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Proximate Analysis for CBM Reservoir Characterization, Mapping and Gas Content Analysis based on Langmuir's Parameters: Bokaro Field, India

Abstract

Coal Bed Methane (CBM) is an important source of unconventional energy in the present situation as an alternate source of energy. Prospectivity of coal seams can only be accurately identified through laboratory studies, which is time consuming and costly. To identify prospective coal seams, a methodology has been developed to identify prospective coal seams with the help of conventional log data like Density and Gamma Ray, to reduce time consumption and making it cost effective. In the present study, fourteen wells from patch A of Bokaro CBM field, India has been used to study the prospectivity of CBM in the entire area. Coal seams K-8 of well W1 from depth interval 914m to 966m has been considered for the study purpose based on conventional log analysis, production testing data and high Vp/Vs ratio which indicates good prospective CBM seam for gas production. Based on conventional log and proximate data of well W1, regression equations between the inorganic (ash and moisture) and organic (fixed carbon and volatile matter) components of seam K-8 with conventional logs are established. Equation for parameters such as ash, fixed carbon and volatile matter are established. Langmuir's equation and Adsorption isotherm parameters such pressure and volume is used to calculate gas content and gas equation with organic content ratio is also established. Well correlation of all wells with coal top is marked to study the lateral thickness variation of K-8 seam. Equations obtained from well W1 are propagated to obtain proximate and gas content for all wells and the entire area for object seam is mapped. The gas estimation for K-8 seam ranges from 11.22 to 29.73 cc/g and error analysis on gas content varied from -2.35% to 13.87 % as calculated from the difference between the predicted and observed value of well W-C and W-D to validate the result obtained. On the basis of mapping prospective zone, lateral thickness variation and gas content of seam can be concluded for further drilling of wells in development phase of CBM block.

1. Introduction

CBM reservoir has contributed an increasing percentage of gas production around the globe. Today, CBM is produced from numerous sedimentary basins in the United States, Canada, and Australia, and exploration efforts are underway in other countries, including China and India. CBM has become one of the exploration targets for the petroleum industry. In India, more than 98% of coal is produced from Gondwana coalfields (CF) to fulfill the requirement of coal consumption. Methane production from coal bed represents a maturing unconventional energy resource that has considerable long term potential for discovery, development and production which government of India is trying to explore. Various kinds of geophysical logging methods, which contain a wealth of information and are of high resolution, can be used to identify and evaluate CBM reservoirs economically and effectively (*Chatterjee and Pal,* 2010). Langmuir rank equation could be deduced to evaluate the gas content combined with the Langmuir equation and sorption isotherm of CBM (*Hawkins et al,* 1992).

2. Geological Background

The Bokaro CF is an elongated strip of Gondwana Sediments, stretching for over 64 km. along east-west having width of around 12 km. Lugu hills divides the Bokaro CF into East and West CF. The Gondwana sediments, continue from east to further west across the Lugu hill, from East to West Bokaro CF (*ONGC Report, 2001*). The geological map of Bokaro field with well location is shown in (Figure1). The present study focuses on East Bokaro CF with areal extent of approximately 237 sq.km. between latitudes 23°44' and 23°49’ (N) and longitudes 85°42’ and 86°04’30” (E) lies in Bokaro district of Jharkhand. The East Bokaro CF displays a complete sequence of the Gondwana rocks form the Talchir to the Mahadeva formations. The major part of the CF is occupied by rocks of the Barakar Formation while the Barren Measure Formation crops out along the axial region of the basin. The younger Raniganj and Panchet strata are exposed mainly along the flanks of the Lugu hill, which is capped by the youngest Supra-Panchet (Mahadeva) Formation. The generalized geological sequence of the East Bokaro CF as per GSI is given in Table1.

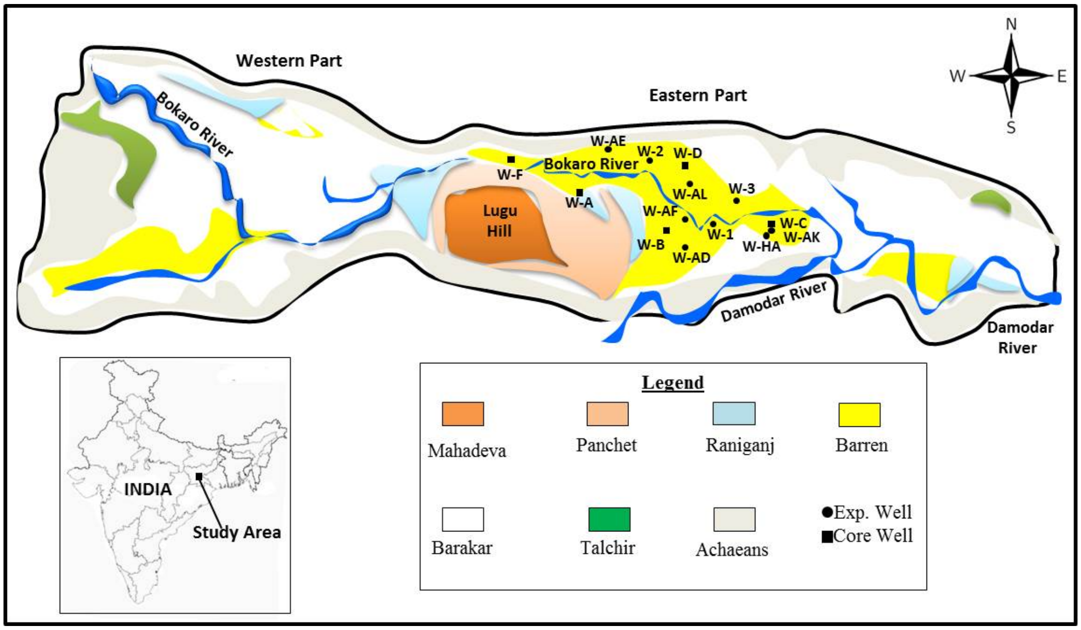


Figure1. Geological Map of Bokaro CBM Block, India (after ONGC Report, 2001).

Table1. General stratigraphic succession of Bokaro field (After GSI).

Name of Formation		Max. Thickness (m)	Age
Alluvium/Soil			Recent/Sub-Recent
Basic and ultrabasic sills and dykes			Lower Cretaceous
Upper Gondwana	Supra Panchet (Mahadeva)	600	Upper Triassic
Unconformity			
Lower Gondwana	Panchet Formation	400 - 600	Lower Triassic
	Raniganj Formation	500 - 625	Upper Permian
	Barren Measures Formation	300 - 600	Middle Permian
	Barakar Formation	250 - 1020	Lower Permian
	Karharbari Formation	60	Lower Permian
	Talchir Formation	160	Early Permian
Unconformity			
Pre-Cambrian Rock			

3. Geophysical well log

The study areas consisting of 14 wells with 9 exploratory and 5 core wells. All wells consisting of log data such as Gamma (GR), Resistivity Deep (LLD), Resistivity Shallow (LLS), Density (DEN) and Neutron (NEU) based on which coal seams have been identified on the basis of cut-off parameters: density < 1.8g/cc, neutron > 0.35 (fraction), gamma < 90 API, LLD > 100 Ohm-m (*Lyons, 2003*). The object seam

K-8 lies in Barakar formation. A total of 15 numbers of coal seams has been identified with thickness varies from 1m to 35m. Seam K-8 of well W1 is selected for the study purpose from depth interval 914m to 966m on the basis of conventional log studies (Figure2), production data, shows the gas production 20-25 m^3/day from the object seam (Figure3) and Vp/Vs ratio Vs depth study shows high Vp/Vs ratio (>2.5) indicataing the presence of fracture and gas in the seams (Figure4).

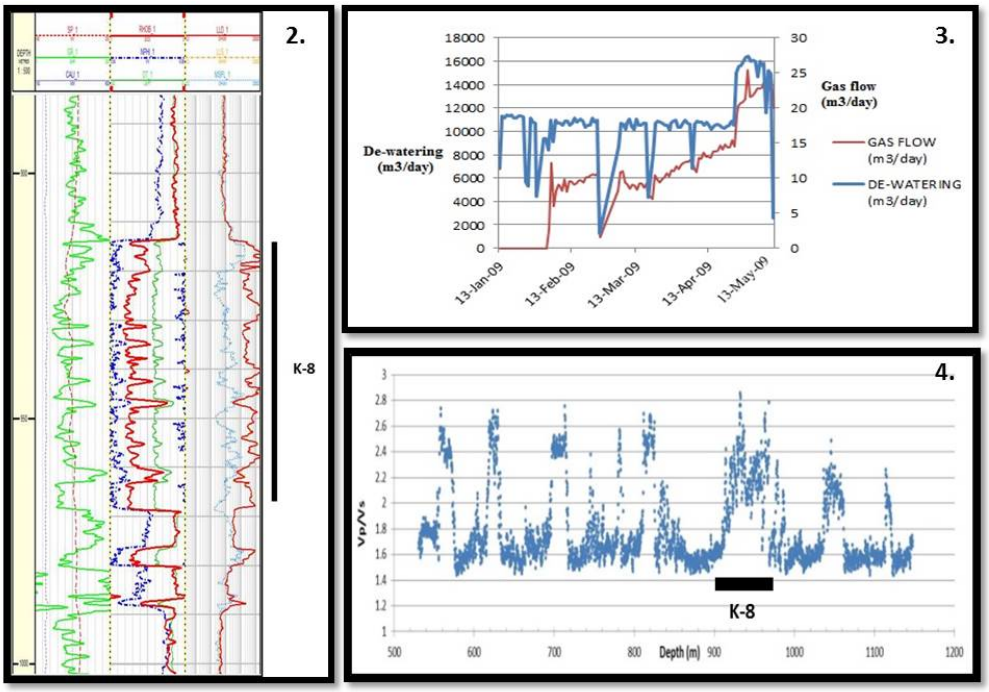


Figure2. Conventional log of well W1, seam K8. **Figure3.** Production (gas flow and de-watering) in m^3/day date wise of object seam K-8 of well W1. **Figure4.** Plot between V_p / V_s ratio with depth, high V_p / V_s ratio above 2.5 shows high fracture density.

4. Method and Model

4.1 Regression equations from conventional well log and proximate analysis

The volume model and regression analysis are generally used to estimate the components of proximate data (Bond *et al,* 1971). For the volume model (M + A + VM + FC = 1), three kinds of porosity log method and the frame parameters of each component of proximate analysis are considered to calculate the four volume contents. Plot between Ash (A) content (%) with density (g/cc) generates a correlating equation (Figure4a). Relations is again obtained from the plot of Fixed Carbon (FC) (%) with Ash (A) (%) (Figure4b). Similar relation is obtained by plotting between the sum of FC and VM (%) with the gamma ray (GR) (Figure4c). Negative slope between the GR and the sum of FC and VM is due to the absence of radioactive substance in the organic component which is measured by the GR log.

4.2 Calculation of gas content

Langmuir's volume and pressure has been used form the adsorption isotherm curve obtained from the laboratory data for the calculation of gas content. Gas regression equation has been obtained by plotting gas content with the ratio of FC to VM (Figure4d). The Langmuir's equation (1) is used for the calculation of gas content as shown below:

$$Vgas = 1 - A - M \, X \, VL + PPL + P \, X \, Sg \quad \ldots\ldots\ (1)$$

Where, Vgas is in cc/g, A and M is the ash and moisture content (%), VL and PL is the Langmuir volume (=20.3cc/g) and pressure (=2.64MPa) obtained from the adsorption isotherm curve from the laboratory core testing data of well W1. Where P = G x h, is the pressure of the strata in MPa, G is the gradient pressure of the area of seam (=0.016Mpa/m) and h is the buried depth in meter and Sg is the saturation of the adsorbed gas obtained from adsorption isotherm parameter.

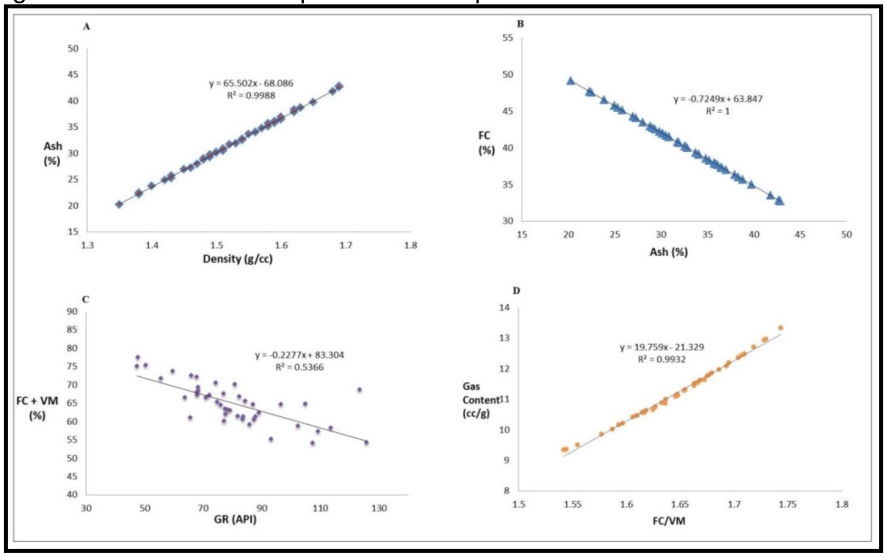
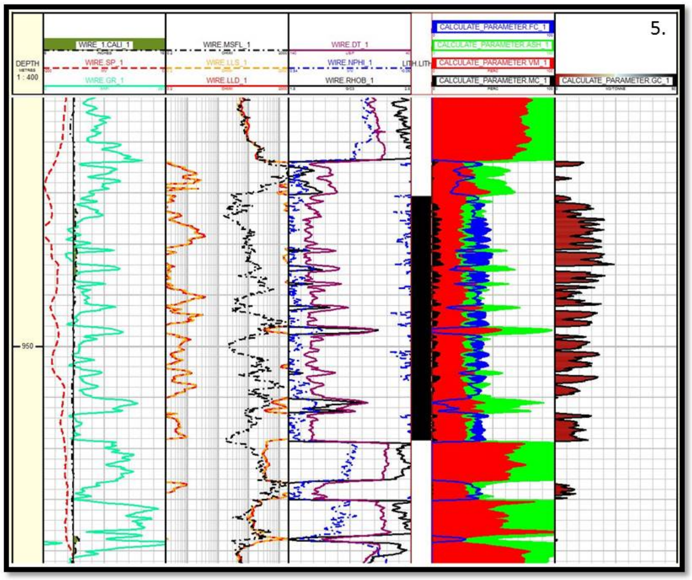


Figure: 4A. Cross-Plot between the Ash (%) with density (g/cc) with regression equation and its fit. **4B**. Cross-Plot between the FC (%) with Ash (%) with regression equation and its fit. **4C**. Cross-Plot between the FC+VM (%) with GR (API) with regression equation and its fit. **4D**. Cross-Plot between the Gas Content (GC) (cc/g) with FC/VM with regression equation and its fit.

4.3 Log Display of Calculated coal content parameter, gas content and Well Correlation

The coal component has been calculated for object seam. The processed parameters and gas content with depth is displayed in pictorial presentation (Figure5). The object seam K-8 of well W1 is correlated with all other wells in patch A and seam thickness is calculated (Figure6). Using the regression equation obtained from the plot of (Figure 4.a.b.c.d), Ash content is obtained from density log, FC is calculated from the obtained Ash content, from GR log sum of FC and VM are obtained where VM is calculated, followed by the propagation of gas content equation for the object seam to all other wells from the conventional log data. The wells with correlated seam thickness and average gas content of K-8 as calculated from the gas regression equation is shown in Table2.



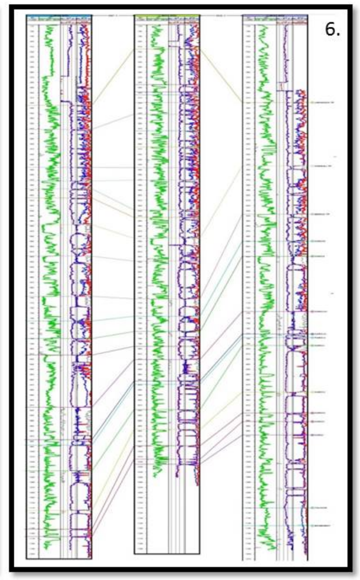


Figure5. Processed coal parameter log of well W1, seam K8 showing calculated proximate data and gas content. **Figure6.** Well correlation of coal seam top depth of well W1, W2 and W3.

4.4 Contour Mapping

The seam thickness and average gas content is mapped for the entire patch A from the result obtained from Table2 (Figure7). The contour map plot helps in identifying the object coal seam thickness and gas content variation laterally. The thickness decreases from east to west direction but the gas content remains constant forming two high lobes along north and south direction.

Table2. Well with K-8 seam top and bottom depth, thickness and calculated average gas content.

Well	W-C	W-AK	W-HA	W-3	W-1	W-AD	W-B	W-AF	W-2	W-AE	W-A	W-F	W-D	W-AL
Top depth (m)	932	1000	NA	726	914	1486	NA	1137	820	665	NA	NA	414	806
Bottom depth (m)	953	1038	NA	765	966	1509	NA	1157	850	683	NA	NA	449	843
Thickness (m)	21	38		39	52	23		20	30	18			35	37
Average gas content (cc/g)	13.51	15		14.64	11.22	28.21		11.64	19.2	11.61			29.78	11.23

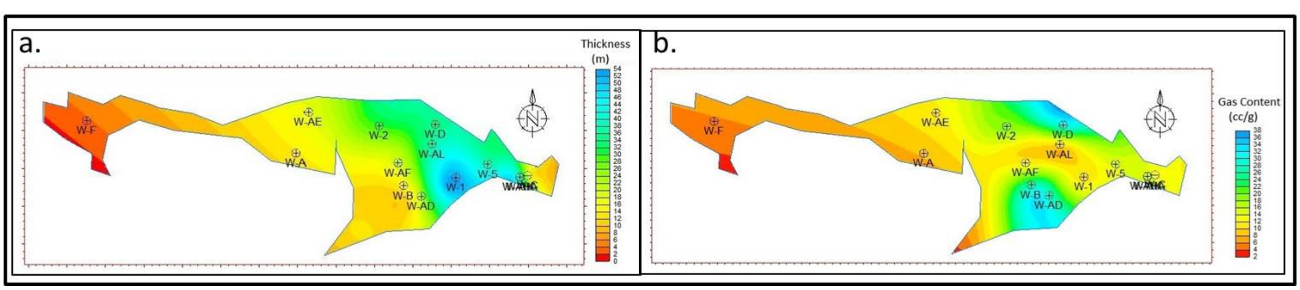


Figure: 7a. Contour map showing the lateral thickness variation of coal seam K-8. **7b.** Variation of average gas content in seam K-8 is shown in this contour map plot.

4.5 Error calculation

Gas content of well W-C and W-D are available from laboratory analysis data. Error in gas content is calculated from the difference obtained from the calculated value using regression equations and proximate data, to verify the accuracy of the result obtained from the study. Table3 shows the error calculation at depth points, ranges from -2.35% to 13.87 %. The vitrinite reflectance (VR_0) of object coal seam at 935.20 – 935.55m was observed to be 1.41 which is medium volatile bituminous coal (*Stach et al.,* 1982).

Table3. Error calculation of well W-C and W-D for K-8 seam with predicted and observed gas content.

	933	15.78	16.16	-2.35
W-C	935	9.05	9.33	-3
	938	12.79	9.64	32.67
	431	10.08	9.07	11.13
W-D	433	8.7	7.64	13.87
	445	13.19	12.63	4.43

5. Result and Discussion

The coal seam K-8 of Bokaro study area lies in Barakar formation has been identified as CBM prospective seam based on the conventional log studies with log cut-off criteria, high Vp/Vs ratio and production data of well W1. Regression equations of one well are established from the cross-plot of conventional log with proximate data and gas content obtained using Langmuir's equation with coal parameters. Gas content modeling is obtained by propagating regression equation on other wells. Entire patch of K-8 seam has been mapped with observed effective thickness and predicted average gas content. The gas content in this seam varies from 11.22 - 29.73 cc/g and seam thickness shows a thinning trend from 38-40m in the east to 10-15m in the west. Gas content shows constant trend from 10-15cc/g from east to west direction but showing high gas content 25-29cc/g at the north and south around the well W-D, W-B and W-AD. The regression cross-plot curves are showing a good fit with fitting coefficient (R^2) greater than 0.99 in three plot and 0.53 in one of the plot. The accuracy and validity of the result obtained by the method is verified from the error analysis of observed gas content from laboratory data of well W-C and W-D with the predicted gas content. The error obtained ranges from -2.35% to 13.87 % lies within the permissible limit.

6. Conclusion

A methodology of obtaining laboratory data and gas content modeling of coal from convention log data has been established. Laboratory data are accurate but time consuming and costly. Using this methodology laboratory data from the conventional log can be obtained, which will not only save the time consumption but also very cost-effective for the oil and gas industry which is present day requirement considering the present scenario. Obtained gas contents for seam K-8 of few wells have been validated with the proximate data with error within permissible limit to justify the methodology of the result obtained. This method of gas estimation in coal seam will also help us to design and plan the perforation in CBM wells so that gas production can be maximized and de-watering can be reduced by perforating the required zone accordingly. Thus gas content of the coal seam can be obtained using basic conventional log data with accuracy using the well-established laboratory data of one well.

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