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Petrophysical Investigation of Hydrocarbon Generation Potential of Coal from Raniganj Basin, India

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Abstract

Methane content in a coal seam is a necessary parameter for evaluating coal bed gas, and it is a threat to underground coal mining activities from environmental aspects. Keeping in pace with comprehensive studies of coal bed gas, the authors had selected 12 coal samples from the Sitarampur block of Raniganj Coalfield. The Petrographic examination illustrated that significant values of reactive macerals present in samples demonstrate that organic matter is dominated by kerogen Type III, making it suitable for hydrocarbon generation. “A” factor (aliphatic/aromatic bands) and “C” factor (carbonyl/carboxyl bands) value concluded that the sample has the lowest aromaticity and the highest hydrocarbon-generating potential, which also validated by the cross plot between atomic H/C and O/C. The plots between the H/C and O/C ratio in the Van Krevelen diagram indicate that the coal samples lie in the type III kerogen, and bituminous coal (gas prone zone) is present in the block, which confirmed by the cross plot between desorbed and total gas (cc/g). The in-situ gas content values are high enough to produce methane from coal beds.

The overall study concludes that the Sitarampur block from Raniganj Coalfield is suitable for hydrocarbon generation and extraction.

Keywords: Hydrocarbon generation potential; Petrographic study; *In-situ* gas content; Oil yield; Kerogen type; FTIR.

1. Introduction:

Natural gas has become a promising substitute for coal and plays a significant role in power generation and other alternative sources of energy in different applications in India (CEA 2019). The demand for natural gas in India steadily increasing over the past few decades from 49.10 to 59.70 billion cubic feet (BP 2020). In India, natural gas consumption grew continuously, with an annual rate of 6.2% between 2000 and 2019 (MPNG 2020). In the last few decades, natural gas production from coal beds has experienced rapid development in many countries such as the USA, Australia, China, India, and Canada (Panwar, Saxena et al. 2016, Panwar, Saxena et al. 2016, Panwar, Suman et al. 2020). When the methane is recovered simultaneously with coal during underground mining of coal is known as Coal Mine Methane (CMM). Coal mine methane mining is done to reduce methane concentration in the mines and working areas around the mines for its effective utilization of coal and CMM. Methane is the principal gas in CMM with varying concentrations from 25-60% (Karacan 2009) and must be released or vented for safety reasons. So, CMM is an unconventional form of natural gas found in association with coal seams, and It's a clean burning fuel with a good heating value >8500 Kcal/Kg. (Ojha, Mandal et al. 2013, Panwar, Saxena et al. 2017, Panwar, Saxena et al. 2017, Panwar, Saxena et al. 2017). Literature reveals that coal is a sedimentary rock, with complex pore and fracture structure (Gao, Mastalerz et al. 2020). The macro-micro pores in coal provide extremely massive surface areas for methane, and it accumulate as free, adsorbed, and dissolved state (Kumar, Mendhe et al. 2018, Wang, Su et al.

2020). The different ranks of coal, maceral composition, and mineral matter significantly influence the methane sorption capacity (Moore, Bowe et al. 2014, Goraya, Rajpoot et al. 2019). Literature reveals that Fourier transform infrared spectroscopy (FTIR) is extensively employed to characterize various source rock to determine hydrocarbon generation potential (Ganz and Kalkreuth 1991, Mishra, Samad et al. 2018, Varma, Mishra et al. 2018).

The Field Emission Scanning Electron Microscopy (FE-SEM) and Electron Dispersive X-ray analysis (EDX) analysis were significantly used for organic matter association with mineral matter and coal surface structure.

A current investigation is based on twelve samples collected from five different coal seams in the Sitarampur block. Physicochemical characterization of the collected samples was conducted based on Petrographic composition, thermal maturity, kerogen type, FTIR, Proximate, and ultimate analysis, etc. Estimation of hydrocarbon generation potential was done by, Petrographic analysis, kerogen type, *In-situ* gas content, FTIR, Proximate, and ultimate analysis.

2. Methods of experiment and analysis:

A total of 12 coal core samples were collected from one borehole during the exploratory drilling in different five coal seams present in the Sitarampur block. The Sitarampur Coal Block covering about 9.00 Sq.km. is situated in the western part of the Raniganj coalfield in Burdwan District, West Bengal, India. It is bounded by the coordinates Latitude N 23° 43' 25'' to N 23° 45' 28.11'' and Longitude E 86° 51' 23'' to E 86° 53' 28.16'' and its location have shown in Figure1. However, the methodology adopted and equipment used for the characterization of the sample was shown in Table 1.

Proximate Analysis: Proximate analysis was carried out in the Department of Fuel and Mineral Engineering, IIT (ISM), Dhanbad. The procedure of Bureau of Indian Standard [BIS Standard: 1350, Part-1, 2003] were used to determine ash content, moisture, and volatile matter of coals.

Ultimate Analysis: The elemental analysis of coal core samples collected from different seams of Sitarampur block of Raniganj coalfield has been analyzed by the elemental analyzer (Elementar Vario EL III-CHNS analyzer) in the Department of Fuel and Mineral Engineering, IIT (ISM), Dhanbad.

Petrographic Analysis: Coal petrography for collected coal samples were carried out at the Department of Applied Geology, IIT (ISM), Dhanbad. Maceral groups were identified. Subsequently, estimation of vitrinite reflectance (Goraya, Rajpoot et al.) has been done in oil medium on polished coal surface in reflectance with white light and fluorescence illumination under an advanced research polarizing microscope using Leica DMRXP-HC setup. Besides this, the Bureau of Indian Standards was followed to prepare the sample [BIS No 9127 part 2 for preparation, grinding and polishing of pellet, part 3 for maceral and mineral identification and part 5 for VRo measurement].

Fourier Transform Infrared spectrometry (FTIR) analysis:

For FTIR spectroscopy, 1 mg of fine (of -75 μm size) coal was grounded with 100 mg KBr and pressed an evacuated die to prepared pellets, following the procedures outlined by Painter et al. (Painter, Snyder et al. 1981). Freshly prepared pellets were dried in a vacuum oven for 48h to reduce the contribution of water over the spectrum. FTIR of the coal samples was carried out in a wavelength frequency range of 4000 cm^{-1} to 200 cm^{-1} in absorbance mode. A Bruker, 3000 Hyperion Microscope with Vertex 80 FTIR system instrument was used for FTIR analysis.

Measurement of Coal Seam Gas Content:

Direct Method: There are mainly three steps involved in measuring in-situ gas content of coal core samples retrieved from exploratory boreholes. Lost gas denoted by Q_1 is the amount of gas lost by the core sample since its extraction from undisturbed coal seam to its confinement in the desorption canister. The cumulative value obtained by desorbed gas volume measurement gave desorbed gas (Q_2) for the coal samples. From the measured volume of gas obtained after crushing a portion of the samples, the residual gas (Q_3) was calculated for the total weight of the samples. The total volume of gas obtained by the addition of Q_1 , Q_2 , and Q_3 divided by the total weight of the sample.

$$Q = Q_1 + Q_2 + Q_3$$

3. Result and discussion:

3.1. Hydrocarbon Generation Potential:

The petrographic study is predominantly used for the determination of kerogen type and its suitability for hydrocarbon generation. In previous studies, many researchers reveal that Vitrinite and liptinite macerals are generally used as an indicator for the determination of hydrocarbon generation potential (Tissot and Welte 1984, Akanksha, Singh et al. 2020, Panwar, Suman et al. 2020). The hydrocarbon generation potential of the Sitarampur block was assessed using petrographic data. The samples have significant values of reactive macerals and liptinite content in the range of 67.57 to 81.10 vol.% and 5.24 to 10.05 vol.%, respectively, make it suitable for hydrocarbon generation (Kotarba, Clayton et al. 2002, Akanksha, Singh et al. 2017, Varma, Biswas et al. 2019). The Petrographic examination illustrated that type III kerogen present in studied samples, as shown in Figure 2. The ternary plot of petrographic constituents indicates that samples are vitrinite ample and mature. It's also deduced from the study that there also a possibility of excellent hydrocarbon (methane) generation potential in coal, as shown in Figure 3.

Literature suggested empirical equations given by Guyot (Guyot 1978, Jin and Shi 1997) are used to assess the conversion of coal into oil and oil-yield.

$$\mathbf{RF} = \frac{1000\mathbf{R_{max}}}{\mathbf{RM}} \quad (1)$$

$$\mathbf{Conversion} \text{ (\%)} = \mathbf{0.2RM} + \mathbf{76.6} \quad (2)$$

$$\mathbf{Oilyield} \text{ (\%)} = \mathbf{0.22RM} + \mathbf{44.8} \quad (3)$$

Where Rmax is the maximum reflectance of huminite, RM is reactive macerals.

The coal samples demonstrate prominent values of conversion (%) and oil yield (%) in the range of 90.11 to 92.82 vol.% and 59.67 to 62.64 vol.%, respectively. It's also depicted from the study that emphasis correlations were found in conversion (%) with vitrinite (%) and oil yield (%), as illustrated in Figure 4 and 5.

3.2. Petrographic investigations:

The petrographic analysis indicates the quantity of organic content, maturity, gas generation, and storage capacity in coal (Kumar, Mendhe et al. 2018, Goraya, Rajpoot et al. 2019). It's also significantly utilized to determine coal formation and diagenesis (Moore 2012, Gao, Mastalerz et al. 2020). The macroscopic petrography of the coal seams is mainly bright coal with black colour, obvious black streaks (Moore 2012, Gao, Mastalerz et al. 2020). The studied samples are mainly bright, vitreous lustre and black in colour, amorphous in nature, and fine-grained. The quantitative distribution of different macerals like vitrinite, liptinite, and inertinite are shown in Table 2. The microphotographs of various macerals and their associated subgroups are illustrated in Figure 6. A ternary facies of various macerals and mineral matter content was plotted. The studied samples mostly fall in the E field. The ternary diagram also exemplifies that they deposited in alternating oxic (dry) moor with sudden high flooding during peat accumulation, as shown in Figure 7 (Kumar, Mendhe et al. 2018, Esen, Özer et al. 2020). The vitrinite groups of macerals are

dominantly present in samples, primarily derived from woody plant tissue, and its value varies from 59.47 to 73.39 vol.% (averaging 66.43%) on a dry ash-free basis (Varma, Biswal et al. 2015, Varma, Khatun et al. 2015). The liptinite is generally derived from waxy or resinous plant parts, and its value varies in samples from 5.24 to 10.05 vol.% (averaging 7.64%) on a dry ash-free basis. The carbon-rich inertinite groups are found in moderate quantity, and their value ranging from 16.18 to 35.31 vol.% (averaging 25.74%) on a dry ash-free basis. The moderate value of inertinite content indicates that studied samples formed under an exposed peat swamps environment (Fu, Tang et al. 2016, Wang, Su et al. 2020). It was observed in several studies that the depth, organic matter, and rank enhance the gas potential of coal seams. The vitrinite reflectance value of studied samples varies from 1.08-1.38 % and indicates the existence of bituminous with a significant quantity of methane in the block (Hou, Wang et al. 2016, Li, Zhang et al. 2020).

3.3. Assessment of Gas content:

Methane is found in coal bed as absorbed and adsorbed from the latter constitutes 90% of the total amount of gas (Yee, Seidle et al. 1993, Evans, Budwill et al. 2020). The quantity of gas present in coal is known as gas content, and it depends on coal geology, seam thickness, depth of burial, igneous intrusions, and bounding strata type (Crosdale, Beamish et al. 1998, Kiani, Sakurovs et al. 2018, Yan, Meng et al. 2020). Methane evolution in coal is a two-step process biogenic (microbial activity) and thermogenic (cracking of organic matter). Gases generated in the succeeding thermogenic stage could migrate due to high-pressure regimes and remain stored in the coal (Altowilib, AlSaihati et al. 2020). The pore and fracture systems were developed in coal during maturation. The micro-pore systems significantly control the gas's storage and flow in the coal matrix (Moore, Bowe et al. 2014, Sharma, Saxena et al. 2019). Methane is trapped in pores and fractures in the free, adsorbed, and dissolved states. Some of the microscopic images of the pore and fracture system are shown in Figure 8. The *in-situ* gas content measurements were performed

by following the modified USBM Direct Method. The in-situ total gas content of samples ranged from 2.09 to 11.64 (cc/g) on a dry basis. The residual gas content varies from 0.17 to 1.07 (cc/g) at standard temperature and pressure (STP). The lost gas of the coal samples of the study area varied from 0.07 to 0.52 (cc/g) on a dry basis (Table.2). The desorbed gas content varies from 1.37 to 10.18 (cc/g) on a dry basis. The study also depicted that emphasis correlations were found between desorbed gas and total gas, as illustrated in Figure 9. It is also; found in a study that total gas content value increases with desorbed gas; it may be due to the high desorption rate of studied samples in the field.

3.4. Coal quality analysis:

The gross calorific value, proximate and ultimate analyses were performed, and their results summarized in Table 3. Due to the existence of significant quantity combustible component in coal samples, calorific value high is in all samples, and it's various from 5160 to 6840 cal/gm. It can be illustrated from the various analyses that samples have lower moisture content, and it is ranging from 0.80 to 1.90%. Samples also contain a moderate to the high amount of ash percentage, and it varies from 16.90-32.60%. Similarly, organic content like volatile matter and fixed carbon vary from 7.20-22.40% and 51.70-70.50% (dry basis).

Samples have a significant quantity of carbon and hydrogen content, and their value varies from 78.59-92.16%, 3.40-5.36% on dry ash free basis, respectively. The sulphur and nitrogen content of samples is below 1.16% and 2.71%. The Van Krevelen diagram (Van Krevelen 1993) chart represents samples' maturity, kerogen type, and nature. The cross plot between H/C and O/C shown in Figure 10 demonstrates that the samples fall in bituminous rank and lies in the category of kerogen types III.

3.5. FTIR studies:

FTIR analysis not only provides information about functional groups, but it is also significant for the determination of hydrocarbon generation potential (Kumar, Mendhe et al. 2018, Hossain, Sampei et al. 2019). “A” factor (aliphatic/aromatic bands) can evaluate the hydrocarbon-generating potential of coal, and the “C” factor primarily the ratio of carbonyl/carboxyl groups to the aromatic group and illustrate the maturity of coal. It has been seen in many studies that as the “C” factor value increases, the maturity level of coal decreases (Ganz and Kalkreuth 1987, Ganz and Kalkreuth 1991, Samad, Mishra et al. 2020).

The “A” factor and “C” factor can be easily determined by the following equation as given below (Varma, Mishra et al. 2018).

$$A\text{—}factor = \frac{2930\text{ cm}^{-1} + 2860\text{ cm}^{-1}}{1630\text{ cm}^{-1} + 2930\text{ cm}^{-1} + 2860\text{ cm}^{-1}} \quad (4)$$

$$C\text{—}factor = \frac{1710\text{ cm}^{-1}}{1710\text{ cm}^{-1} + 1630\text{ cm}^{-1}} \quad (5)$$

It was described in different studies that as the A-factor value increases, the maturity decreases and the aliphatic nature increases in coal (Durand and Espitalié 1976, Lis, Mastalerz et al. 2005, Esen, Özer et al. 2020). Identically, the C-factor value decreases with maturity, which reveals a decrease in oxygenated components in coal. A factor (>0.664) and C factor (>0.501) value of studied samples demonstrate that samples have moderate aromatic and aliphatic hydrocarbon (Yao, Zhang et al. 2011, Chen, Mastalerz et al. 2012). A factor and C factor indicate that types II and III kerogen present in investigated samples (Varma, Khatun et al. 2015, Varma, Mishra et al. 2018, Misra, Das et al. 2020). A similar result found from the plot between atomic H/C and O/C of the coal samples demonstrates that the samples lie in the kerogen types II and III consecutively (Akanksha, Singh et al. 2017, Akanksha, Singh et al. 2020).

4.0 Conclusion:

Based on the current examination, the following conclusions are drawn:

- The hydrocarbon generation potential of the Sitarampur block was assessed using petrographic data. The petrographic examination illustrated that significant values of reactive macerals present in samples, and its value varies from 67.57 to 81.10 vol. % respectively. Similarly, the petrographic analysis also demonstrates that organic matter is dominated by kerogen Type III, making it suitable for hydrocarbon generation.
- The petrographic analysis confirms the appearance of textinite and attrinite as a primary contributor to vitrinite macerals groups. Sporenite, cutinite, and resinite macerals were dominantly present in liptinite macerals groups. Similarly, semifusinite is the only visible maceral present in samples from the inertinite group.
- Some positive correlations were also found between conversion, reactive macerals, and oil yield, which integrates the participation of various macerals during oil and gas generation in studied samples.
- Fourier transforms infrared (FTIR) spectroscopy was significantly utilized in our study to determine various functional groups. “A” factor (aliphatic/aromatic bands) and “C” factor (carbonyl/carboxyl bands) value concluded that the sample has the lowest aromaticity and the highest hydrocarbon-generating potential, which also validated by the cross plot between atomic H/C and O/C.
- The plots between H/C and O/C ratio in the van Krevelen diagram indicate that the coal samples were lies in the type III kerogen and bituminous coal (gas prone zone) is present in the block; which is also confirmed by the cross plot between desorbed and total gas (cc/g).
- The SEM analysis reveals the occurrence of several size pores and fracture and distribution in studied samples.

- The studied samples of Sitarampur block were characterized by low moisture, high ash, and moderate volatile matter content in nature, which is suitable for methane production.

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Figures

Figure 1

Sitarampur block location in map.

Figure 2

Ternary diagram of maceral composition indicating the hydrocarbon potential of samples.

Figure 3

Kerogen type based on petrographic components for representative samples.

Figure 4

Correlation between conversion (%) and vitrinite (%) for studied samples.

Figure 5

Correlation between conversion and oil yield for studied samples.

Figure 6

Description: Representative photomicrographs of macerals of Raniganj Bituminous coal. Figure (A) shows bed of vitrinite [Vt] and inertinite [It] macerals; frame (B) shows sporenite [Sp] and cutinite [Cu] macerals of liptinite group, under fluorescence light; (C) frame of telenite [Tl] and (D) semifusinite [Sf] macerals; (E) groundmass of telovitrinite [Tv] with inertodetrinite [Id]; (F) bed of fusinite [Fu] macerals.

Figure 7

Ternary facies diagram involving maceral and visible mineral matter contents.

Figure 8

Characteristics of the SEM pore-fracture system of the coal samples.

Figure 9

Correlation between desorbed gas and total gas content for studied samples.

Figure 10

Cross-plot between H/C and O/C atomic ratio for studied samples.