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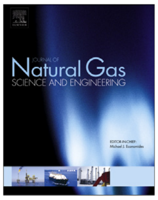

# Fractal and pore dispositions of coal seams with significance to coalbed methane plays of East Bokaro, Jharkhand, India

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## ABSTRACT

In India, much attention has been paid to the Gondwana coals of Permian age of Damodar valley, which comprises the major CBM producing blocks. East Bokaro Coalfield is part of Damodar valley and one of the promising potential CBM plays. In this study, the technological properties, TOC content, thermal maturity (Ro%), low pressure N2 sorption isotherm and SEM analyses were performed to find out the significance of fractal dimension, pore dispositions and associated geological influence on pore structure and fractal dimensions for better understanding of gas adsorption capacities of coal seams of East Bokaro. The micropore and mesopore specific surface area obtained through DR and multi-point BET ranges from 0.18 to 8.86 $m^2/g$ and 0.42–7.41 $m^2/g$ respectively, signifying dominance of micro and mesopores involvement in specific surface area. The BJH and DFT pore volume varying from 0.002 to 0.007 and 0.001–0.007 cc/g respectively. It is observed that the considerable pore volume contributed by mesopores of the range 3–50 nm and least fractions of macropores ranges from 50 to 278 nm. There is a tremendous increase in pore volume, when the pore size in between 4 and 16 nm, these pores are particularly more suitable for gas storage and associated with carbon rich vitrinite maceral. The pore size distribution obtained through BJH, DFT, DA, DR and average pore diameter values ranges from 2.99 to 10.20, 1.77–3.17, 1.42–2.48, 0.46–3.28 and 4.48–16.43 nm respectively. The opening of the hysteresis loop at lower pressure ~0.2 (P/P0) and closing of hysteresis loop between 0.6 and 0.8 (P/P0) acutely connects to the adsorption branch is revealing of cavitation and irregularities in pore structures, consequently rapid decline in desorption curve due to the condensation and evaporation characteristics of micro and mesopores, often associated with combined slit and bottle neck pores and bottle-neck open ended shaped mesopores. The variations in correlation coefficients of two separate linear segments of fractal dimensions (D1 and D2), summarizes the suitability of D1, for pore structure analysis. Nevertheless, the low values of fractal dimensions ($D1 = 1.1600–2.5450$ and $D2 = 1.5580–2.8730$), signifies the pore surfaces are controlled by heterogeneity of coal composition. However, the correlations of D2 with ash, average pore diameter, specific surface area, Ro%, pore volume and depth accentuated that D2 may be considered for CBM reservoir characterization of East Bokaro Coalfield. The very good correlations between depth with D2, total pore volume and thermal maturity (Ro%) signifies the intensification of fractal dimensions as a function of reduction and variations in pore diameter with increasing degree of coalification. The effects of rank upon fractal dimensions are mainly due to structured variety of micropore and mesopore of coals. SEM studies supports the variations in surface morphology, pore structure and

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fractal dimension controlled by complex coal compositional parameters like carbon content, volatile matter, thermal maturity and pore size distribution.

## 1. Introduction

Coal is an extremely heterogeneous material which can be characterized by its matrix and pores structures. The fundamental of pore connectivity and allied porosity evaluation of coal may be enhanced by a better understanding of its microstructural features. Coal is known for dual porosity, primary porosity called matrix porosity deals with micropores and secondary porosity unveils by cleat and fracture. However, considering organic and inorganic content, two types of matrix porosity are being taken care like pores found within the macerals and pores located in between macerals, clays, or mineral matter (Gamson et al., 1993). The increase in micropore capacity with vitrinite content is due to an increase in the number of micropores, different studies have shown that the relative abundance of pores is related to organic composition and coal type (Gan et al., 1972; Harris and Yust, 1976; Unsworth et al., 1989; Clarkson and Bustin, 1999; Giffin et al., 2013). The pore classification have been suggested by various researchers based on the physical adsorption, absorption and capillary condensation model (Hodot, 1961; Shi and Durucan, 2005; Clarkson et al., 2012). Mostly followed classification for pores of clays or mud rocks developed by Rouquerol et al., 1994 and subsequently adopted by the IUPAC (International Union of Pure and Applied Chemistry) on the basis of size into three categories such as macropores (>50 nm), mesopores (2–50 nm) and micropores (<2 nm) (Rouquerol et al., 1994; Zou et al., 2013; Mendhe, 2014). The pore size, pore volume, specific surface area of microporous and mesoporous materials controls the adsorption capacity and commonly used to determine through low pressure adsorption isotherm or mercury injection (Amarasekera et al., 1995; Yangbo et al., 2012). Fractal theory is an effective means for characterizing fractal dimension is an intrinsic, quantitative measurement of the surface irregularity (Liu et al., 2015). A surface of pores look like two dimensional in low magnification and three porous media on the pore structure and also on the diffusivity and permeability dimensional under high magnifications (Pfeifer et al., 1983; Ng et al., 1987; Pfeifer and Liu, 1997; Wu and Yu, 2007; Mahamud and Novo, 2008; Yu, 2008; Yu et al., 2009; Othman et al., 2010; Zhang et al., 2014). It is observed that inner pore network of coal have fractal characteristics (Diduszko et al., 2000; Nakagawa et al., 2000; Sastry et al., 2000). The fractal dimension does not depend on the size of the pores or percentage of surface area (Sing, 2004; Yao and Liu, 2006; Yao et al., 2009). Commonly used method for surface fractal analysis based on adsorption isotherm is the Frenkel-Halsey-Hill (FHH) model (Rigby, 2005; Lee et al., 2006; Wee, 2007; Fang et al., 2008; Yao et al., 2008). Several authors have revealed that the pore structure of coal has fractal characteristics and the FHH model is suitable to coal for fractal dimension calculation (Radlinski et al., 2004; Song et al., 2004; Mahamud and Novo, 2008; Yao et al., 2008; Liu et al., 2010; Cai et al., 2013)However, there are controversies associated with obtaining the fractal dimension from experimental adsorption data (Ismail and Pfeifer, 1994; Tang et al., 2003; Watt-Smith et al., 2005; Yao et al., 2008; Liu et al., 2010).

In this study, the technological properties, TOC content, low pressure $N_2$ sorption isotherms, thermal maturity (Ro%) and images obtained through SEM have been investigated to find out the various parametric controls and associated geological influence on pore structure and fractal dimensions for better understanding of gas adsorption capacities of coal seams in East Bokaro coalfield. The effects of coal rank upon fractal dimensions are mainly due to the variety of micropore contents and aromaticity of coals with coalification (Yao et al., 2009). The fractal dimension can be used to evaluate adsorption capacity (Yang et al., 2014). Fractal analysis is of great significance for better understanding of the surface irregularity and methane storage capacity of a coal reservoir (Xianfeng and Baisheng, 2016). Fractal theory is an important tool for evaluating surface roughness, which has already been used to investigate either the permeability or surface appearance of coal and shale samples (Yu and Cheng, 2002; Cai et al., 2013; Liu et al., 2014; Yang et al., 2014). Although using it to describe the geometry of irregularly shaped objects is relatively new, fractal theory has been identified as an effective approach for studying the irregular surfaces of pores and micro-structures (e.g., Katz and Thompson, 1985; Cox and Wang, 1993; Schlueter et al., 1997; Ma et al., 2003). Using fractal analysis of porous materials, it has been shown that the irregularity of surfaces and pores is important for processes such as diffusion, reaction dynamics, and adsorption (Lefebvre and Jolicoeur, 1992; Xie, 1993; El hafei et al., 2004; Pyun et al., 2004; Watt-Smith et al., 2008; Posnansky et al., 2012; Cai et al., 2013; Sun et al., 2015).

The coalbed methane production has begun in East Bokaro since 2010, the complex nature of reservoir is yet to be comprehend for better and efficient recovery. Besides, the role of geochemical parameters and associated pore structure of coal seam reservoir has not been evidently understood. An attempt has been made to calculate the value of the fractal dimension for evaluation of pore surface area, pore structure and pore size distribution. It is accentuated that pore structure controls the gas transport, however, if higher the fractal dimensions lesser the flow capacity, the studied coal seams has low values of fractal dimensions counsels the effective flow of gas during recovery. This paper also focuses relationships among pore fractal dimension ($D_1$ and $D_2$) obtained following FHH model using $N_2$ adsorption and desorption isotherms, and their relationships with different geochemical and rank parameters with implications to influence on surface area, pore volume and storage capacity.

## 2. Study area and coal seam occurrence

East Bokaro Coalfield is on east-west aligned synclinal half basin closing towards east, covers an area of about 237 sq. km between Latitudes 23° 44′ N and 23° 49′ N and Longitudes 85° 42′ E and 86° 30″ E. The study area is located in the eastern part of East Bokaro coalfield, known for Gondwana deposits contains a number of thick persistent regional Barakar and Karharbari as well as thin, interbanded regional Raniganj coal seams along with a continuous deposition from Talchir to Supra-Panchet- Mahadeva Formations (Table 1). However, southern limb of Barakar Formation became attenuated against the southern boundary fault, while the north and northwest, along the margin of the coalfield, the Barakar strata in the northern limb occurs as narrow, elongated, detached and faulted wedges/slices against the Basement rocks, Barren Measures and Panchet formations (Raja Rao, 1987). The geological map