The research work presented in this thesis deals with the various aspects of coal bed methane and production including in-situ gas content measurement or direct gas content measurement, petrographic analysis of the samples, isotherm studies of the selected samples, CO$_2$ sequestration and performance of water production analysis. Jharia coalfield, Raniganj coalfield and Singareni coalfield were chosen as the study area. Chemical and petrographic analysis of the collected samples was determined in the laboratory and type of kerogen present was evaluated by plotting H/C and O/C atomic ratio in the van-Krevelin diagram. In-situ gas content measurements have been carried out by canister desorption studies for Jharia and Raniganj coalfields. Gas saturation and gas sorption characteristics have been determined from the adsorption isotherm curves, gas content data and reservoir pressure.

Experiments on enhanced recovery of methane from coalbeds have been carried out on samples from Jharia coalfields as this field shows maximum CBM reserves among the studied area and some parts of this field is also geologically stable. Model has been prepared and simulated for predicting and optimizing the primary & enhanced recovery of methane from these fields in future with variation in the variable parameters. Fekete CBM software and Eclipse simulators were used for this. The predicted results were compared with the experimental results. The simulated results could not be history matched due to non-availability of field production data because most of our CBM fields are at initial stage of production and no enhanced recovery project has been implemented so far.

The following conclusions have been drawn from the research work presented in this thesis:

1. Coal proximate analyses of coal samples from different locations of Jharia coalfield reveal that the moisture content varies from 0.13% to 2.81%, ash content varies from
1. Proximate analysis results for samples from Jharia coalfield show that the moisture content varies from 10.26% to 40.06%, volatile matter varies from 6.93% to 28.40% and fixed carbon percentage varies from 45.14% to 83.53%.

2. Elemental analysis results and H/C versus O/C atomic ratio plots in the van-Krevelin diagram for the samples of Jharia coalfield indicates that the studied coal samples belong to type-III kerogen and bituminous in rank. This type-III kerogen and bituminous rank of coals are more favorable for presence of methane gas.

3. Coal petrographic analysis of coal samples from Jharia coalfield shows that vitrinite ranges from 32.04% to 74.90%, semi-vitrinite ranges from 0.60% to 4.10%, inertinite ranges from 15.02% to 51.40%, liptinite ranges from 0.02% to 10.40%, mineral matter ranges from 4.6% to 23.00% and vitrinite reflectance ranges from 1.23% to 2.03%. Based on proximate and petrographic analysis results, the rank of most of the coals recovered from 3 different locations of 3 wells, namely, well J1, well J2 and well J3 are inferred to be medium volatile bituminous (mvb) to low-volatile-bituminous (lvb) rank and these rank of coals are also important for prospect of coal bed methane.

4. Vitrinite reflectance of the collected coal samples from Jharia coalfield was determined in the laboratory and compared with depth. From the correlation in most of the samples it was found that with increasing depth of coal seams the values of vitrinite reflectance increases.

5. Proximate analysis results for samples from Raniganj coalfield show that the moisture content varies from 0.77% to 2.0%, ash content varies from 7.6% to 24.92%, volatile matter varies from 19.80% to 38.89% and fixed carbon percentage varies from 41.91% to 70.70%. Estimated vitrinite reflectance values from the proximate analysis results show that values ranges from 0.57% to 1.45%. From the proximate analysis results it can be inferred that the rank of these coal samples from Raniganj coalfield are medium volatile bituminous to high volatile-C bituminous in rank.
6. Elemental analysis results of the samples from Singareni coalfield are plotted in the van-Krevlin diagram and it shows that H/C versus O/C atomic ratio belongs to type-III kerogen and the coals are belonging to lignite to sub-bituminous in rank. Although this field shows type-III kerogen but it is less favorable for CBM prospect due to presence of low rank coal.

7. From coal proximate analysis of the samples from Singareni coalfield, it was found that ash content vary from 10.52% to 26.59%, moisture content vary from 2.46% to 3.82%, volatile matter vary from 23.30% to 40.26% and fixed carbon content of the samples vary from 26.01% to 53.21% respectively. The vitrinite reflectances have been determined from empirical equation and the values range from 0.45% to 0.88%. Atomic ratio of H/C are plotted against O/C atomic ratio in the van Krevelen diagram and observed that the coal samples from this coalfield belongs to type-III kerogen with a maturity of Lignite and sub-bituminous stage, hence gas content capacity is low.

8. Coal samples collected from different part of the Jharia field showed a large variation in gas content, values vary from 3.37 to very high value of 17.80 cc/gm (as received basis). Hence while one part of the field does not contain economically viable gas, other part of this area is highly productive. This shows that continuous and extensive study must be carried out before venturing into the CBM business. This is due to mainly heterogeneous characteristics of coalbeds and its depositional history. However, in general, Jharia coalfield is considered as very prospective CBM field and this could be confirmed from production data of development wells in this area.

9. Gas content of coal samples from 2 wells of Raniganj coalfield was found to be 4.42 cc/g to 4.52 cc/g at STP (156 SCF/ton to 159.66 SCF/ton) and this gas content is less as compared to economic limit of methane presence in the coal bed. So, these wells are not considered for CBM extraction, in future these fields may be considered for methane extraction using advance technology. However, others blocks of Raniganj coalfields (not studied here) have very good gas content and started CBM production.
10. The adsorption isotherm experiments show that gas adsorption capacity of studied coal samples from Raniganj coalfield ranges from 15.90 cc/g to 16.26 cc/g (daf basis) and in-situ gas content data showed much lower values varying from 3.93 cc/g to 4.23 cc/g, which is approximately 40% of adsorption capacity. This requires a long dewatering period as also observed from simulation study on this reservoir.

11. Gas storage capacity or maximum gas holding capacity measured from isotherm studies for coal samples from J1 well of Jharia coalfield varies from 18.9 cc/g to 22.4 cc/g (daf basis) whereas direct gas content value varies from 12.20 cc/g to 15.80 cc/g (daf basis). So, when in-situ gas content data were compared with adsorption isotherm data, it is found that the gas saturation varies from 60% to near saturation (99.28%). The reservoir pressure varies from 6693.23 KPa to 10532 KPa depending upon the depth of the coal seams and critical desorption pressure determined from Langmuir isotherm curve varies from 2260 KPa to 6693 KPa. Methane adsorption values of the samples from location 2 (J2) of Jharia coalfield varies from 17.10 cc/g to 20.50 cc/g (daf basis) and saturation of gases determined were compared with in-situ gas content values and it is found that the degree of gas saturation varies from 34.90% to 67.73%. The estimated reservoir pressure of the coal samples of this field varies from 11086 KPa to 14311 KPa and critical desorption pressure from isotherm studies varies from 1200 KPa to 4900 KPa. For location 3 (J3) the methane adsorption value varies from 21.20 cc/g to 23.00 cc/g (daf basis) and gas saturation value varies from 47.51% to 95.13% which is the value of near saturation. The reservoir pressure varies from 10528 KPa to 14237 KPa and critical desorption pressure determined from isotherm studies varies from 2840 KPa to 10025 KPa. For all the coal samples collected from 3 different locations of different wells (well J1, well J2 and well J3) of Jharia coalfield in order to produce CBM adsorbed in the coal matrix, it is required to reduce the reservoir pressure below a pressure called Critical Desorption Pressure achieved by dewatering of the coal seams.

12. It is observed from the adsorption isotherm study on coal samples for Jharia coalfield that with increasing ash and moisture percentage of coal samples gas adsorption capacity decreases and increases with increasing fixed carbon percentage.
13. Recovery of methane by primary method (depletion in pressure) and by CO₂ injection were studied. Laboratory investigation 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 difference of experimental and simulation study may be because of matrix swelling effect which was not considered in simulation study. The experimental and simulation study recommends that CO₂ injection should be beneficial for enhanced recovery of methane for the area under study.

14. The sensitivity analysis of well spacing between producer and injector gives an optimal well spacing of 1060 ft as profit per unit area was maximized at an optimized CH₄ production rate for the given input data.

15. A sensitivity analysis of CO₂ injection pressure gives useful information to decide the CH₄ production period and to carry out economic evaluations. Cost of separation of CO₂ from the flowing stream will be an economic factor in deciding when to stop CO₂ injection after CO₂ breakthrough.

16. A mathematical correlation has been developed for the water production rate with dynamic water level. The data were collected from the field well testing. The developed model can be used directly in this region to find the water potential of the pay zones and thus it can be used to design the artificial lift facility. The developed model is much faster and provides more accurate results compared to that of the conventional methods of CBM well test analysis. The water influx at a particular time can be formulated from the above mentioned method using the correlation of ‘Q’ with dynamic water level, ‘L’ at any time and thus the capacity of the wells (water influx) has to be formulated for different wells at equal time interval, the graph is plotted with water flow potential versus time. This plot will give the general decline of the influx of the well. Once the graph is extracted, it can be extrapolated to find the water influx at the end of future time periods and finally the dewatering period of the well. So, the time parameter can be used to find the “maximum flow rate” of the gas from the well. Thus, the developed
model can be considered as a helpful mathematical tool for predicting the water production rate and designing of artificial lift for efficient production of methane from coal bed.

The present study represents a thorough investigation on a part of Indian CBM field starting from preliminary analysis including geological, petrographic or chemical analysis to gas content measurement, isotherm study, ECBM by CO₂ injection and finally optimization by simulation. So far, no such intensive information is available on any CBM field in India. This study will be very much helpful to provide detail information about various coal properties and its effect on gas content of coal, its maximum gas content capacity, methane production rate and recovery with variation in other reservoir and economic properties, feasibility of CO₂ injection, and finally water production rate as a function of dynamic water level of the study area.
Recommendation for future work

This thesis has been documented with detailed study of petrography and chemical analysis of coal and their importance for coal rank determination and gas storage capacity. Zone of CBM potential have been identified from petrography, chemical analysis of the coal seams and from in-situ gas content data. Also a detailed study of sorption isotherm for methane and CO2, reservoir pressure, critical desorption pressure and saturation of the coal seams have been done. The Primary and secondary production of coalbed methane, importance of CO2 sequestration, modeling and simulation study and water prediction performance analysis have been covered in this thesis. Although this thesis covered almost all the aspect for production of CBM but more intensive study is required for implementation to the field. Thus following recommendations are made for future works:

1. To study the adsorption-desorption isotherm of methane and CO2 with varying compositions at different pressure and temperature conditions.
2. Experimentation on recovery of CBM by CO2 injection with variable pressure, temperature, gas composition and flow rate conditions for number of samples.
3. For safe and effective injection of CO2, geological and mechanical properties of cap rock and coal seam are vary important and must be studied in detail.