

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 computed tomography (CT) is a non-destructive technique that can provide information of internal structure of coal in 2D, this technology is now widely used in geoscientific research. This technique is used for the measuring cleat dimension and pore width of the coal. The slicing study of Thar coal shows that the length of cleats in various seams ranges from 0.5mm to 5mm and the aperture of these cleats vary between 0.1mm to 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 0.1mm to 0.7mm. The present investigation shows that seam III and V of the Thar coalfield can be considered as viable as hold a potential for CBM resources, however, the coal samples from these seams need to be analyzed for the presence of methane.

Keywords: X-ray Computed Tomography, Cleats, Picker-IQ, CT slices.

INTRODUCTION

Computed tomography (CT) is a technique that provides information about the internal structure of coal by an 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 (Duliu, 1999; Mess *et al.*, 2003). Computed tomography technique is also useful for the coal petrological and petrophysical research. Another study Verhelst *et al.* (1995); Van Geet *et al.* (2001) had carried out extensive 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 (Close and Mavor, 1991). Micropores are responsible for most of the porosity in coal and size or width of pore also plays an important role. Computed tomography (CT scan) technique enables us to study the cleat aperture and length as well as the width or size of pores.

The Thar coalfield is the largest coalfield of Pakistan, with proven reserves of 175 billion tons 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.

GEOLOGY OF THE STUDIED AREA

The Thar coalfield is located between latitudes 24°15'N and 25° 45'N and longitudes 69° 45'E and 70° 45'E (Fig.1, Survey of Pakistan topographic sheet Nos. 40 L/2, L/5 and L/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 140km and east-west width of 65km. The resource potential of this single coalfield is about 175 billion tonnes (Jaleel *et al.*, 1999). Thar coalfield is the largest coalfield of Pakistan, located on the Indus Platform, in the Thar desert in southeastern 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 to 206m, which comprises of Clay stone, carbonaceous claystone, coal, sandstone, siltstone, silty claystone, clayey sandstone and sandy claystone (Table 1). Sub-Recent deposits consist of variegated colored sandstone, siltstone claystone and sometimes clayey sandstone and silty sandstone. 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

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Table 1. General stratigraphic sequence of Thar coalfield (Jaleel *et al.*, 1999).

Formation	Age	Thickness	Lithology
Dune Sand	Recent	14m to 93m	Sand, Silt and Clay
.....	.....Unconformity	.....	.....
Alluvial Deposits	Sub Recent	11m to 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

Table 2. Seam-wise distribution of cleat length and width and their types in Thar coal.

Seam No.	Interval (m)	CT Scan Slice No.	Type of cleat fracture identified	Cleat dimension (mm)	Seam No.	Interval (m)	CT Scan Slice No.	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		III	S #40	Face & Butt	L: 2 W: 0.2-0.3
		S #25	Butt & Isolated 'S'	L: 1.5 - 3 W: 0.1 - 0.5			S #42	Butt	L: 2 W: 0.2
		S #26	Butt & Isolated 'S'	L: 2.1 - 2.2 W: 0.1 - 0.3			S #46	**Butt	Nil
		S #28	Butt	L: 0.5 - 3 W: 0.1 - 0.3			S #51	Butt	L: 2-4 W: 0.2- 0.3
III	242.85-247.92	S #29	Butt	L: 1 - 2 W: 0.2 - 0.3			S #58	Nil	Nil
		S #30	Butt	L: 2.6 - 2.7 W: 0.2 - 0.3	V	248.74-257.92	S #59	Nil	Nil
		S #31	Butt	L: 1.3 - 2.7 W: 0.2 - 0.3			S #60	Nil	Nil
		S #34	Nil	Nil			S #63	Butt	L: 1.5 W: 0.3
		S #35	Butt	L: 3 - 5 W: 0.3 - 0.5			S #97	***Butt	Nil
		S #36	Butt	L: 3 - 5 W: 0.3 - 0.5			S #101	Butt	L: 3 W: 0.2
		S #37	Butt	L: 4-5 W: 0.2 - 0.3			S #105	Butt & Face	L: 1.5-2.7 W: 0.1- 0.2
		S #39	Face	L: 3 W: 0.1					

*L: length of cleat, **W: width of cleat, ***Mineralized/pyritized pores

brownish black and grayish black in color, the coals from Thar coal basin are slightly banded and poorly to well cleated and compacted. It contains scattered resin of brown and greenish yellow color. 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' (Pakistan Energy yearbook, 2010). The thickness of coal beds in the investigated block varies from 4.5m to 19 meters.

MATERIALS AND METHODS

Three representative coal seam samples of Block-XI were obtained from the 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 to 192.86, 242.85 to 247.92 and 248.74 to 257.92 meters (Figs. 2 and 3). For the X-ray CT scanning, Picker-IQ X-ray scanner equipment was used for the cleat study (Fig. 1). The scanner operated at 130kV and 85mA and it produced a series of 2D images known as 'slices' as it looks that object has been sliced along the scan plane. The scanning time was 4sec per slice, the X-ray source was 0.8 x 0.9mm spot size. Slice thickness of 2mm and 5mm have been used, the reconstruction matrix each consists of pixel 512x512 pixels, in the XY plane (Mazumder *et al.*, 2006). The images are usually seen as monochromatic, with various shades of grey color (Figs. 4-7).

Table 3. Showing total 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 #51	18	11	07	V	S #76	11	06	05
II	S #25	Nil	Nil	Nil	III	S #52	18	08	10	V	S #77	08	05	03
II	S #26	Nil	Nil	Nil	III	S #53	15	10	05	V	S #78	14	06	08
II	S #28	01	01	Nil	III	S #54	13	01	12	V	S #79	10	05	05
III	S #29	06	Nil	06	III	S #55	12	02	10	V	S #80	16	10	06
III	S #30	09	Nil	09	III	S #56	18	12	06	V	S #81	14	06	08
III	S #31	08	Nil	08	III	S #57	15	08	07	V	S #82	14	08	06
III	S #32	14	Nil	14	III	S #58	18	11	07	V	S #83	16	10	06
III	S #33	14	Nil	14	V	S #59	16	06	10	V	S #84	12	03	09
III	S #35	06	Nil	06	V	S #60	24	14	10	V	S #85	04	02	02
III	S #36	06	02	04	V	S #61	10	06	04	V	S #86	08	04	04
III	S #37	04	02	04	V	S #62	18	12	06	V	S #87	10	06	04
III	S #38	10	05	05	V	S #63	16	08	08	V	S #89	14	08	06
III	S #39	06	03	03	V	S #64	16	05	11	V	S #90	16	07	09
III	S #40	08	03	05	V	S #65	24	16	08	V	S #91	14	10	04
III	S #41	22	08	14	V	S #66	23	15	08	V	S #92	14	05	08
III	S #42	10	03	07	V	S #67	02	01	01	V	S #93	09	05	04
III	S #43	06	03	03	V	S #69	01	Nil	01	V	S #95	14	08	06
III	S #44	12	05	07	V	S #70	21	13	08	V	S #96	04	04	Nil
III	S #45	12	07	05	V	S #71	07	Nil	07	V	S #97	20	10	10
III	S #46	09	03	06	V	S #72	11	05	06	V	S #100	05	03	02
III	S #47	18	09	09	V	S #73	12	08	04	V	S #101	11	07	04
III	S #49	11	08	03	V	S #74	12	04	08	V	S #102	03	02	01
III	S #50	22	14	08	V	S #75	11	05	06	V	S #104	04	02	02
										V	S #105	11	06	05

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 to 192.86, 242.85 to 247.92 and 248.74 to 257.92 meters.

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.

The X-ray view of slices of sample No. BP-10 (Figs. 4 and 5) show cleats of isolated 'S' type, with the length of 2.1mm and aperture or width of 0.3 to 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. 5) shows the prominent isolated 'S' type cleats in seam-II in the hole core BP-10 at the depth of 188.24 to 192.86m. In seam-III, figure 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 mm to 2.7mm and aperture of 0.2-03mm.

An indistinct network of primary continuous face cleats and secondary localized butt cleats have been observed in the X-ray view of slices in figure 5 (hole/core No. 5 and seam-V) is identified, displaying butt and face cleats with the length of 1.8 to 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 coalbed methane, the volume occupied by pores between cleats fractures in coal is known as porosity and these cleats in coal have the capacity of storing less than 10% of the in place gas (Allen, 1997).

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 (S. # 46) out of 13 cleats 7.69% of the cleats are blocked due pyrite mineralization, at the depth of 242.85-247.92m. While the among the cleats, out of 12 cleats 25% of the cleats are

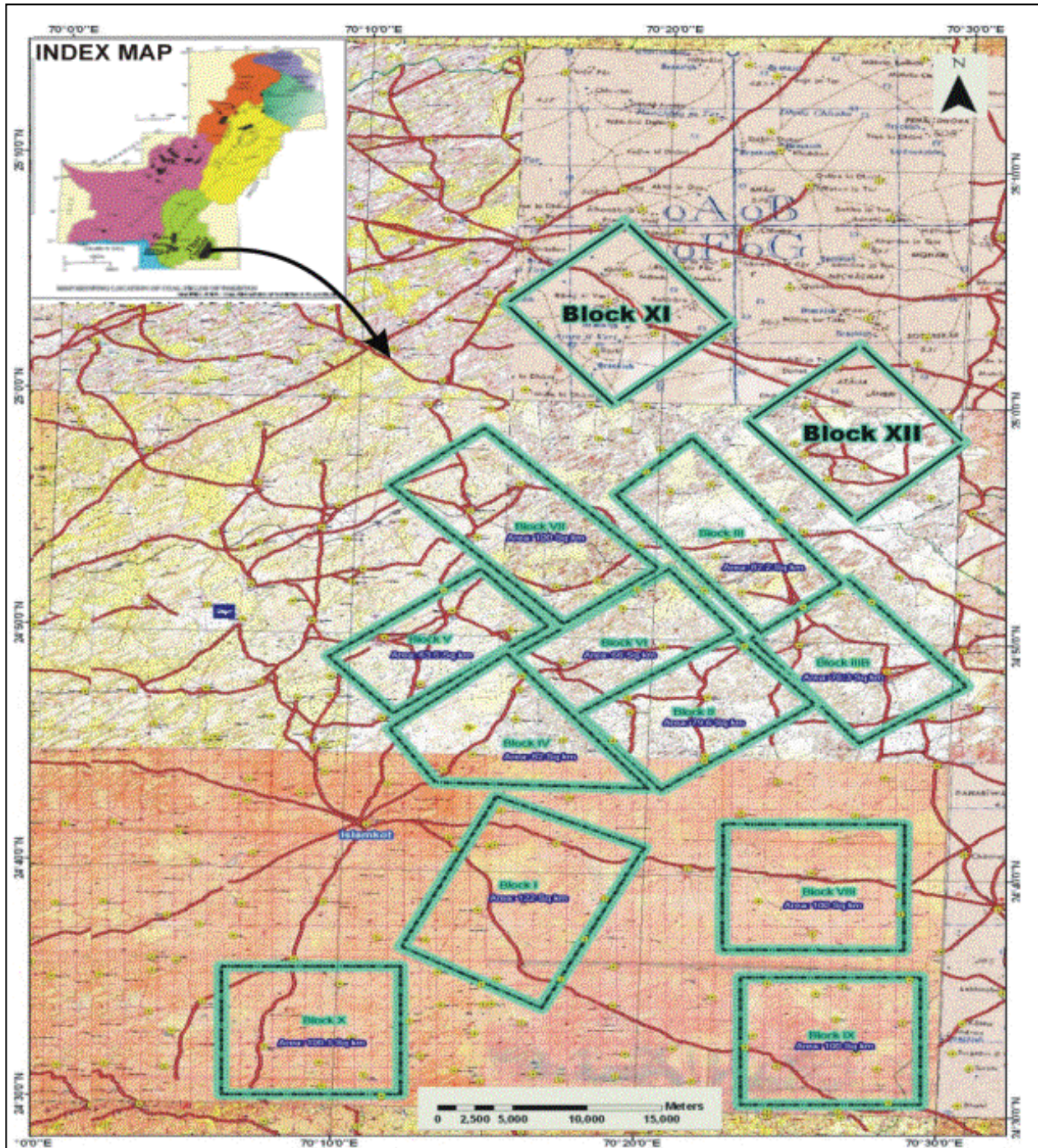


Fig. 1. Map showing various coal blocks (in topographic sheet Nos. 40 L/2, L/5 and L/6) in Thar coalfield of Pakistan.

heavy blocked due to pyritization (Siddiqui *et al.*, 2011). Generally it is found that in Thar majority of the coal have closed pores.

The absorbability and flowability of coalbed methane in coal depends upon the pores. According to International Union of Pure and Applied Chemistry (1982)

classification, pores having < 0.002 mm width are known as micropores, while mesopores are those having between 0.00002 and 0.00005 mm width and macropores are those having with of > 0.00005 mm (IUPAC, 1982). The X-ray view of slice of sample No. BP-10 shows random pores with the width of 0.1 mm. The size of pores in sample No. BP-30 (seam III) is less than 0.1 mm. The size



Fig. 2. Showing X-ray Computed Tomographic Scanning machine used in this study.

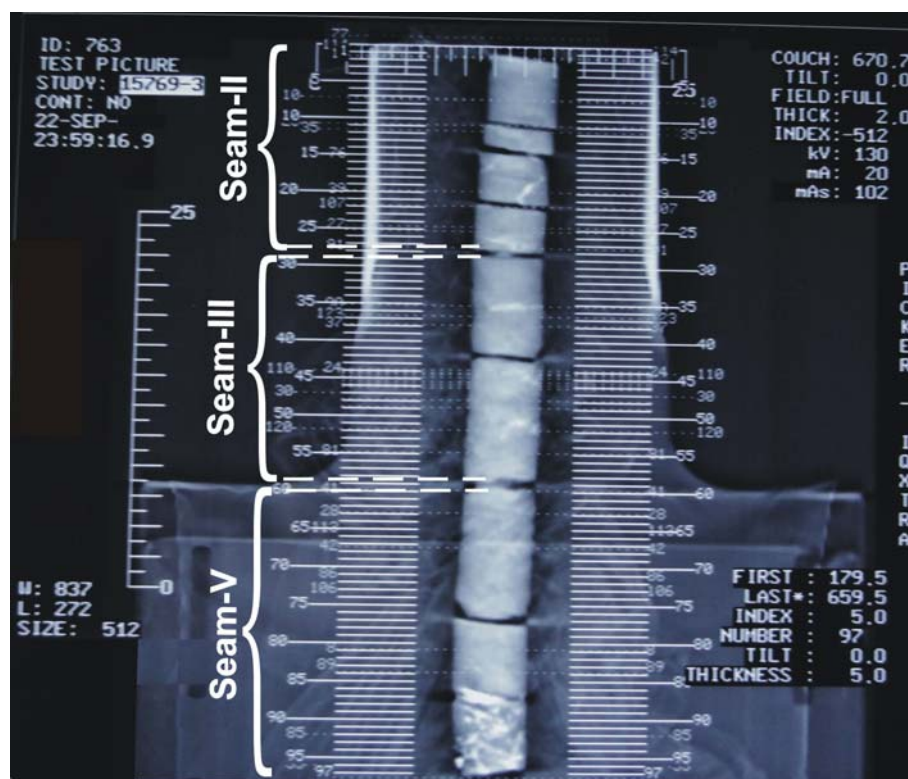


Fig. 3. X-ray view of the sample (collected II, III and V, the lines with figure shows slicing data of the samples.

of pores in sample No. BP-5 (seam-V), ranges between 0.1mm to 0.2mm. However, these pores and cleats are filled in with syn or post deposited pyrite minerals (Fig. 6).

The table 2 displays that Thar coal possess macro-pores, and because of its maceral composition i.e. Huminite

group; the coal may possess little or no methane gas. Beside that as Thar coal possess macro-pores which 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. Siddiqui *et al.*

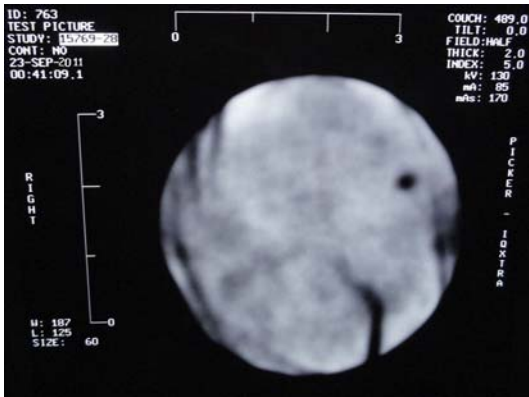


Fig. 4. X-ray view of slice, showing isolated 'S' cleats and pores.

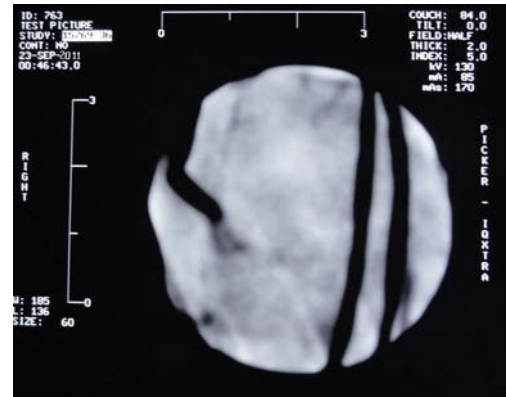


Fig. 5. X-ray view of slice, showing butt cleats and isolated 'S' cleat.

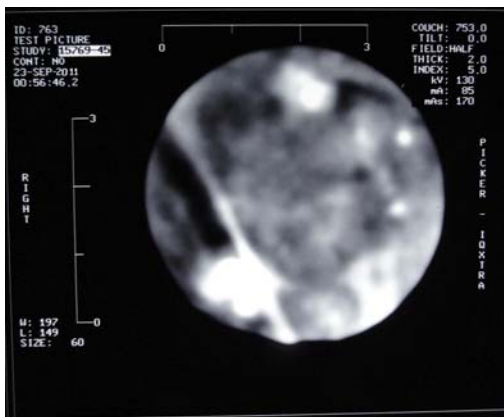


Fig. 6. X-ray view of slice, showing mineralization (pyritization) in cleats and pores.

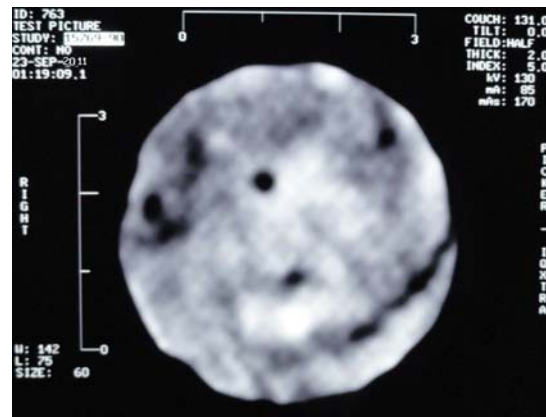


Fig. 7. X-ray view of slice showing porosity in coal.

(2012) had studied the porosity in Thar coal and as per his study the pore volume ranges from 0.06 to 2.36 cc/g and pore diameter in Thar coal ranges from 34.81 to 121.51Å, that is termed as meso-pore and macro-pore. 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 table 2 that high porosity values are due to the presence of cleat fracture networks, which are identified by CT scanned images as shown in figures 5 and 6. Based on the research on coal sample from Saun Juan basin, Zonguldak-Turkish basin and Jharia-Indian coal basin (Close and Mover, 1991; Karacan and Okandan 2000; Mandal *et al.*, 2004, Mahajan and Walker, 1978) it has been observed that permeability of coal if affected by network of cleat fractures in coal. The frequency of cleats fractures, their interconnections along with aperture size, may affect permeability in coal that plays important role in coalbed methane production. Face and butt cleats are primary contributors for coal permeability while the third set of cleats that formed latter in geologic time i.e. tertiary cleats oriented differently and terminates against either but or

face cleats and plays an important role in producing cleat permeability.

CONCLUSION

Based on the present research following conclusion can be made:

1. The slicing analyses identifies extensive cleat network in the coal seam-III and IV, at the depth of 242.85 to 247.92m and 248.74-257.92m.
2. In studied samples cleat length ranges from 0.5mm to 5mm.
3. With the help of Computed Tomography technique cleat aperture measured ranges from 0.1mm to 0.5mm.
4. The pores identified by Computed Tomography technique show that the size or width of pores range from 0.1mm to 0.7mm.
5. The slicing analyses also show that seam II and V are promising seams for producing coalbed methane as these seams have network of cleats and good porosity.

6. There is possibility that pyrite mineralization within the cleats and pores may block the flow of CBM in coal.
7. 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.

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