discusses about the gas content measurements (i) in-situ gas content measurement in the drill site and (ii) adsorption isotherm study in the laboratory. This chapter clearly describes the procedure for measurement of in-situ gas content, description of volumetric apparatus and isotherm study. Is-situ gas content of coal samples which were measured from canister desorption test at well drill-site vary between 4.81 cc/g to 25.43 cc/g as dry ash free basis (daf) and 4.42 cc/g to 4.52 cc/g (dry ash free basis) for Jharia and Raniganj respectively. The range of gas content for Jharia coalfield fall within and above the range of economic limit and should be the targeted as suitable zone for CBM extraction.

The gas adsorption capacity, reservoir pressure, critical desorption pressure and gas saturation of selected coal samples have been determined from the isotherm study using adsorption isotherm apparatus. The maximum adsorption capacity of samples from Jharia coalfield varies from 12.20 cc/g to 23.00 cc/g (daf), and the degree of gas saturation varies from 34.90% to near saturation (95.13%). The critical desorption pressure (CDP) is less than the reservoir pressure for most of the cases. So, dewatering period is required before
initial gas production from these areas. Predicted production characteristics are seen to behave similarly as observed from those of nearby development wells.

In the present study, various adsorption isotherm models were tested with the experimental data and best fit model is considered. Sorption data obtained from adsorption isotherm study were fitted with the various isotherm models and their absolute error and regression values are compared to determine best fit one. Langmuir isotherm model was found to be the best fit model with the lowest absolute error and better regression value for all the cases. The gas content in coal determined by field desorption study and adsorption study are different. Adsorption isotherm gives higher value because it measures the maximum gas content capacity whereas desorption test measures only the volume of gas retained on coal at present condition. During coalification and storage within reservoir, gas may escape from coal due to change in pressure, temperature or presence of migration path like fracture, fissures etc.

Chapter 5 describes the primary recovery process, gas transport mechanism through the coal cleats, gas reserve estimation and simulation study. The material balance equation and volumetric method are used for gas reserve estimation. The Fekete CBM software is used to predict the future production of gas and water. The simulation study shows that longer dewatering is required to start gas production; rate of production is also less due to low permeability of the reservoir. To enhance production rate, fracturing of coalbeds is essential. Multilateral wells like Z-Pinnate type also may increase the accessibility of wells to larger area (e.g. Jharia field) and thus can enhance the production rate.

Chapter 6 consists of comparative study on primary and enhanced CBM recovery by CO₂ injection and effects of various parameters like pressure, wells spacing and pattern, water saturation and injection pressure on this. Laboratory investigations as well as simulation studies have been carried out using Eclipse simulator. Laboratory investigations showed an enhancement of 2.87 times methane recovery whereas simulation study using ECLIPSE simulator showed a 3.4 fold increase in methane recovery compared to primary recovery. The process has been optimized considering various economic and technical parameters.
Chapter 7 covers the prediction of water production from reservoir as a function of water level because water production has high impact on the recovery of the methane from reservoir because inefficient dewatering can damage the coalbeds and hence the fluid flow network path. Water production data with variation in water level were collected from fields and analysed. A new mathematical correlation has been developed for predicting water production rate from dynamic water level which is much simpler compared to conventionally used type curve analysis [Agarwal et al., 2013].

Chapter 8 presents the summary of the work for each chapter which is included in the thesis. The future work of this research is also recommended in this chapter.

References:


