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ScienceDirect
Procedia Earth and Planetary Science 11 (2015) 38 – 48
Procedia
Earth and Planetary Science

Global Challenges, Policy Framework & Sustainable Development for Mining of Mineral and Fossil Energy Resources (GCPF2015)

Petrographical Characteristics of Bituminous Coal from Jharia Coalfield India: It's Implication on Coal Bed Methane Potentiality

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Abstract

The ever increasing demand for energy resources forces India to hunt for alternate resources like coal bed methane (CBM) and shale gas. CBM is considered as clean source however its occurrence and extraction poses many challenges. The challenges vary widely across region, depth of occurrence, rank of coal, feature of cover etc. So, its characterization is important for successful extraction. The present paper discussed about the Petrographic study of coal and its correlation with different parameters that influence the recovery of CBM. Sample from deep seated coal field have been evaluated with respect to its proximate and ultimate parameters. Mutual correlations have also been developed statistically among parameters.

Keywords: Coal Bed Methane, proximate analysis, Ultimate analysis, Vitrinite reflectance, Gas content.

1. Introduction

Increasing energy demand requires exploitation of earth resources. Fossil fuel has been the major resources to meet the energy need. But its limited occurrence is not only a concern but also adverse impact on environment is major challenge. CBM a trapped gas in the coal matrix has been found to be a promising alternative to reduce dependency on coal. CBM is similar to natural gas which contains about 95% of pure methane (*Rice, 1993; Levine, 1993*). Formation of coal bed methane takes place because of biogenic or thermosgenic degradation of buried plant materials (*Singh, 2010*). Microbial action in biogenic conversion is responsible for degradation of plant materials into methane gas (*Claypool and Kaplan, 1974*) while high temperature and pressure in thermosgenic conversion/thermal decarboxylation is responsible for plants degradation (*Carothers and Kharaka, 1980*). But trapped or adsorbed methane is a serious hazard in deep underground coal excavation method. It causes global warming apart from accidental fire and explosion when released into the atmosphere. But it is a clean energy when burnt, that produce less GHG effect. It is considered as very cost effective compared to coal and oil. CBM is a clean gas having heating value of approximately 8500 KCal/kg compared to 9000 KCal/kg of natural gas (*Ojha et. al., 2011*). The commercial extraction of coal bed methane is increasing worldwide (*Moore, 2012*).

doi:10.1016/j.proeps.2015.06.006

India is the third largest coals producing country in the world. The Gondwana and tertiary sedimentary basins consists approx. 253 BT of coal in nearly 60 coalfields (*Patra et. al., 1996; Acharyya, 2000, 2001; Dutt et. al., 2001; Das Gupta, 2006; Pophare et. al., 2008*). Estimation indicates the coal reserve of India which is about 522 BT and CBM magnitude varying from 2.6 to 4.6 TCM (Table 1) (*Ojha et. al., 2011*). Successful exploitation of coal bed methane needs the complete knowledge of the coal and its behaviour at varying condition hence characterization of coal is important. This investigation reports the gas content (GC (cc/g)), Vitrinite reflectance (R_0 (%)), fixed carbon (FC (%)), volatile matter (VM (%)), etc. of coal samples at different depth.

Nomenclature

CBM	Coal Bed Methane
VM	Volatile Matter
FC	Fixed Carbon
A	Ash Content
GC	Gas Content
R_0	Vitrinite Reflectance
M	Moisture Content
S	Sulphur Content
C	Carbon Content
daf	Dry Ash Free basis
dmmf	Dry Mineral Matter Free basis
D	Depth of occurrence

Table 1. Coal resources and CBM across the world (Chandra, 2012).

SI. NO.	Country	Coal resources (BT)	CBM resource (TCM)
1	Canada	7,000	6.5-76.4
2	Russia	6,500	13.3-73.6
3	China	4,000	16.4-34.0
4	US	3,970	12.7-25.5
5	Australia	1,700	8.8-14.2
6	India	522	2.6-4.6
7	Germany	320	1.7-2.5
8	U.K.	190	1.1-1.7
9	Poland	160	1.4-2.0
10	South Africa	150	1.4-2.0
11	Indonesia	17	0.1-0.2
12	Zimbabwe	8	0.04-0.05

2. Geological location

The samples for the study were collected from the Moonidih coal block which is located in the central part of Jharia coal field, Jharkhand, India. It falls between latitude 23042’47” and 23045’42” North and longitude 860 19’21” and 86022’26” East (Figure 1). The coal block covers 15 km^2 areas. There are 18 standard coal seams (Seam-I to XVIII). Upper seams XVIII to XVI are worked by Longwall method. The virgin seams XV to II are the target seams for CBM recovery (GMI, 2013). The formations generally show NW-SE strike in the block with dip varying from 100 to 150 towards South- West. The area is also affected by faults having varying throw (CMPDIL, 2010).

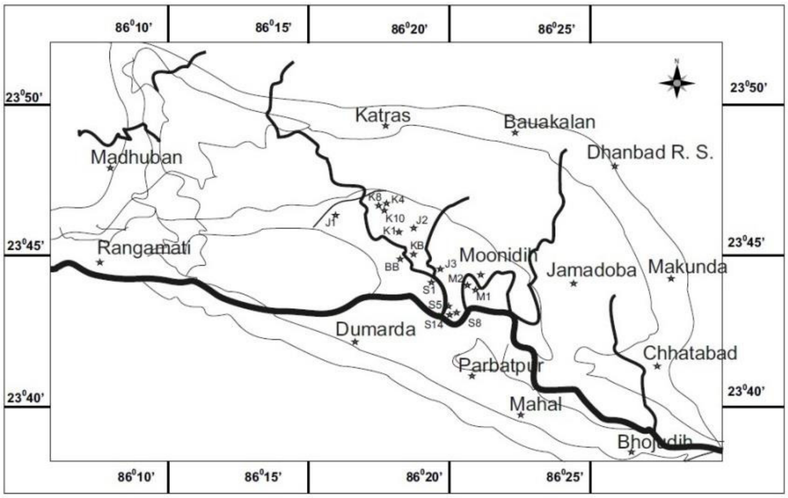


Fig. 1. Geological map of the Jharia Coalfield showing Moonidih coal block.

3. Material and methods

3.1 Sample collection

Coal samples were collected from the seams at varying depth from 450 m – 500 m (Table 2). Samples were collected from freshly exposed coal surface and kept in air tight multi cover bags to prevent moisture loss. Petrographic Analysis (Proximate Analysis and Ultimate Analysis) was done to determine the Rank, Gas content, Vitrinite Reflectance etc. of coal.

Table 2. Samples collected from different depth

Sample	Depth (m)
XV	500
XVI-B	475
XVI-T	450
XVII	450

3.2 Petrographic analysis

Coal petrographic evaluation is a microscopic technique typically used to predict the coal rank, degree of coalification and its type in term of amount and category of macerals. It describes the coal characterization on the basis of chemical composition. Petrographic study helps in determination of coal Rank, Gas content, Vitrinite Reflectance and other parameters which are required to determine CBM potential of particular seam. Proximate and Ultimate analysis of coal samples (Figure 2) have been predicted/evaluated with reference to the results of CBM potential of the coal field area.

Fig. 2. Powdered coal samples for Proximate and Ultimate Analysis

3.2.1 Proximate analysis

3.2.1.1 Determination of moisture content (m)

Coal sample was prepared as per prescribed guideline [IS: 436 (Part l/Section 1) - 1964]. Moisture content of coal was determined using standard test method [IS: 1350 (Part I) - 1984]. 1 gram of finely crushed and powdered (-212µ) air dried coal sample was taken in a silica crucible and was then placed inside an electronic hot air oven, maintained at 108±2˚C. The crucible with the coal sample was allowed to be heated in the oven for 1.5 hours. The crucible with sample was then taken out using tongs and cooled in a dessicator for 15 minutes (Figure 3). Samples after being cooled were weighted. The loss in weight is reported as moisture (on percentage basis). The calculation was done as:

$$\%Moisture = \frac{Y - Z}{Y - X} \times 100 \quad (1)$$

Where,
X = Weight of crucible (g)
Y = Weight of coal + crucible (g) (before heating)
Z = Weight of coal + crucible (g) (after heating)

Fig. 3. (a) Samples in hot air oven, (b) Moisture Content Determination; (c) Samples kept in desiccator after taken out from oven.

3.2.1.2 Determination of volatile matter content (vm)

Coal sample was prepared as per suggested method [IS: 436 (Part l/Section 1) - 1964]. Moisture content of coal was determined using standard test method [IS: 1350 (Part I) - 1984]. 1 gram of finely crushed and powdered (-212µ) air dried coal sample was taken in a VM crucible and was placed inside a muffle furnace maintained at 925 10˚C. The crucible was then covered with its lid. The heating was carried out for exactly 7 minutes (Figure 4), The crucible with sample was then taken out using tongs and cooled in air for some time and then in a dessicator for 15 minutes and weighed again. The calculation is done as:

$$\%VM = \frac{Y - Z}{Y - X} \times 100$$

(2)

Fig. 4. (a) Samples in muffle furnace, (b) Muffle furnace for volatile matter of samples, (c) Samples in desiccator after taking out from furnace.

3.2.1.3 Determination of ash content (a)

Coal sample was prepared as per standard [IS: 436 (Part l/Section 1) - 1964]. Moisture content of coal was determined using standard test method [IS: 1350 (Part I) - 1984]. 1 gram of finely crushed and powdered (-212µ) air dried coal sample was taken in silica crucible. Crucible was heated at 800˚C for 1 hour before conduction of test in order to remove any foreign particles in the crucible. The crucible along with the sample was kept in muffle furnace at 450˚C for about 30 minutes (Figure 5). After defined time the temperature of the furnace was raised to 850 10˚C and the sample was further heated for about 1 hr. The calculation is done as:

$$\%Ash = \frac{Z - X}{Y - X} \times 100 \tag{3}$$

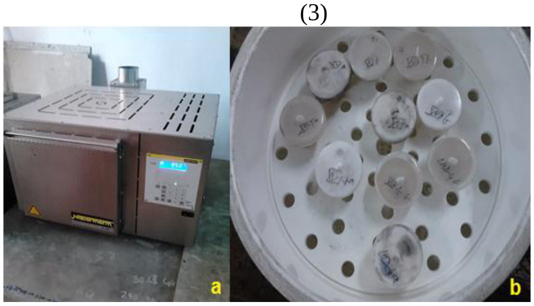


Fig. 5. (a) Muffle furnace to determine ash content of samples, (b) Sample kept in dessicator.

3.2.1.4 *Determination of fixed carbon (fc)*

Fixed carbon is the amount left after evaporation of the volatile material, moisture and ash. Fixed carbon of the sample was determined using the formula as:

$$\%FC = 100 - (\%M + \%VM + \%A) \tag{4}$$

3.1 Ultimate analysis

Coal samples were prepared as per norm [IS: 436 (Part l/Section 1) - 1964] for ultimate analysis and elemental composition of coal samples were determined using CHNS Analyser (Make Evisa Vario EL III- CHNS analyzer) as per [IS: 1360 (Part IV/Set 1) - 1974].

4. Result and discussion

A total of 12 samples were analysed for different parameters with average of 3 samples representing each seam. The average representative value from three tests for each parameter has been represented here and analysed. It was observed that the ash content varies from 9.0112 % to 18.49 % while Moisture content vary from 0.9393 % to 1.4027 % and volatile matter varies from 18.9222 % to 26.8860 % whereas fixed carbon content varies from 55.0635 % to 62.70 % (Table 3). From ultimate analysis result it was found that the carbon percentage varies from 70.17 % to 84.88% and sulphur content varies from 0.103 % to 0.174 % (Table 3). It is observed that as the depth of coal seam increases the fixed carbon percentage increases (Figure 6) that contains to the determination elsewhere (Laxminarayana and Crosdale, 1999). Irregular and unusual values of proximate analysis parameters of some coal seam are due to weathering or localized stresses. The shearing stress is uncertain for metamorphic grade of coal and variation of macerals in coal is another reason for anomalous behaviour of parameters with depth of occurrence (Trent et al., 1982).

Table 3. Results of Proximate Analysis

Sample	Depth (m)	M (%)	A (%)	VM (%)	FC (%)	VM (d) (%)	FC (d) (%)	VM (daf) (%)	FC (daf) (%)	S (%)	C (%)
XV	500	0.93	18.49	18.92	61.64	19.1	62.4	23.48	76.51	0.174	70.17
XVI-B	475	1.26	15.38	25.28	58.06	25.61	59	30.33	69.66	0.135	84.88
XVI-T	450	1.4	9.01	26.88	62.7	27.26	63.72	30.01	69.98	0.132	75.45
XVII	450	1.19	13.46	24.81	60.53	25.11	61.42	29.07	70.92	0.103	72.47

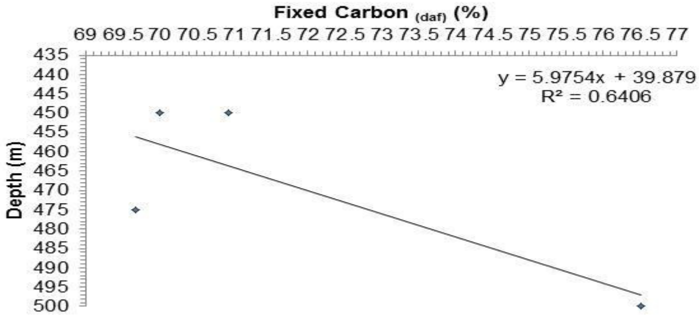


Fig. 6. Variation of Fixed Carbon with Depth.

4.1 Determination of coal grade

Coal Rank and Grade is generally determined by Vitrinite reflectance of coal and the governing correlation between volatile matter and Vitrinite reflectance is (Rice, 1993).

$$R_0\% = -2.712 \times \log\left(VM_{(daf)}\right) + 5.092 \quad (5)$$

Where,
R_0 = Vitrinite reflectance (%)
VM (daf) = Volatile matter (dry ash free basis) (%)

The Vitrinite reflectance was determined for different coal samples (Table 4). It is observed that the values are in between 1.0727% to 1.3743%. The coal sample belongs to Medium Volatile Bituminous Rank according to the rank parameter discussed elsewhere (Diessel, 1992). The Vitrinite reflectance of coal specimens exhibited an increasing trend with depth of occurrence that contains to similar observation (Ramon et al., 1997). It is observed that there is little variation of Vitrinite reflectance at 450 m as well as between 450 and 475 m depth of occurrence. This is due to the variation of macerals of coal seam at this region. However there is a sharp increase of Vitrinite reflectance between 475 m and 500 m depth. Maximum Vitrinite reflectance was found to be 1.37 at 500 m deep which reflects the commercial CBM prospects of reflectance value 0.7 - 2.0 % (Chandra, 1997). This signifies the CBM potential of seam (Figure 7). It is observed that, as volatile matter (dry ash free basis) increases the Vitrinite reflectance decreases (Figure 8 (a)) that confirms to similar trend reported elsewhere (Grieve, 1991; Langenberg et al., 1992). It is observed that Vitrinite reflectance increases with increase in fixed carbon (dry ash free basis) (Figure 8 (b)). Vitrinite reflectance exhibit an increasing trend with fixed carbon (dry ash free basis) that contains similar observation elsewhere (Ward et al., 2003a; Ward et al., 2003b; Ward et al., 2005).

Table 4. Calculated Vitrinite Reflectance of coal samples

Sample Id	VM (daf)	R_0 (%)
XV	23.4863	1.37435
XVI-T	30.0114	1.0856
XVI-B	30.3396	1.07279
XVII	29.0733	1.12301

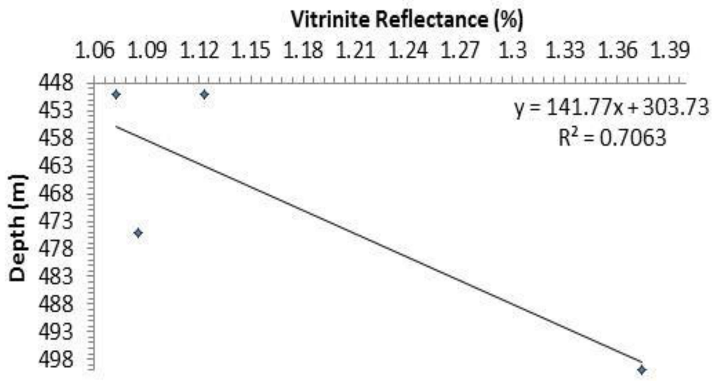
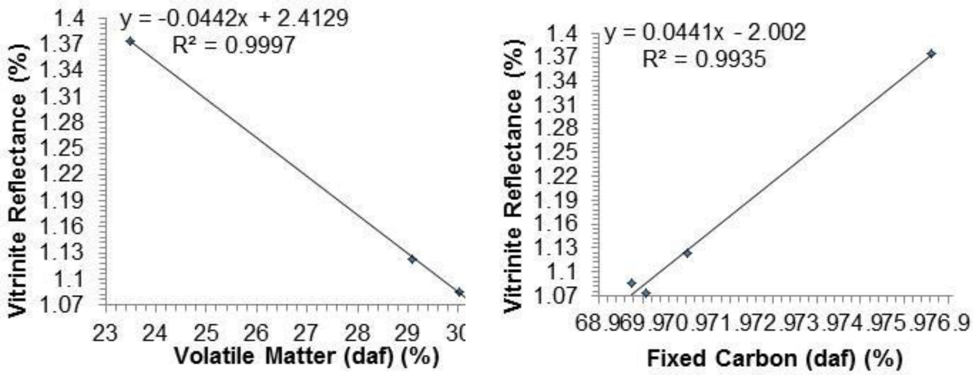


Fig. 7. Variation of Vitrinite Reflectance with Depth in study area.



a b

Fig. 8. Variation of (a) Vitrinite Reflectance with Volatile Matter (daf); (b) Vitrinite Reflectance with Fixed Carbon (daf)

4.2 Determination of methane content

Most of the gas in coal remains adsorbed on the internal surface of micro pores and varies directly with pressure and inversely with temperature (Pophare et al., 2008). The typical relationship between volume of gas content and pressure and temperature with results of proximate analysis is (Kim, 1977).

$$G_{saf} = 0.75 \times [1 - A - M] \times \left[K(P)^N - 0.14 \times \frac{1.8D}{100} \right] \tag{6}$$

Where,

G_{saf} = Dry, ash free gas storage capacity (cc/g), M = Moisture content (%), A = Ash content (%), D = Depth of sample (m)

$$N = \text{Constant} = 0.315 - 0.01 \times \frac{FC_{(daf)}}{VM_{(daf)}} \quad (7)$$

Where,
$FC_{(daf)}$ = Fixed Carbon (Dry ash free basis) (%), $VM_{(daf)}$ = Volatile Matter (Dry ash free basis) (%)

$$K = 0.8 \times \frac{FC_{(daf)}}{VM_{(daf)}} + 5.6 \quad (8)$$

$$P = P_{hyd} = 0.096 \times D \text{ (atm.)} \quad (9)$$

The adsorbed gas content variation as determined by the above equation was found in the range from 17.9165 cc/g to 18.7145 cc/g (Table 5). The range indicates good potentiality of methane gas in the Moonidih Underground coal block. The range observed satisfy the economic viability of CBM which is much more than threshold of 8.5 cc/g of methane (Mukherjee et al. 1999).

4.3 Correlation between gas content and results of proximate and ultimate analysis

In this study various parameters of proximate and Ultimate Analysis was correlated with gas content of coal. These parameters give outline of the CBM potentiality of study area. Correlations of different parameters are shown in Figure 9 (a-g). In Figure 9 (a) Gas content of coal was found increasing as the depth increases. Pressure and temperature increases and plant material undergoes coalification with increasing depth of occurrence. During coalification, coal becomes progressively enriched in carbon and continues to expel volatile matter. It leads to progressively enriched methane content due to the thermal maturation which confirms the potentiality of CBM as depth of overburden increases. The trend is similar to that found elsewhere (Karmakar et al., 2013). Gas content of coal increases with increase in fixed carbon (%) (Kim, 1977). Similar trend was found for the study area. Gas content of coal was found increasing with increase of Fixed carbon (daf) (Figure 9 (b)). The increment in gas content with fixed carbon confirms the viability of CBM with greater percentage of fixed carbon in coal block. But from Ultimate analysis results gas content was found decreasing with increasing carbon content (Figure 10 (a)). Gas content of coal was also correlated with Vitrinite reflectance which is one of the most important parameter to determine CBM potentiality. It is also found that gas content increases with Vitrinite reflectance (Figure 10 (b)) indicate the commercial potentiality of CBM. Gas content was found increasing with decreasing Volatile matter (daf) (Figure 10 (c)). As volatile matter decreases methane occupy the space in coal matrix and remains adsorbed on the surface. The correlation between Gas content (daf) and gas content (dmmf) shows proportionality curve (Figure 10 (d)). There is a strong relation between Gas content (as received) and gas content (dry mineral matter free basis) (Figure 10 (e)). The curve is proportional because of presence of volatile matter. Gas content on the basis of (dmmf) was found greater than other two i.e. (as received) and (daf).

Table 5. Calculated gas storage capacity of coal block

Sample Id	N	K	P	Gas Storage Capacity (cc/g)
XV	0.28242	8.20624	48	18.7145
XVI-T	0.29168	7.46566	38.4	18.4801
XVI-B	0.29204	7.43682	45.6	17.9165
XVII	0.2906	7.55167	43.2	18.2849

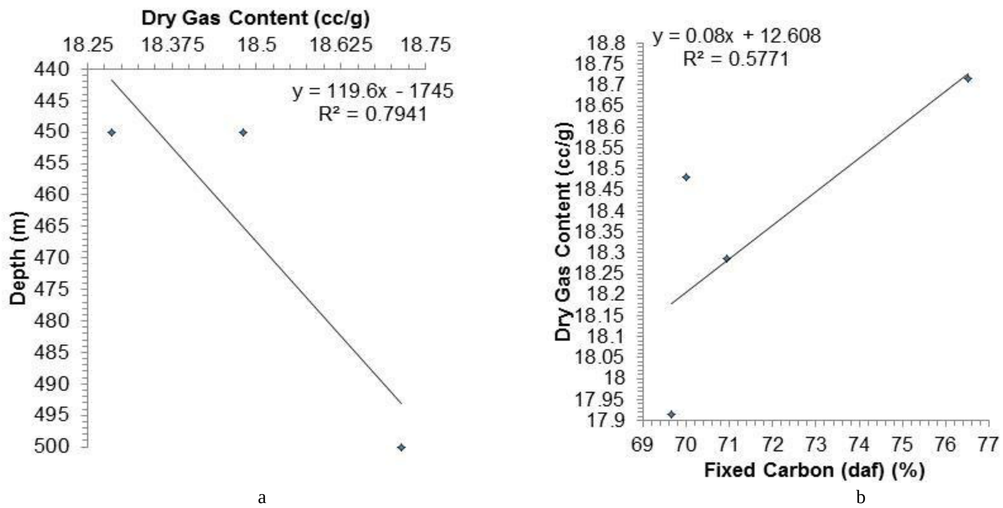
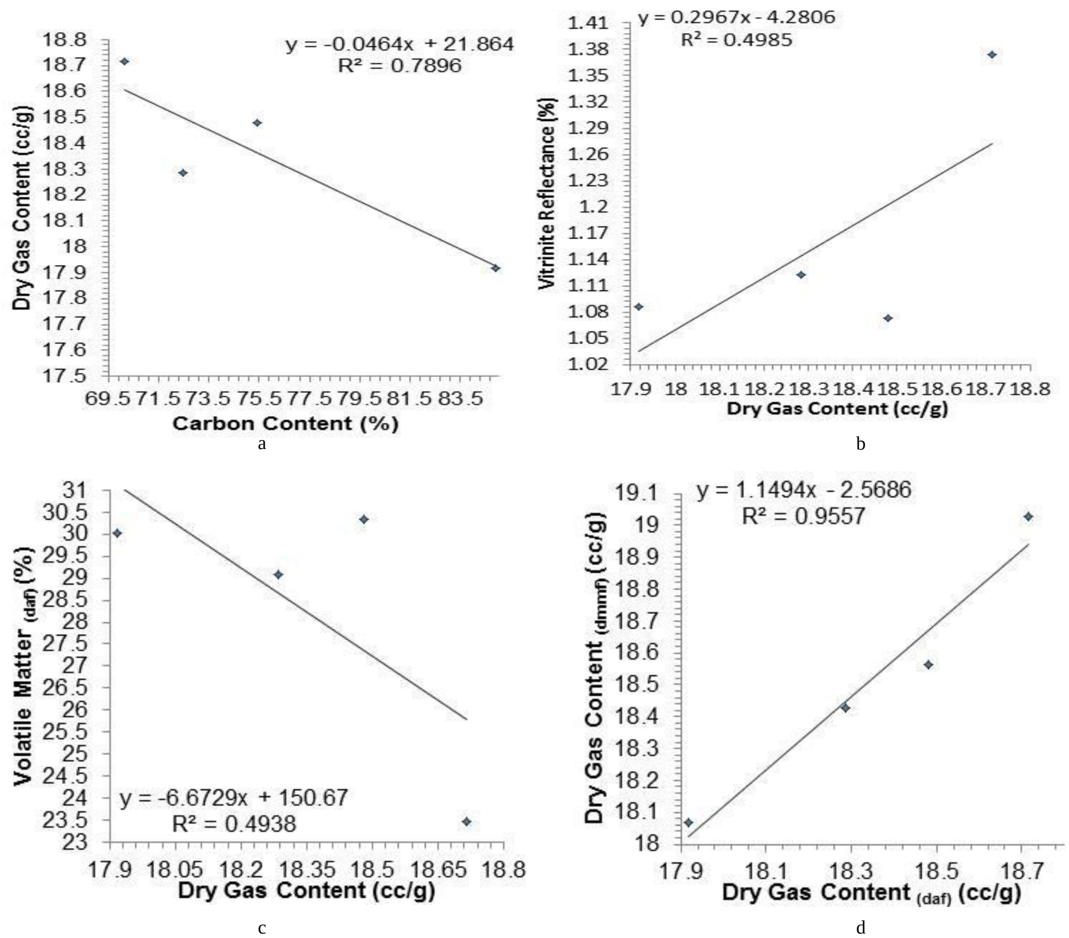


Fig. 9. (a) Variation of Depth with Dry gas content (b) Variation of Fixed Carbon (dry ash free basis) with Dry gas content



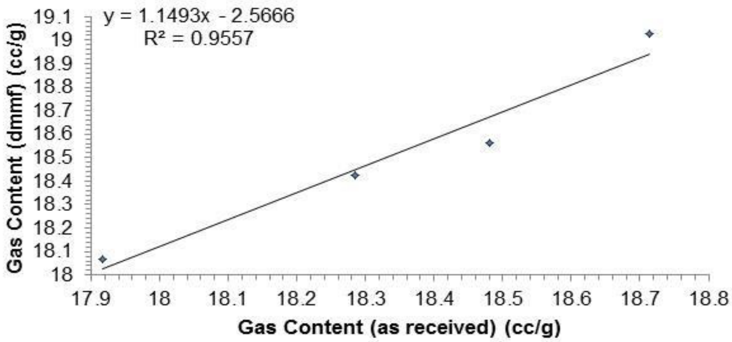


Fig. 10. Variation of (a) Carbon content with Dry gas content (b) Vitrinite reflectance with Dry gas content (c) Volatile matter with Dry gas content (d) Dry gas content (daf basis) with dry gas content (dmmf basis); (e) Dry gas content (as received) with Dry gas content (dmmf basis)

5. Conclusions

Coal bed methane is a promising fuel. Coal reservoirs at places held high gas content adsorbed in coal matrix. The main parameters influencing the coal-bed gas enrichment are the depth of occurrence and gas content. Petrographic investigation confirms the CBM potential of the reservoir to a great extent. The following conclusion is drawn from the mine under investigation at Jharia area.

- Coal of study area belongs to medium-volatile- bituminous (mvb) rank.
- The average methane content is estimated at 17.98 cc/g.
- As depth of occurrence increases maturation of coal increases that cause formation of more methane in coal.
- Higher percentage of fixed carbon (daf basis), higher percentage of Vitrinite reflectance and lower percentage of volatile matter (daf basis) reflects more methane in coal
- The reservoir at Jharia has strong potential of coalbed methane

Acknowledgements

The authors acknowledge the financial assistance provided by SERB, DST, vide approval No: SB/S4/ES-697/2013.

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