Application of X-Ray Computed Tomography for Analyzing Cleats and Pores for Coalbed Methane in Coal from Thar Coalfield

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ABSTRACT

The CT (Computed Tomography) is a non-destructive technique that can provide information of internal structure of coal in two-dimensional, this technology is now widely used in geoscientific research. This technique is used for the measuring cleat dimension and pore width of the Thar coal. The slicing study of Thar coal shows that the length of cleats in various seams ranges from 0.5-5mm and the aperture of these cleats vary between 0.1-0.5mm. The porosity also plays an important role in storage and production of coalbed methane, the size or width of pores in coal under investigation ranges between 0.1-0.7mm. The present investigation shows that Seam-III and V of the can be considered as viable as hold a potential for CBM (Coalbed Methane) resources, however, the coal samples from these seams need to be analyzed for the presence of methane.

In Thar coalfield, the pore volume ranges from 0.06-2.36 cc/g and pore diameter in Thar coal ranges from meso-pore and macro-pore (34.81-121.51Å). These meso and macro-pores serve as transport pathways, and little methane is stored in these pores in the adsorbed state.

Key Words: **X-Ray Computed Tomography, Cleats, Picker-IQ, CT Slices**

1. INTRODUCTION

CT is a technique that provides information about the internal structure of coal by X-Ray source detector that in turn produces the cross-sectional images of slices of interior of coal in 2 directions. This technique is now widely used in geoscientific research [1-2]. CT technique is also useful for the coal petrological and petrophysical research. Verhelst, et. al. [3] and Van Geet, et. al. [4] had carried out research on coal with CT techniques.

The coal is composed of three basic components, i.e. the cleat fracture, coal matrix, pores and mineral. The network of cleat fractures in coal plays an important role in the production of methane from coalbeds. The major characteristics of cleats include cleat length, cleat aperture and extent of mineral filling [5]. Micropores are responsible for most of the porosity in coal and size or width of pore also plays an important role. CT scan technique enables us to study the cleat aperture and length as well as width or size of pore.

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The Thar coalfield is the largest coalfield of Pakistan, with proven reserves of 175 billion tones of coal. At present efforts are being made to produce coalbed methane and underground coal gasification from this coal, but there is need of geoscientific research on coal for clean coal utilization of Thar coalfield.

2. GEOLOGY OF THE STUDIED AREA

The Thar coalfield is located between latitudes 24°15 and 25°45' N and longitudes 69°45 and 70°45' E (Survey of Pakistan Topo-Sheet Nos. 40L/2, 5 and 6) situated in District Tharparkar of south-eastern Sindh. It is the largest coalfield of Pakistan having an area of about 9100 square kilometres. It has north-south length of 140 km and east-west width of 65km. The resource potential of this single coalfield is about 175 billion tonnes [6]. Thar coalfield is the largest coalfield of Pakistan, located on the Indus Platform, in the Thar desert in south-eastern corner of Pakistan.

The coal samples were obtained from Block-XI of Thar coal field. Geologically this block is covered with sand dunes, and coal bearing Bara formation is encountered at 180-206m, which comprises of Clay stone, carbonaceous claystone, coal, sandstone. Siltstone, silty claystone, clayey sandstone and sandy claystone. Sub-Recent deposits starts from 51-61m. It consists of variegated colored sandstone, siltstone, claystone and clayey sand-stone and silty sandstone (Table 1). Maximum 10 coal seams are encountered in this block while the thickest coal seam of this block is about 9.18m. Megascopically the coal is brownish black and grayish black in colour, the coals from Thar coal basin are slightly banded and poorly to well cleated and compacted. It contains flakes of brown and greenish yellow coloured resin. Coal contains very fine to fine grained pyrite in patches upto one sq. cm size. The rank of coal is lignite ' A' to lignite ' B' [7]. The thickness of coal beds in the investigated block varies from 4.5-19m.

3. METHODOLOGY

Three representative coal seam samples of Block-XI were obtained from Sindh coal authority. The samples obtained were from Seam-II (Sample No. BP-10), Seam-III (Sample No. BP-30) and Seam-V (Sample No. BP-5) the depth of these seam samples are 188.24-192.86, 242.85- 247.92 and 248.74-257.92m (Fig. 1). For the X-ray CT scanning, Picker-IQ X-ray scanner equipment was used for the cleat study (Fig. 2). The scanner operated at 130kV and 85mA and it produced a series of two-dimensional images known as ' slices' as it looks that object has been sliced along the scan plane. The scanning time was 4 sec/slice, the X-ray source was 0.8x0.9mm spot size. Slice thickness of 2 and 5mm have been used, the reconstruction matrix each consist of pixel 512x512 pixels, in the XY plane [8]. The images are usually seen as monochromatic, with various shades of grey color (Fig. 2).

TABLE 1. GENERAL STRATIGRAPHIC SEQUENCE OF THAR COALFIELD [6]

Formation	Age	Thickness	Lithology
Dune Sand	Recent	14-93m	Sand, Sil and Clay
-	Unconformity	-	-
Alluvial Deposits	Sub Recent	11-209m (Variable)	Sandstone, Siltstone, Clay Stone, Mottled
-	Unconformity	-	-
Bara Formation	Palaeocene to Early Eocene	+52m (Variable)	Clay Stone, Shale, Sandstone, Coal, Carbonaceous Clay Stone
-	Unconformity	-	-
Basement Complex	Pre-Cambrian	-	Granite, Quartz and Diorite

For the determination of pore volume BJH (Barrett, Joyner and Halenda) low temperature of nitrogen at 77.4k using Quntachrome Nova 2200e surface area analyzer instrument with NOVAWin PC based program was used for the operation of instrument was used as method described by Singh [9], Yao, et. al. [10]. The sample was out gassed at 100°C for 2 hours.

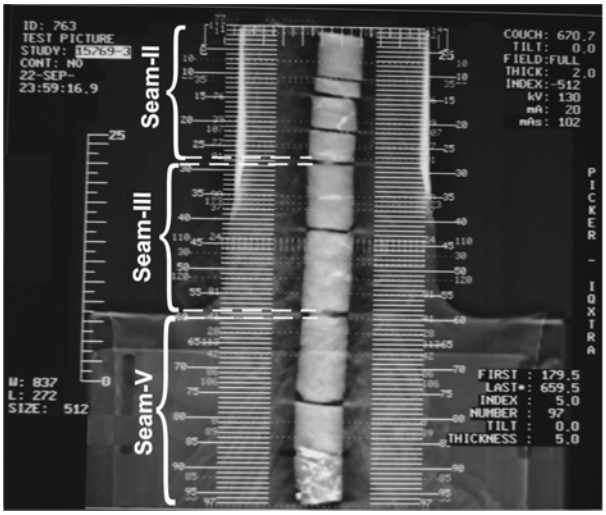

FIG. 1.X-RAY VIEW OF THE SAMPLE (COLLECTED II, III AND V, THE LINES WITH FIGURE SHOWS SLICING DATA OF THE SAMPLES

4. RESULTS AND DISCUSSION

For generation and production of coalbed methane, coal must have porosity through which desorption of gas from coal surface may occur. The micropores must have considerable size or width so that diffusion of gas may occur and the coal also must have network of cleats with considerable aperture for the flow of gas. The study of cleats provides important information about the possibility of the occurrence of CBM. Computed Tomography technique provides quantitative images showing cleat dimension and porosity in coal. Comprehensive CT scan study was conducted on samples of three coal seams, from the depth of 188.24 -192.86, 242.85-247.92 and 248.74-257.92m.

The details of slices or sample are given in Table 2. The CT images, identifies network of cleat fractures i.e. face, butt and isolated ' S' cleats. The Face cleats are the primary continuous micro fractures having wide aperture, giving a directional permeability. While Butt cleats are the secondary cleats and are discontinuous, shorter in extent and localized between adjacent cleats. And isolated ' S' cleats are developed in coal due to tectonic activity.

FIG. 2.SHOWING X-RAY COMPUTED TOMOGRAPHIC SCANNING MACHINE.

TABLE 2. SEAM-WISE DISTRIBUTION OF CLEAT LENGTH AND WIDTH AND THEIR TYPES IN THAR COAL

Seam No.	Interval (m)	CT Scan Slice	Type of Cleat Fracture Identified	Cleat Dimension (mm)
II	188.24-192.86	S #23	Isolated 'S'	L: 1.5 - 3 W: 0.1 - 0.3
		S #25	Butt and Isolated 'S'	L: 1.5 - 3 W: 0.1 - 0.5
		S #26	Butt and Isolated 'S'	L: 2.1 - 2.2 W: 0.1 - 0.3
		S #28	Butt	L: 0.5 - 3 W: 0.1 - 0.3
III	242.85-247.92	S #29	Butt	L: 1 - 2 W: 0.2 - 0.3
		S #30	Butt	L: 2.6 - 2.7 W: 0.2 - 0.3
		S #31	Butt	L: 1.3 - 2.7 W: 0.2 - 0.3
		S #34	Nil	Nil
		S #35	Butt	L: 3 - 5 W: 0.3 - 0.5
		S #36	Butt	L: 3 - 5 W: 0.3 - 0.5
		S #37	Butt	L: 4-5 W: 0.2 - 0.3
		S #39	Face	L: 3 W: 0.1
		S #40	Face & butt	L: 2 W: 0.2 - 0.3
		S #41	Nil	Nil
		S #42	Butt	L: 2 W: 0.2
		S #44	Butt	L: 2.6 W: 0.4
		S #45	Butt	L: 2.6 W: 0.4
		S #46	Mineralized Butt	Nil
		S #51	Butt	L: 2-4 W: 0.2 - 0.3
		S #58	Nil	Nil
IV	248.74-257.92	S #59	Nil	Nil
		S #60	Nil	Nil
		S #63	Butt	L: 1.5 W: 0.3
		S #64	Butt	L: 1.7 W: 0.2
		S #65	Butt	L: 2.0 W: 0.2
		S #66	Butt	L: 2.5 W: 0.3
		S #67	Butt	L: 1.8 W: 0.4
		S #71	Mineralized Butt and Face	Nil
		S #80	Nil	Nil
		S #83	Nil	Nil
		S #90	Diagonal	L: 2.2 W: 0.3
		S #91	Mineralized Butt and Face	Nil
		S #92	Butt	L: 2.5 W: 0.2
		S #97	Mineralized Butt	Nil
		S #101	Butt	L: 3 W: 0.2
		S #105	Butt and Face	L: 1.5 - 2.7 W: 0.1 - 0.2

L: length of Cleat, W: width of cleat

The X-ray view of slices of sample No. BP-10 Fig. 3 show cleats of isolated ' S' type, with the length of 2.1mm and aperture or width of 0.3-0.1mm. These types of cleats are produced due to tectonic activity and enhance reservoir porosity and permeability in coal.

Slices of CT images (Fig. 3) shows the prominent isolated ' S' type cleats in Seam-II in the hole core BP-10 at the depth of 188.24-192.86m. In Seam-III, Fig. 4, the X-ray view of slice sample No. BP-30, shows well developed Butt and isolated ' S' cleats, with the length of 0.3-2.7mm and aperture of 0.2-03mm.

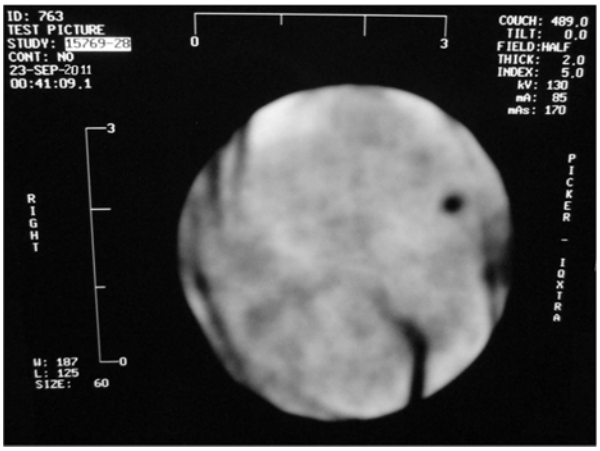

FIG.3. X-RAY VIEW OF SLICE, SHOWING ISOLATED ' S' CLEATS AND PORES

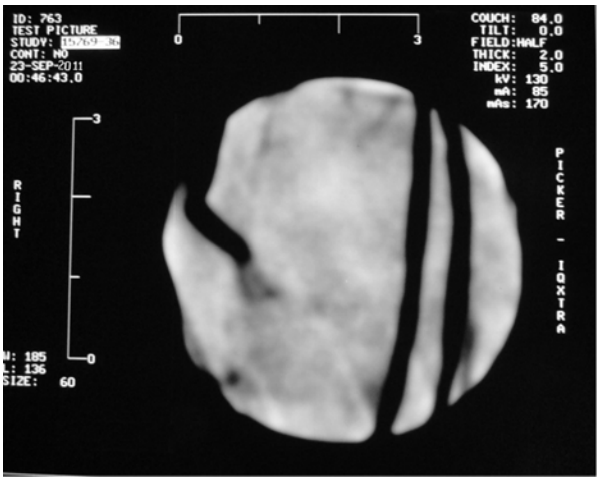

FIG.4. X-RAY VIEW OF SLICE, SHOWING BUTT CLEATS AND SOLATED ' S' CLEAT

An indistinct network of primary continuous face cleats and secondary localized butt cleats have been observed in the X-ray view of slices in Fig. 5 (Hole/Core No. 5 and Seam-V) is identified, displaying Butt and Face cleats with the length of 1.8-2mm, and aperture width of 0.2-0.3mm. However, post or syn diagenetic mineralization of pyrite has blocked these cleats.

The porosity has direct impact on CBM, the volume occupied by pores between cleats fractures in coal is known as porosity and these cleats in coal has the capacity of storing less than 10% of the in place gas[11].

Table 3 shows that in Seam-II, out of four pores one pore (1% of all of these pores) is open there is no closed pore. While in Seam-III, out of total 639 pores 46% are open pores and 54% are closed pores and in Block-V out of 500 pores 53% are open pores and 47% are closed pores. Table 3 shows that in Seam-III; slice (No. 46) out of 13 cleats 7.69% of the cleats are blocked due pyrite mineralization, at the depth of 242.85-247.92m. While in Seam-V 25% of the cleats are heavy blocked due to pyritization and this may obstruct the flow of CBM in coal [12].

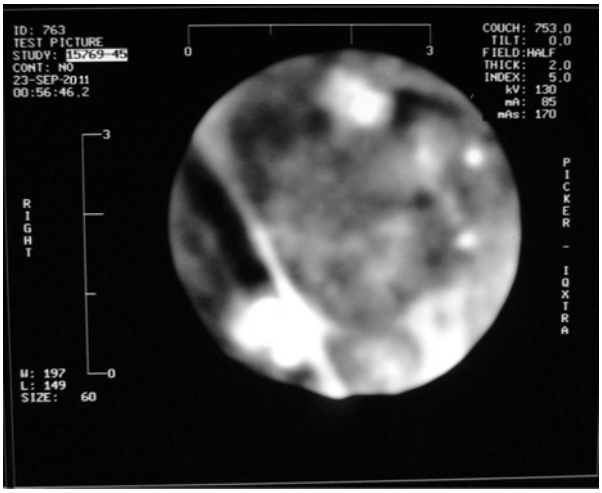

FIG. 5. X-RAY VIEW OF SLICE, SHOWING MINERALIZATION (PYRITIZATION) IN CLEATS AND PORES

Generally it is found that in Thar majority of the coal have closed pores. The absorbability and flow ability of coal bed methane in coal depends upon the pores. According to IUPAC classification [13], pores having <0.002mm width are known as micropores, while mesopores are those having between 0.000002 and 0.00005mm width and macropores are those having with of >0.00005mm . The X-ray view of slice of Sample No. BP-10 shows random pores with the width of 0.1mm. The size of pores in Sample No. BP-30 (Seam-III) is less 0.1mm. The size of pores in Sample No. BP-5 (Seam-V), has ranges between 0.1-0.2mm. However, these pores and cleats are filled in with syn or post deposited pyrite minerals (Fig. 5).

The Table 2 displays that Thar coal posses macro-pores, and it is thought that little methane gas may had stored in coal as macro-pores serve as transport pathways, and in these pores little gas is stored in the adsorbed state.

The pore volume distribution may be used to predict the methane adsorption capacity in coal. In this regard total pore volume were determined by BJH micropore volume determined by DR (Dubinin Radushkevich) method [14].\ The results shows that pore volume ranges from 0.06-2.36 cc/g and pore diameter in Thar coal ranges from 34.81-121.51Å, and termed as meso-pore and macro-pore [15]. These meso and macro-pores serve as transport pathways, and little methane is stored in these pores in the adsorbed state.

In the present study, it is evident from the Fig. 6 and Table 2 that high porosity values are due to the presence of cleat fracture networks, which are identified by CT scanned images. Based on the research on coal sample from Saun Juan basin, Zonguldak-Turkish basin and Jharia-Indian coal basin, conducted by Close and Mover [5], Karacan and Okandan [16] and Mandal, et. al. [17]

TABLE 3. SHOWING TOAL PORE, OPEN AND CLOSED PORES IN THAR COAL

Seam No.	CT Scan Slice No.	Total Pores	Open Pores	Closed Pores	Seam No.	CT Scan Slice No.	Total Pores	Open Pores	Closed Pores	Seam No.	CT Scan Slice No.	Total Pores	Open Pores	Closed Pores
II	S #23	Nil	Nil	Nil	III	S #52	18	08	10	V	S #78	14	06	08
II	S #25	Nil	Nil	Nil	III	S #53	15	10	05	V	S #79	10	05	05
II	S #26	Nil	Nil	Nil	III	S #54	13	01	12	V	S #80	16	10	06
II	S #28	01	01	Nil	III	S #55	12	02	10	V	S #81	14	06	08
III	S #29	06	Nil	06	III	S #56	18	12	06	V	S #82	14	08	06
III	S #30	09	Nil	09	III	S #57	15	08	07	V	S #83	16	10	06
III	S #31	08	Nil	08	III	S #58	18	11	07	V	S #84	12	03	09
III	S #32	14	Nil	14	V	S #59	16	06	10	V	S #85	04	02	02
III	S #33	14	Nil	14	V	S #60	24	14	10	V	S #86	08	04	04
III	S #35	06	Nil	06	V	S #61	10	06	04	V	S #87	10	06	04
III	S #36	06	02	04	V	S #62	18	12	06	V	S #89	14	08	06
III	S #37	04	02	04	V	S #63	16	08	08	V	S #90	16	07	09
III	S #38	10	05	05	V	S #64	16	05	11	V	S #91	14	10	04
III	S #39	06	03	03	V	S #65	24	16	08	V	S #92	14	05	08
III	S #40	08	03	05	V	S #66	23	15	08	V	S #93	09	05	04
III	S #41	22	08	14	V	S #67	02	01	01	V	S #95	14	08	06
III	S #42	10	03	07	V	S #69	01	Nil	01	V	S #96	04	04	Nil
III	S #43	06	03	03	V	S #70	21	13	08	V	S #97	20	10	10
III	S #44	12	05	07	V	S #71	07	Nil	07	V	S #100	05	03	02
III	S #45	12	07	05	V	S #72	11	05	06	V	S #101	11	07	04
III	S #46	09	03	06	V	S #73	12	08	04	V	S #102	03	02	01
III	S #47	18	09	09	V	S #74	12	04	08	V	S #104	04	02	02
III	S #49	11	08	03	V	S #75	11	05	0	V	S #105	11	06	05
III	S #50	22	14	08	V	S #76	11	06	05					
III	S #51	18	11	07	V	S #77	08	05	03					

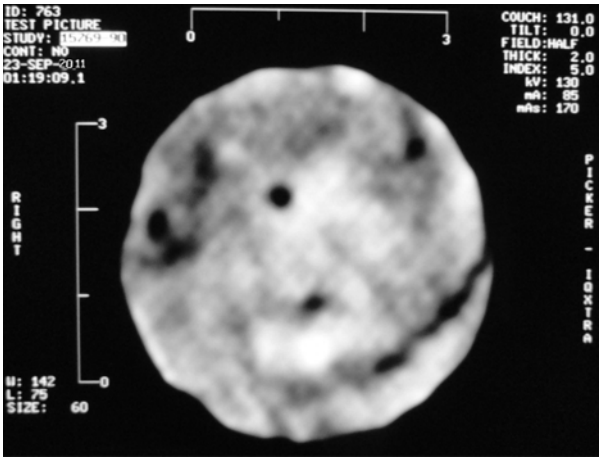

FIG. 6. X-RAY VIEW OF SLICE SHOWING POROSITYZ IN COAL

5. CONCLUSIONS

Based on the present research following conclusion can be made:

(i) In studied samples cleat length ranges from 0.5-5mm.

(ii) Computed Tomograpy technique shows that cleat aperture ranges from 0.1-0.5mm.

(iii) The pores identified by CT technique show that the size or width of pores range from 0.1-0.7mm.

(iv) In Seam-II, 1% of all of these pores are open there is no closed pore. While in Seam-III, 46%

pores are open pores and 54% are closed pores and in Seam-V, 53% pores are open pores and 47% are closed pores.

(v) The study shows that in Seam-III; 7.69% cleats are blocked due pyrite mineralization. While in Seam-V 25% of the cleats are heavy blocked due to pyritization and this may obstruct the flow of CBM in coal.

(vi) The absorbability and flow ability of coalbed methane in coal depends upon the pores. The X-ray view of slices shows random pores with the width of 0.1mm. The size of pores in Seam-III is less 0.1mm. The size of pores in Seam-V, ranges between 0.1-0.2mm. But these pores and cleats are filled in with syn or post deposited pyrite minerals.

(vii) The pore volume distribution used for estimating the methane adsorption in coal shows that as per BJH and DR or dr method, pore volume in investigated coal ranges from 0.06-2.36 cc/g and the pore diameter in it ranges from meso-pore to macro-pore (34.81-121.51Å). These meso and macro-pores may serve as transport pathways, and little methane is stored in these pores in the adsorbed state.

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