Analysis of Micro-fractures in Coal for Coal Bed Methane Exploitation in Jharia Coal Field

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ABSTRACT: Network of naturally occurring microfractures, called cleats provide the important parameter for flow modeling in coal. In any coal bed methane (CBM) prospect, the key of estimating production potential lies in presence of cleat networks/fractures in coal seam. The paper presents the detailed study of coal cleats/fractures identified in coal samples recovered from three R&D wells drilled in Jharia coalfield, India. Generally five different types of natural fractures are observed in CBM prospective coals. In Jharia coal seams, four types of natural fractures i.e. face cleats, butt cleats, tertiary cleats and joints have been identified with the help of CT scan imaging technique. These natural fractures have great influence on porosity and permeability of coal. Cleat porosity and permeability have been determined in the range of 3.01% to 5.93% and 0.03 mD to 2.88 mD respectively. Detailed description of these parameters of coal could be useful for coal characterization, its flow modeling and performance prediction for any successful exploitation of CBM.

INTRODUCTION

Coal is an important source and reservoir rock for natural gas, and commercial advantage has long been taken of this fact. Coal is also a reservoir rock, but only in the development of the coalbed methane process has this fact been commercially exploited. Even though the coal may retain only a fraction of the gas its generates as a source rock, that fraction may represent two to seven times more gas per unit volume as a reservoir rock than a conventional gas reservoir because the coal may have 1 million ft²/lb of adsorption surface area. In order to develop the coalbeds economically, gas content and permeability of the reservoir must meet minimum criteria, which may be about 150 Scf/ton gas content in thin seams and 1 mD permeability. A minimum criterion of permeability is required before hydraulic fracturing can successfully interconnect the natural cleat system to the wellbore.

The mechanisms for gas flow in the coal involves: a) desorption of the gas from the coal surface inside the micropores; b) diffusion of the gas through the micropores governed by Fick’s law; and c) Darcy flow through the cleat system, natural fracture network in the coal to the wellbore. So fractures and cleats (Fig.1) are the critical parameters for economic viability of coal bed methane. At initial stage, the cleats are saturated with water. By producing formation water from coal seams and thus lowering reservoir pressure, methane gas desorbs, the released gas diffuses through the coal matrix until it reaches a cleat system and then flows through the cleat network to the wellbore.

India has huge coal reserves, which offer enough scopes for the exploration and development of coalbed methane in Gondwana and Tertiary coal basins. Oil and Natural Gas Corporation Ltd. has focused on drilling CBM wells in its exploration programme and drilled R&D wells in Parbatpur block of Jharia Coal field in Gondwana basin. The Jharia coal field covers an area of about 450 sq km. and is located mainly in the Dhanbad district of Jharkhand, India (Fig. 2). The Gondwana sediments here are represented by Talchir, Barakar, Barren Measures and Raniganj Formation overlain and surrounded from all sides by the basement metamorphic rocks of Pre Cambrian age. The Barakar formation of Lower Permian age is the main coal bearing horizon.

NATURAL FRACTURES IN COAL

In coal five types of different natural fractures are observed. Most coals have at least two regular fracture sets (cleat), generally oriented perpendicular to each other and...
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bedding (Fig. 3). The dimensions of the fractures vary from a spacing of a few micrometers to ten centimeters. The best developed regular fractures are generally referred to as “face cleat” whereas the lesser developed regular fractures are “butt cleat”. The face and butt cleats are also referred to as primary and secondary cleats, respectively. The oldest and most prominent of these two micro-fractures sets is called the face cleat. The butt cleats terminates against face cleats, which is interpreted as indicating that they were formed later in geological time.

Three other fracture systems, referred to as tertiary cleats, joints/fractures (Fig. 4) and faults may also be present in coal reservoirs. Tertiary cleats are micro-fractures whose orientations are different than those of either the face or butt cleats. The tertiary cleats terminate against either face or butt cleats, which is interpreted as indicating that they were formed later in geological time. Fractures and faults are larger-scale that typically cut across coalbeds and non-coal interbeds.

It is important to understand the origin, orientation and spacing of cleat to optimize well placement and spacing. Cleat/fracture develop as a result of desiccation, devolatilization, and tectonic stress coalification, and unloading overburden during uplift and erosion. Rank of coal, bed thickness, maceral and mineral composition, and structure also may help to develop cleat/fracture network in coal. The network of cleats is most highly developed in low volatile bituminous coals, whereas the lowest ranks and anthracite show the poorest cleat system.

METHODOLOGY

Comprehensive X-ray Computed Tomography (CT) technique is useful in identifying coal cleat networks/fractures. X-ray Computed Tomography is a non-destructive analysis that produces an image of the internal structure of a material by computerized reconstruction of attenuation coefficients of X-rays passing through the object. An X-ray source and detector array rotate about the axis of the object in a single plane (Fig. 5). At discrete angles, this source detector configuration measures a one-dimensional projection of X-ray attenuation coefficients. The attenuation coefficients in various directions are processed to produce cross-sectional images. The attenuation coefficients are conventionally normalized to that of water, yielding a value known as the CT number.

IDENTIFICATION OF COAL CLEATS/FRACTURES

Coal must have an extensive cleat system in order to produce gas at economic rates. The pre-identification of such cleats provides significant information about the extent and
frequency of their occurrence through the coal bed and subsequent formulation of an optimal methane gas production strategy. Computed Tomography technique provides quantitative images showing density and atomic number variation, and from that, cleat development in coal can be easily identified.

Comprehensive CT scan studies were done on 17 whole core coal samples at the depth intervals of 545 – 1138 m from well #A, 752 – 1027 m from well #B and 315 – 1061 m from well #C. Megascopically the coals are indistinctly banded, sub-bituminous, rich in dull constituents. Sample details of CT scan is given Table 1. From CT image, prominent cleat (face and butt) networks were identified on two whole cores from well #A at depth of 545- 557 m (Fig. 6) and 610- 620 m (Fig. 7) and weak cleat network was observed on one whole core from well #C at depth of 315.0 – 320.0 m (Fig. 12). Tertiary cleats were identified at depth of 805.0 – 816.0 m of Well #A (Fig. 9) and at depth of 752.0 – 757.75 m of Well #B (Fig. 10). Isolated single fractures were also seen in at depth of 805.0 – 816.0 m of Well #A (Fig. 8), 1018.0 – 1027.0 m of Well #C (Fig. 11) and 768.0 744.0 m of Well #C (Fig. 13).

Detailed cleats/fractures identified in whole coal core samples are given in Table 1. So in well #A cleat/fractures are
mainly identified at depth from 545.0 m to 816.0 m, in well #B from 752.0 m to 1027 m and in well #C from 315.0 m to 1061.0 m.

**CLEAT POROSITY**

Coal seams are characterized by their dual porosity: they contain both micropores (<0.15 micrometer called matrix porosity or primary porosity) and macropores (>1.0 micrometer called cleat porosity or secondary porosity).
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Sedimentary rocks in having microporosity which makes up about 70% of its total porosity.

In the present study, porosity has been determined on core plugs using High Pressure Mercury Porosimetry test. A brief summary of the total porosity, macro and micro porosity derived from this test is given in the Table 2. It is evident from the table that high porosity values are due to presence of cleat/fracture networks, which are already identified by CT scan image. In general, total porosity ranges from 4.74% to 9.69% and macro and micro porosity values ranges from 3.01% to 5.93% and 1.54% to 4.15% respectively. Fairly high values of fracture porosity indicate large volumes of water stored in these coals, which are required to be produced to bring down the reservoir pressure considerably to achieve higher gas recovery.

CLEAT PERMEABILITY

Permeability is one of the most critical parameter for economic viability for coal bed methane production as well as in forecasting gas drainage before and during drilling. The networks of natural fractures provide the permeability for commercial flow rates of methane through coal seam. Many coal bearing sedimentary basins having high gas content and coal volume, get downgraded for its prospects of coal bed methane if permeability is not good. Therefore, the frequency of natural fractures, their interconnections, degree of fissure aperture opening and in-situ stresses all effect permeability.

Figure 11: Well #B Sam No 13  Depth: 1018.05m Slice 1

Figure 12: Well #C Sam No 14  Depth: 315.01m Slice 1

Figure 13: Well #C Sam No 15  Depth: 768.07m Slice 2
Analysis of Micro-fractures in Coal for Coal Bed Methane

Table 2: Porosity & Permeability of Jharia Coal

<table>
<thead>
<tr>
<th>Sample No</th>
<th>Porosity (%)</th>
<th>Micro</th>
<th>Macro</th>
<th>Permeability (mD)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well #A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>9.52</td>
<td>5.37</td>
<td>4.15</td>
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<tr>
<td>3</td>
<td>9.69</td>
<td>5.93</td>
<td>3.76</td>
<td>-</td>
</tr>
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<td>6</td>
<td>8.94</td>
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<td>3.53</td>
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<td>7</td>
<td>6.29</td>
<td>3.01</td>
<td>3.28</td>
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</tr>
<tr>
<td>8</td>
<td>4.74</td>
<td>3.20</td>
<td>1.54</td>
<td>-</td>
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<tr>
<td>9</td>
<td>6.94</td>
<td>3.59</td>
<td>3.35</td>
<td>0.32</td>
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<td>Well #B</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>5.82</td>
<td>4.39</td>
<td>1.43</td>
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<tr>
<td>11</td>
<td>7.02</td>
<td>4.97</td>
<td>2.05</td>
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<td>1.89</td>
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<tr>
<td>13</td>
<td>5.12</td>
<td>3.63</td>
<td>1.49</td>
<td>0.78</td>
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<tr>
<td>Well #C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>6.19</td>
<td>3.99</td>
<td>2.20</td>
<td>0.03</td>
</tr>
<tr>
<td>15</td>
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<td>4.39</td>
<td>2.39</td>
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<tr>
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<td>6.07</td>
<td>3.42</td>
<td>2.65</td>
<td>0.60</td>
</tr>
</tbody>
</table>

Face cleat, butt cleat and fracture are the primary contributors for coal permeability but third set of natural fractures oriented differently than primary and secondary fractures, called tertiary cleats, also promote permeability.

With core test, accurate measurement of permeability is difficult because permeability of coal is a function of sample size. Permeability values measured in the laboratory tend to be less than realized in the field because the small cores may not contain cleats, fractures or joints. So sample selection is very important parameter for determination of coal permeability because coal sample must contain cleat/fracture networks. In this respect CT scan is very useful tool for identification of such cleat/fracture networks. Air permeability was determined using Steady State method loaded in Hassler type core holder with 300 psi overburden pressure. The results of Klinkenberg corrected air permeabilities measurement on plugs are given in Table 2. Samples containing cleats/fractures show low permeability values in the range of 0.03 to 2.88 mD. Reasonably high fracture porosity compared with low permeability indicates possibility of long dewatering time at low rates.

CONCLUSION

In Jharia coal field good cleat or fracture networks are identified with the help of Computed Tomography technique. Four types of natural fractures i.e. face cleats, butt cleats, tertiary cleats and fractures are observed in coal seams. The pre-identification of these natural micro-fractures provides significant information about the identification of promising coal seams for coal bed methane.

1. The extensive cleat networks have been identified in coal seams at depth of 545-557 m and 610-620 m in well #A.
2. Fairly good cleat porosity values in the range of 3.01% to 5.93% and corresponding low permeability values in the range of 0.03 mD to 2.88 mD have been determined in Jharia coal.
3. Due to low permeability, hydraulic fracturing will be beneficial to connect the natural fractures/cleat networks in the prospective coal seams of Jharia field for maximizing the coal bed methane.

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