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Thar Coal, Sindh, Pakistan: A Potential Candidate for Liquefaction.

Abrar Ahmad[1], Muhammad Nawaz Chaudry[2], Asad Shabbir[2], Mohsin Ali[3]

ABSTRACT

The Middle to Late Palaeocene Thar coal mostly comprises matrix lithotype and falls in lignite to sub-bituminous C rank stage. Twenty, coal layers of variable thickness are reported at depths between 137.04 to 178.72 m beneath surface. Cumulative coal bed thickness varies from 8.08 to 36.00 m. Coal-petrography and geochemical methods were applied for characterization of Thar coal in respect of liquefaction. Rock Eval Pyrolysis data shows very high values of S1, S2 and hydrogen Index (HI). Total organic content (TOC) ranges from 31.64 to 69.5%. Sulfur content varies from 0.48 to 6% and its average content is 1.4% whereas sulfur content of the main seam averages about 1%. S1 ranges from 6.20 to 86.1 mg HC/g rock with an average of 29 mg HC/g and S2 ranges from 67.9 to 527 mg HC/g rock with an average of 229.2 mg HC/g. Hydrogen Index varies from 137.4 to 838 mg HC/g TOC with an average of 409 mg HC/g TOC. Extractable organic matter (EOM) yield using dichloromethane, ranges from 1397 to 10563 ppm and EOM/TOC ranges from 4.89 to 20.38 mg/g. This type of organic matter can be classified as kerogen type II and is comparable with good quality oil shale. Due to the high S1 and S2 values and the significant amount of EOM, the Thar coal can be used for liquefaction.

Organic petrography examination of thirty one samples from three boreholes at Block no. 1, was carried out. Huminite is the main maceral group varying from 85 to 95%, Liptinite is the second maceral group which varies from 1.0 to 8.11% and Inertinite group ranges between 1.1 to 8.1%. Pyrite content varies up to 2.0%. Oil droplets having strong green fluorescence are observed under blue light excitation. Liptinite macerals like fluorinite, resinite and alginite also gave strong fluorescence colors.

On the basis of above geochemical and petrographic results (high percentage of reactive macerals), Thar Coal seems to be a good candidate for surface gasification and liquefaction.

1. INTRODUCTION

The high price of crude oil during the last 7-8 years and the depletion trend of oil and gas fields make the commercial production of coal-derived synthetic liquid fuels economically competitive to other unconventional hydrocarbon resources (CBM, shale gas and shale oil). This has, once again, stimulated the coal liquefaction/gasification research and countries like China and Indonesia - along with pioneering South Africa intend starting commercial production. With rising crude oil prices, and concerns about its ability to meet demand into the future, coal liquefaction is increasingly being used as a source for chemical production.

Pakistan is heavily depended upon imported crude oil resulting in problems in balance of payment; hence, every local energy resource may be exploited and coal liquefaction for the production of oil and other petrochemicals is one of the options.

Traditionally coal was considered as deficit in hydrogen and rich in oxygen as compared with marine source rocks. It was classified as kerogen type III and considered as potential gas source (Hunt 1991). Similarly in chemical industry coal was considered as source for syngas, the latter being raw material for power generation; for production of liquid fuels it has to pass through hydrogenation process. Now it has been recognized that coals are capable of generating and expelling economic quantities of liquid hydrocarbons in a number of basins worldwide (Clayton, 1993).

The rate of fragmentation reactions during liquefaction depends on the nature of coal macerals. Maceral composition of coal has a strong influence not only on the liquid yield but also on the conversion ratio (Chakrabartty, 1981).

The objective of the present study is to highlight the composition of Thar Field coal, Sindh, Pakistan (Figure 1), in respect of its hydrogen-rich components. The aim is to evaluate the Thar coal for its potential to produce liquid hydrocarbons through liquefaction.

2. GEOLOGICAL SETTINGS

Thar Coal Field is located in Lower Indus Basin, Pakistan (Figure l). At the time of discovery the geology was poorly understood because the area is covered by dune sand. But it is now well established, based on data from a large number of boreholes drilled in more than ten Thar Coal blocks.

Nagar Parkar Granite of Pre-Cambrian age is the only outcropping bedrock in the Thar Desert. The granite can be distinguished into two types, grey and pink, intruded by fine grained basic and intermediate rocks. Thar Coal Field rests upon a structural platform in the eastern part of the Desert. This platform is underlain by relatively shallow granitic basement (Jaleel et al., 2002).

Granitic basement is overlain by coal-bearing Bara Formation of Middle Palaeocene to Early Eocene age. Bara Formation has unconformable contact with overlying Sub-Recent alluvial deposits.

In Block no. 1, the coal-bearing Bara Formation is composed of claystone, siltstone and coal seams of variable thickness (Khan et al., 1996). Thar coals are brownish black, grayish back, and black in colour, poorly to well cleated and compact. The Bara coals also contain scattered globule resins and fine-grained pyrite in form of patches (Khan et al., 1996). The good quality Bara coals are characterized by light weight, low ash yield and sulphur content (Khan et al., 1996).

[1]Pakistan Petroleum Ltd, Pakistan.
[2]University of the Punjab, Lahore, Pakistan.
[3]United Energy Pakistan.

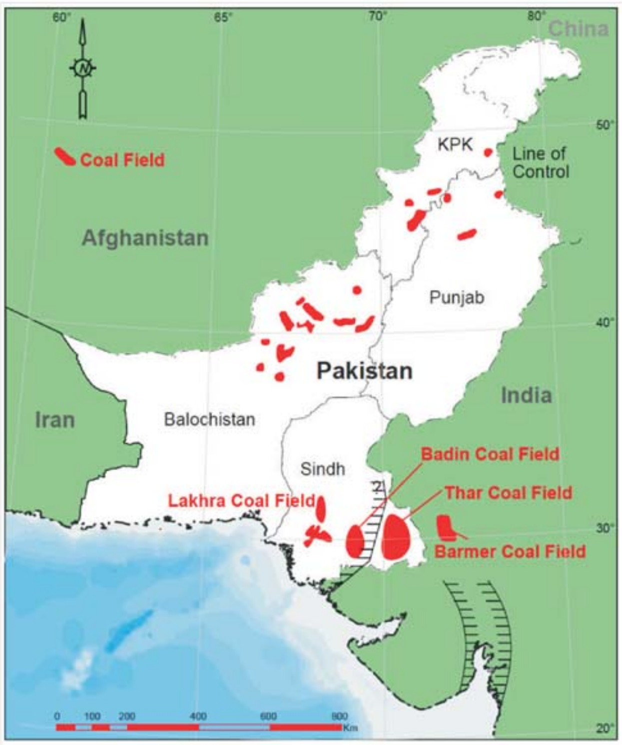


Figure 1 - Location map of the main coal fields of Pakistan (modified after SanFilipo, 2000).

The coal seams of Bara Formation have maximum thickness of 22.81 m encountered at 167.6 m depth interval in borehole VV-15.

Based on detail macroscopic examination of air-dried core of borehole # VV-14, Ahmad (2004) classified Thar Coal as matrix coal. This is mostly unstratified, however micro-laminations were observed in some layers. Resin grains and leaf fragments are common.

The stratigraphic sequences encountered in boreholes drilled at Thar Coal Field, are generally similar (Table 1). Figure 2 shows the location map of Block # 1 of Thar Coal Field and Figure 3 shows the stratigraphic correlation of five boreholes in Block # 1 including three boreholes sampled for this study (VV-04, VV-14 and SV-3).

The maximum of 20 seams have been observed in the Thar coalfield, however, they vary from place to place. The thickness of coal seams in Block # 1 varies from less than one centimeter to a maximum of 22.81 m, encountered in borehole VV-15. The minimum and maximum depths at which the first coal encountered are 137.04 and 178.72 m, respectively, and the cumulative thickness of coal beds varies between 8.08 and 36.0 m (Khan et al., 1996).Published palynological studies of well cuttings of two water wells near Islamkot (Figure 2), clearly indicate that the coal-bearing strata are of Late Palaeocene to Early Eocene age (as reported on fossils by Frederiksen (appendix 6 in SanFilipo et al., 1992). Khan (2001) and Nasir (2001) also on the basis of palynological investigations, assigned Late Palaeocene to Early or Middle Eocene age for the coal-bearing sequence.

3. MATERIALS AND METHODS

3.1. Samples

As coal is not exposed on the surface (Jaleel et al., 2002), the core samples and borehole logs were collected by Geological Survey of Pakistan (GSP), from VV-14, SV-13, VV-12 boreholes at Block #1 (Figures 2 and 3) after detail core examination. Block #1 is divided into Sinhar Vikian (SV) and Varvai (VV) sub-blocks and borehole codes are given after the sub-block codes. The shallowest and deepest of coal samples are obtained at 143.8 m (VV-12) and 245.28 m (SV-13) depths (Table 2). Efforts were made to sample all major varities within coal seams and more than one sample was taken from thick seams.

3.2. Analytical Methods

The following analytical techniques were applied for this study:

1. For organic petrography, polished blocks were prepared according to ISO 7404-2 (2004) procedure. Maceral analyses and vitrinite/huminite reflectance measurements (Rr %) were carried out using a Zeiss MPV3 microscope equipped with a photomultiplier. For maceral analysis at least 500 points on each polished block were counted under incident white light and blue light excitation (ISO 7404-3, 2004). The maceral nomenclature applied was this of the Stopes-Heerlen System as modified by ICCP (1971, 2001) and Sýkorová et al. (2005). Huminite reflectance was measured according to ISO 7404-5 (2004).

2. For geochemical analyses, the core samples were crushed and grinded to -200 mm mesh size. Total organic carbon (TOC) and sulphur (S) content was measured by combustion of sample in Leco Carbon Sulphur Analyser CS-244 after carbonate removal with 5% HCl.

3. Extraction of bitumen or extractable organic matter (EOM) was assessed using Soxhlet Apparatus and dichloromethane as solvent. EOM was fractionated into saturated (C15+), aromatic hydrocarbons and non-hydrocarbons (NSO) by liquid Column Chromatography on silica gel/aluminum oxide by eluting with n-hexane and dichloromethane, respectively.

4. Rock Eval pyrolysis is applied to identify the type and maturity of organic matter and to assess petroleum potential in sediments. Rock Eval pyrolysis was performed using the Delsi-Nermag Rock Eval II Plus TOC module. Four basic parameters, S1, S2, S3 and Tmax were determined by pyrolysis. Hydrogen Index (HI = [100 X S2]/TOC), Oxygen Index (OI = [100 X S3]/TOC) and Genetic Potential (GP = [100 X S3]/TOC) were calculated using the above parameters.

5. Pyrolysis was carried out using a closed steel vessel of 100 ml volume capacity with air tight facility. About 11.26 g of grinded coal with double water amount were added in a steel vessel, air was evacuated by nitrogen flushing and tight. Vessel was kept in a muffle furnace at a temperature of 350°C for 24 hours. It was removed and extracted with dichloromethane.

Table 1 - Stratigraphic Sequence of Thar Coal Field (after Jaleel et at., 2002)

Formation	Age	Thickness	Lithology
Dune Sand	Recent	14-93 m	Sand, Silt & Clay
------------------------Unconformity-------------------			
Alluvial Deposits	Sub-Recent	11-209 m	Sandstone, Siltstone, Claystone, mottled
------------------------Unconformity-------------------			
Bara Formation	Middle Palaeocene to Early Eocene	0-185 m	Claystone, Shale, Coal, Sandstone, Carbonaceous Claystone
------------------------Unconformity-------------------			
Nagar Parkar Granite	Pre-Cambrian		Granite, Gabbro & Diorite

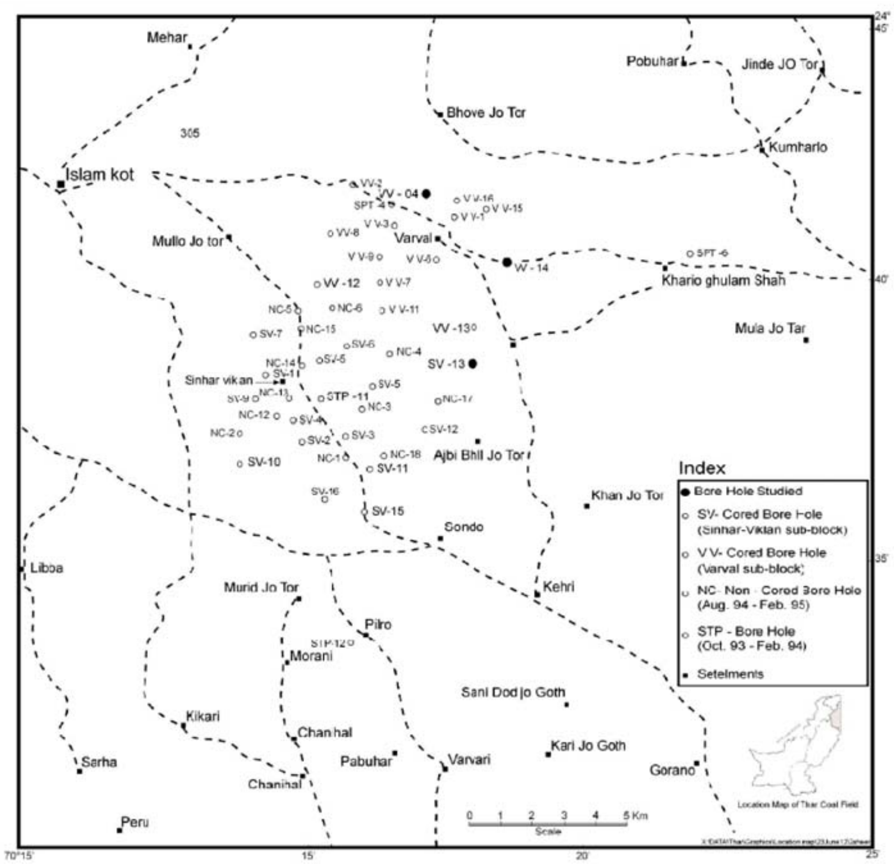


Figure 2 - Location map of the boreholes studied and drilled in Block No.1

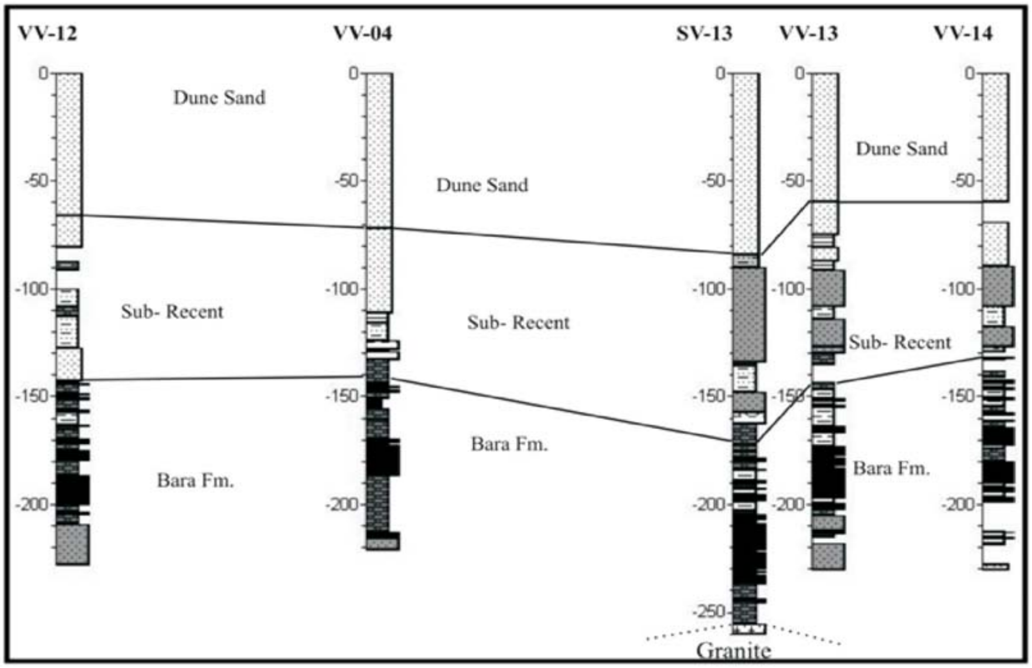


Figure 3 - Stratigraphic cross section of the boreholes drilled in Block #1 showing coal seams and overburden.

4. RESULTS AND DISCUSSION

4.1. Organic Petrography

Maceral analysis of thirty two (32) samples was carried out. Detail results are given in Table 2. Average huminite, liptinite and inertinite contents are 88.7%, 9.0% and 2.3% respectively. Based on diagnostic maceral assemblage Ahmad (2004) stated that Thar coal derived dominantly from herbaceous vegetation being accumulated in limno-telmatic environment.

Attrinite (35.2%), densinite (20.2%), gelinite (13.1%) and textinite (11.2%) are the main macerals of huminite group in the Thar coal. Gelinite is mainly porigelinite and gives week fluorescence (Plate 1A). Liptinite macerals consists of alginite (3.1%), sporinite (0.4%), cutinite (0.4%), resinite (2.6%), fluorinire (0.5%) and liptodetrinite (2.1%).

Liptinite macerals such as resinite, alginite, cutinite, sporinite and suberinite are classified as Kerogens I and II displaying oil generation potential. Resinite is present in most of the samples as discrete and also as clustered bodies (Plate 2). Oil droplets are observed in fractures of several samples from boreholes VV-04 and VV-12 (Plate-3).

The huminite random reflectance of the samples varies between 0.33 and 0.40%, being off the oil window.

An 1-m thick oil shale bed is encountered in borehole SV-13. Lateral extend could not be followed in other boreholes, perhaps due to the small size. It comprises >90.0% alginite and liptodetrinite (derived from alginite) (Plate 1C and D). Alginite seems to be driven from unicellular or filamentous algae.

4.2. Geochemical Results

Total organic carbon (TOC) content was carried out to determine the amount of organic matter in the samples. Dirty coal and carbonaceous claystone samples were analysed along with coal samples. Total organic carbon content of coal ranges from 19.86 to 69.51 wt.% (Table 4), whereas carbonaceous claystone has 2.33 to 5.82 wt.%. Sulphur content varies from 0.41 to 8.93% with the highest values in the top thin layer. The sulphur content of the main seam ranges from 0.45 to 1.66% on as received basis (ar) with an average less than 1%. The ash yield ranges from 3.24 to 8.46% (ar) with an average value of 6.23% (Ahmad, 2004). The TOC of oil shale interval encountered in SV-13 is 19.86%.

4.3. Extractable Organic Matter

The huminite reflectance values (Rr < 0.50%) indicate that Thar Coal is immature for the generation of hydrocarbons but S1 pyrolysis values (chapter 4.4) and the occurrence of oil droplets in a number of samples indicate the presence of hydrocarbons. To confirm this, extractable organic matter (EOM) content was determined using Soxhlet apparatus and dichloromethane as solvent. The results are given in Table 2. EOM ranges from 1397 to 10563 ppm / 4.35 to 20.40 mg/g, which is considered to be good to excellent for potential source rocks (Peter and Cassa, 1994). EOM was fractionated into saturated (C15+), aromatic hydrocarbons and non-hydrocarbons (NSO) by liquid Column Chromatography. Saturated, aromatic and NSO contents range from 4.75 to 33.20%, 2.4 to 33.10% and 57.4 to 87.4%, respectively.

Table 2 - Maceral composition (in vol.%, on mineral matter free basis) and random huminite reflectance (%) of selected core samples from VV-04, VV-14 and SV-13 boreholes.

Sample No.	Depth (m)	Attrinite	Densinite	Textinite	Ulminite	Corpo-huminite	Gelinite	Total Huminite	Spori-nite	Cutinite	Resinite	Fluori-nite	Suberinite	Alginite	Lipto-detrinite	Total Lipitinite	Semi-Fusinite	Fusinite	Fungi-nite	Inerto-detrinite	Total Inertinite	Rr (%)
Borehole # VV -04																						
643-V	155.43	18.1	30.2	15.9	11.1	3.2	12.7	91.1	0.0	0.6	5.1	0.0	0.0	0.0	0.0	5.7	2.4	0.0	0.0	0.8	3.2	0.34
644-V	170	26.9	22.0	22.0	11.0	2.2	8.8	92.9	0.2	0.7	3.7	0.0	0.0	0.0	0.9	5.5	1.1	0.0	0.0	0.6	1.7	0.34
646-V	178.61	26.8	4.1	14.9	5.4	0.0	35.1	86.2	0.5	0.8	4.6	2.4	0.3	0.0	2.4	11.1	1.4	0.0	1.4	0.0	2.7	0.37
647-V	180.63	28.5	15.7	15.7	10.1	12.4	7.9	90.3	0.0	**0.2**	3.4	1.1	0.0	0.0	3.8	8.5	0.0	0.0	0.0	1.1	1.1	0.35
648-V	180.61	46.3	23.2	1.1	0.0	3.2	13.7	87.4	0.0	0.4	10.1	0.6	0.2	0.0	0.2	11.6	0.4	0.0	0.2	0.4	1.1	
649-V	213.15	38.3	13.7	21.1	9.5	2.1	1.1	85.7	0.4	0.2	8.6	1.3	0.0	0.0	2.7	13.3	0.0	0.0	0.0	1.1	1.1	0.36
Borehole # VV -14																						
612-V	142.5	27.8	26.4	12.5	1.4	0.0	26.2	94.3	0.0	0.0	1.5	0.0	0.0	0.0	3.0	4.5	0.0	0.0	1.3	0.0	1.3	0.33
613-V	145.88	35.8	7.0	7.0	2.3	0.0	37.2	89.3	0.7	2.3	0.0	0.0	0.0	0.0	5.4	8.4	1.6	0.0	0.7	0.0	2.3	0.38
614-V	146.9	32.6	8.6	18.3	4.4	1.2	26.6	91.7	1.4	0.3	2.2	0.0	0.0	0.0	2.2	6.0	0.0	0.7	0.7	1.1	2.4	0.35
615-V	151	33.1	26.9	10.8	4.3	5.4	9.7	90.1	0.2	0.0	1.1	0.0	0.0	0.0	1.1	2.4	2.2	2.2	3.2	0.0	7.5	0.38
618-V	166.4	38.5	1.7	3.5	2.1	2.8	41.9	90.5	0.0	0.0	1.7	0.0	0.0	0.0	5.2	6.9	0.0	0.0	0.9	1.7	2.6	0.38
619-V	168	28.3	17.4	18.5	1.1	1.1	25.0	91.3	0.0	0.0	1.1	0.0	0.0	0.3	3.3	4.4	0.0	2.2	0.0	2.2	4.4	0.37
620-V	180.46	25.6	15.4	30.8	2.2	4.4	16.5	95.2	0.0	0.4	1.4	0.0	0.0	0.0	2.2	4.1	1.1	0.0	0.0	0.0	1.1	0.36
623-V	186.99	63.8	0.0	14.6	1.2	2.4	9.8	91.8	0.4	0.0	2.1	0.9	0.0	0.0	1.2	4.5	1.2	0.0	1.2	1.2	3.7	0.38
624b-V	196.8	32.9	4.9	15.9	2.4	3.7	29.3	89.0	0.4	0.0	0.4	0.5	0.0	0.4	2.1	3.7	2.4	2.4	1.2	1.2	7.3	0.39
626-V	212.93	29.7	8.7	14.1	2.2	2.2	37.0	93.8	0.0	0.0	0.8	0.0	0.0	0.0	2.2	2.9	1.1	0.0	0.0	2.2	3.3	0.39
Borehole # SV -13																						
533-V	175.7	57.8	6.9	8.4	17.8	1.6	0.4	92.9	0.4	0.7	2.2	0.0	0.0	0.0	2.2	5.6	0.7	0.0	0.9	0.0	1.6	0.34
536-V	178.8	38.9	24.3	8.1	16.6	1.2	1.0	90.1	0.4	1.2	2.0	0.0	0.0	0.0	1.6	5.3	1.4	0.6	2.0	0.6	4.7	0.4
543-V	193.5	33.3	36.7	7.1	7.1	5.1	3.1	92.5	0.2	0.2	1.8	0.6	0.2	0.0	1.4	4.5	1.0	1.4	0.4	0.2	3.1	0.35
544-V	195.6	51.0	18.4	3.3	8.9	2.2	5.1	89.0	0.0	0.2	5.6	1.1	0.4	0.0	2.2	9.5	0.5	0.5	0.5	0.0	1.5	
545-V	198	32.2	42.3	5.4	4.4	1.7	7.5	93.4	0.6	0.2	1.7	1.0	0.0	0.0	2.3	5.8	0.2	0.2	0.4	0.0	0.8	0.35
548-V	202.5	71.1	8.0	8.0	0.0	0.0	0.0	87.2	0.0	1.1	4.8	0.0	0.0	0.0	5.9	11.8	0.0	0.0	0.0	1.1	1.1	
551-V	206.5	38.6	33.0	10.0	4.0	4.0	4.0	93.6	0.4	0.4	1.8	0.2	0.4	0.0	1.2	4.4	1.0	1.0	0.0	0.0	2.0	0.33
552-V	207.5	33.3	23.2	13.1	11.1	11.1	3.0	95.0	0.0	0.4	1.6	0.2	0.0	0.0	0.8	3.0	1.0	1.0	0.0	0.0	2.0	0.35
553-V	208.55	1.7	0.0	0.0	0.0	0.0	0.0	1.7	3.9	0.0	0.0	0.0	0.0	94.4	0.0	98.3	0.0	0.0	0.0	0.0	0.0	
555-V	216.6	20.2	54.6	3.0	3.0	8.1	4.0	92.9	0.4	0.0	2.4	0.4	0.0	0.0	1.8	5.1	0.0	0.0	1.0	1.0	2.0	
557-V	221.2	36.4	36.0	6.0	1.0	5.0	8.0	92.4	0.8	0.4	1.6	1.2	0.2	0.0	3.2	7.4	0.0	0.0	0.0	0.2	0.2	0.34
559-V	223.6	35.0	26.8	16.0	5.0	9.0	4.0	95.8	0.0	0.0	1.0	1.2	0.0	0.0	1.8	4.0	0.0	0.0	0.0	0.2	0.2	
560-V	227.6	30.4	37.0	9.0	3.0	9.0	8.0	96.4	0.0	0.0	0.4	0.0	0.0	0.4	0.8	1.6	1.0	1.0	0.0	0.0	2.0	
563-V	233.1	43.7	31.4	5.1	0.6	8.1	4.7	93.5	0.0	0.0	0.6	0.2	0.0	0.2	1.8	2.8	0.0	0.4	1.2	2.0	3.6	
567-V	244.8	35.0	21.0	9.0	7.0	6.0	13.8	91.8	0.0	0.6	4.6	2.0	0.0	0.0	0.8	8.0	0.0	0.0	0.0	0.2	0.2	0.36

4.4. Rock Eval Pyrolysis

Rock Eval Pyrolysis of thirty two (32) and organic richness of thirty seven (37) samples were carried out.

The S1 and S2 values range from 1.46 to 86.08 and 0.34 to 527.36 mg/g rock, respectively. The S2/S3 value and Hydrogen Index of oil shale interval discussed in section 4.1, are 5.90 and 311, respectively. Hydrogen Index (HI) ranges from 2.60 to 838.15 mg/g TOC. Although the alginite content of most of the samples is low, still twenty samples out of thirty-two display HI > 200. Based on HI, Peter and Cassa (1994) classified organic matter into different kerogen types. The cross plot of Hydrogen Index (HI) vs. Oxygen Index (OI) on the modified van Krevelen diagram is shown in Figure 4. Three samples represent kerogen type I (> 600 HI), nine samples type II (300-600 HI), eight types II/III (200-300), seven type III (50-200 HI) and five type IV (<50 HI).

4.5. Hydrous Pyrolysis

Hydrous pyrolysis refers to the thermal decomposition which takes place when organic compounds are heated to high temperatures in the presence of water. Hydrous pyrolysis is a significant process in the production of liquid fuels. Hydrous pyrolysis fraction/yield of Thar Coal was 4.56 g, i.e. 40% w/w of the coal. Pyrolysis yield was further fractionated providing 10% saturate, 15% aromatic and remaining NSO compounds.

4.6. Maturity

The Tmax values range from 391° to 422°C and random vitrinite reflectance from 0.33 to 0.40%. The presence of oil droplets observed in these coals, points toward the early generation of oil. According to Powell et al. (1987) and other researchers resinite generates liquid hydrocarbons at very low maturity (0.3-0.7% Rr).

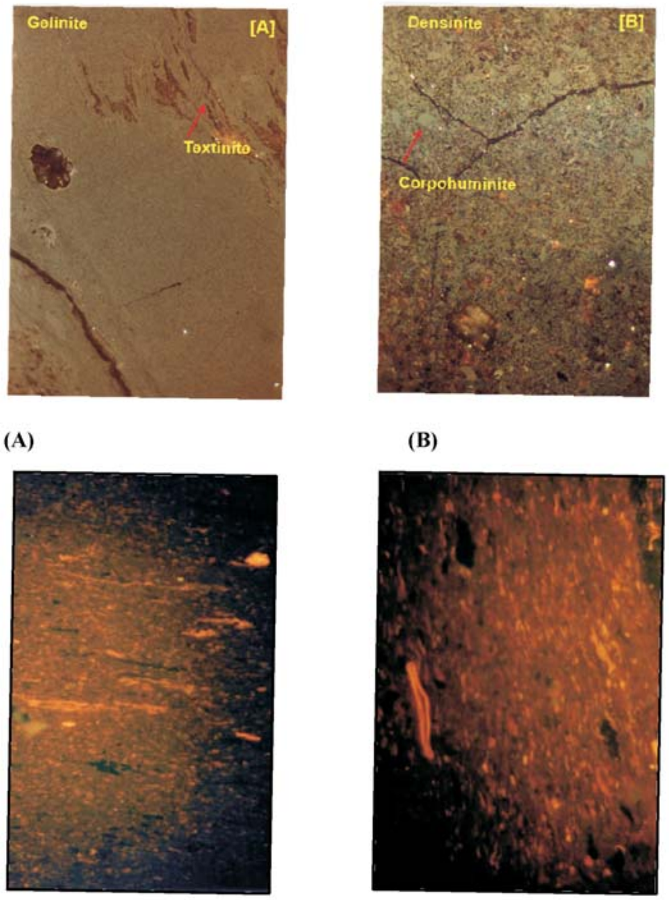
5. LIQUEFACTION PROPERTIES OF THAR COAL

Coal liquefaction is a process applied to convert coal into a substitute for liquid fuels such as diesel and gasoline. Hydrogen can represent a major cost item of the liquefaction process and, accordingly, several process options have been designed to limit the hydrogen consumption or even to increase the hydrogen/carbon atomic ratio without the need for added gas-phase hydrogen (Spreight, 2013).

The lower-rank coals (particularly brown coal, i.e., lignite) are more reactive and require a lower hydrogen pressure for liquid production than the bituminous coals (Wu and Storch, 1968). The petrographic composition of coals may be an important variable in determining the yields of liquid products.

Earlier experiments indicated that the gelified huminite/vitrinite, namely gelinite and ulminite, react first, followed by textinite/telinite (Shibaoka, 1980).

Thar coal contains about 85 to 95% huminite macerals wherein gelified macerals (densinite and gelinite) constitute



(A) (B)

(C) (D)

Plate 1 - Photomicrographs of huminite macerals in oil immersion, 400X: (A) Gelinite with minor textinite, sample no. 553-V, Borehole no. SV-13; white incident light, (B) Densinite with few corpohuminite and desiccation crack. Sample no. 646-V Borehole no. VV-04; white incident light, © and D) Photomicrographs of alginite of an oil shale facies from Borehole SV-13, under blue light excitation. Sample no. 553-V, 553a-V.

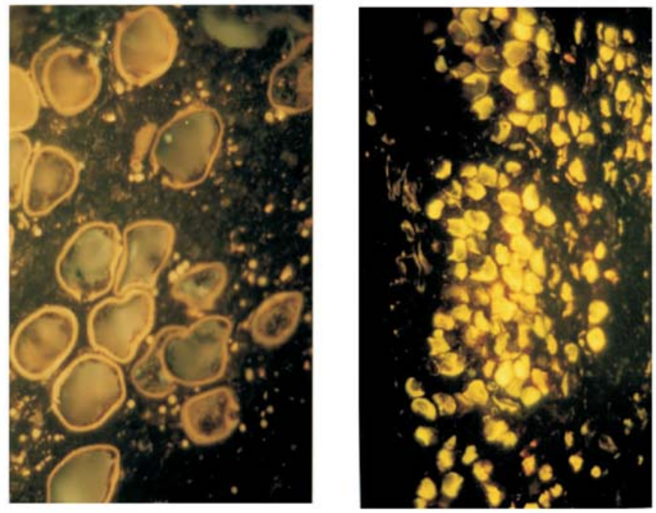


Plate 2 - Photomicrographs of sporinite and resinite under blue light, in oil immersion, 400X. (A) Cluster of sporinite, in sample no 643-V, Borehole no. VV-04. (B) Resinite giving bright yellow fluorescence, sample no. 626-V Borehole no. VV- 14.

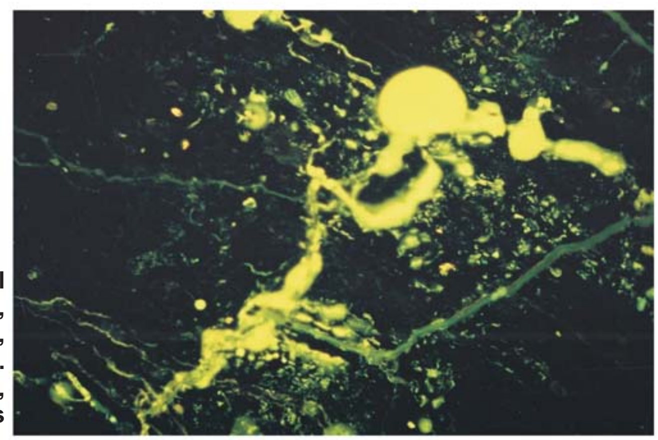


Plate 3 - Photomicrographs of oil droplets in microfractures, under blue light excitation, sample no. 650-V Borehole no. VV12. oil imm., 400X .

30 to 50%. Anomalously high Hydrogen Indices classify it as kerogen types I, II, II/III and III appropriate for liquefaction. Hydrous pyrolysis analysis at 350°C, gave 44% yield which on fractionation gives 10% saturate and 15% aromatic compounds. The amount of the yield may be higher, if tested at different temperatures and with different additives.

6. CONCLUSIONS

Dominance of herbaceous vegetation and its deposition in limno-telmatic environment make Thar coal significantly different from other coals. It has very low ash yield and sulfur content that qualify it as clean coal.

Average huminite content of Thar coal is >85%, consisting mainly of attrinite, densinite and gelinite. The reactive maceral content of the Thar coal is high. The coal macerals follow a path between kerogen types II and III during coalification and are considered good for liquefaction.

Significant amounts of resinite and alginite, hydrogen-rich macerals, are present in Thar coal.

Thar coal displays high Hydrogen and low Oxygen Indices and has significant proposition of oil prone kerogens (I, II and II/III).

The amount of hydrocarbons produced during pyrolysis (S2) is exceptionally high ranging from 17.44 to 527.36 mg/g. S2 yield positively correlates with hydrous pyrolysis Yield. The presence of oil droplets at low maturity (max. Rr 0.38%) is another indication of oil-prone coal.

All the above results indicate that Thar coal is rich in hydrogen, contains high amount of reactive macerals and can produce liquid fuels.

Table 3 - The extractable organic matter (EOM), saturated (SHC) and aromatic (AHC) fractions.

Sr. No	Sample No.	Borehole	TOC [%]	EOM [ppm]	EOM [g]	EOM/TOC [mg EOM/g TOC]	SHC C_{15}+[%]	AHC C_{15}+ [%]	NSO [%]
1	553-V	SV-13	19.38	1396.8	0.35	7.21	8.35	11.70	79.95
2	615 -V	VV-14	51.83	10563.2	2.64	20.38	4.75	9.75	85.50
3	618-V	VV-14	66.71	10324.8	2.16	15.48	33.20	8.88	57.92
4	621-V	VV-14	55.32	5456.0	1.36	9.86	5.00	7.60	87.40
5	626-V	VV-14	53.33	9503.6	2.38	17.82	18.00	2.40	79.60
6	649-V	VV-04	56.42	2759.7	0.97	4.89	1.70	33.10	65.20
7	650-V	VV-12	28.12	2346.8	0.82	8.35	17.1	17.9	65.00
8	660-V	VV-12	57.34	3799.7	1.33	6.63	19.4	23.2	57.40

Table 4 - The results of the Rock-Eval pyrolysis of Thar coal.

S NO.	Sample No.	TOC%	S%	Tmax ^{0}C	S1	S2	S3	HI (mg HC/g TOC)	OI (mg HC/g TOC)	GP (mg HC/g)
Borehole # VV -04						(mg HC/g)				
1	V-643	26.13	8.93	364	7.41	20.68	1.13	79.14	4.32	28.09
2	V-644	54.59	0.8	406	10.01	116.16	1.15	212.79	2.11	126.17
3	V-645	61.04	0.87	341	26.92	29.72	1.09	48.69	1.79	56.64
4	V-646	58.03	1.66	400	26.92	229.76	1.1	395.93	1.9	256.68
5	V-647	53.93	1.19	410	6.72	84.48	1.13	156.65	2.1	91.2
6	V-648	64.8	0.84	412	30.68	343.68	1.09	530.37	1.68	374.36
7	V-649	56.42	0.83	413	16.28	192	1.11	340.3	1.97	208.28
Borehole # VV -14										
1	V-612	46.48	1.12	408	11.1	131.52	6.08	282.96	13.08	142.62
2	V-613	31.64	5.95	392	27.6	170.88	3.52	540.08	11.13	198.48
3	V-614	52.9	1.39	406	21.32	223.04	6.72	421.63	12.7	244.36
4	V-615	63.47	2.77	399	16.52	128.48	8	202.43	8.56	145
5	V-616	59.56	0.41	401	53.28	499.2	4.48	838.15	7.52	552.48
6	V-617	54.54	0.73	409	20.4	176.96	6.4	324.46	11.73	197.36
7	V-618	66.71	0.6	391	86.08	527.36	3.68	790.53	5.52	613.44
8	V-619	55.53	0.7	400	25.4	214.08	5.76	385.52	10.37	239.48
9	V-620	54.69	1.37	404	14.8	154.24	6.4	282.03	11.7	169.04
10	V-621	55.32	1.25	398	35.2	199.3	5.76	360.27	10.41	234.5
11	V-622	61.79	1.08	422	1.46	17.44	1.16	28.22	1.88	18.9
12	V-623	59.62	1.06	0	0	0	0	0	0	0
13	V-624	69.51	0.73	0	0	0	0	0	0	0
14	V-625	61.47	1.48	399	48.48	380.16	6.06	618.45	9.86	428.64
15	V-626	53.33	0.48	407	11.2	106.72	1.13	200.11	2.12	117.92
Borehole # SV -13										
16	553-V	19.86	4.01	419	13.36	61.77	10.48	311.03	52.77	75.13
17	554-V	64.4	6.71	400	19.18	146.4	10.13	227.33	15.73	165.58
18	555-V	49.21		418	16.11	154.56	29.76	60.48	60.48	184.32
19	556-V	46.51		359	24.74	52.7	25.28	113.31	54.35	77.44
20	557-V	53.99		412	16.2	158.24	25.44	293.09	47.12	174.44
21	558-V	2.33		437	0.06	0.34	0.05	2.15	2.15	0.39
22	559-V	46.51		409	9.7	107.96	26.56	232.12	57.11	117.66
23	560-V	49.92		0	0	0	0	0	0	0
24	561-V	13.47		406	0.06	0.35	0.05	2.6	0.37	0.41
25	562-V	15.81		427	0.25	2.01	0.03	12.71	0.19	2.26
26	563-V	49.4		421	24.34	88.6	24.16	179.35	48.91	112.94
27	564-V	48.87		411	7.8	126.8	15.44	259.46	31.59	134.6
28	565-V	5.07	0.61	0	0	0	0	0	0	0
29	566-V	5.81	0.63	0	0	0	0	0	0	0
30	567-V	48.5		421	20.54	68.4	24.96	141.03	51.46	88.94

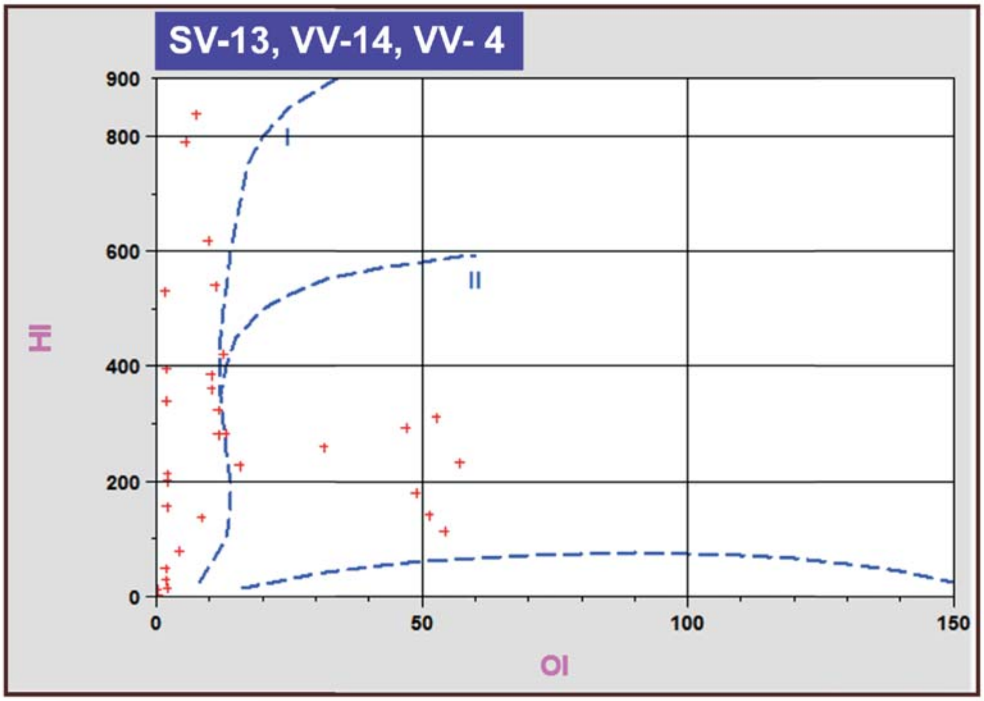


Figure 4 - Hydrogen Index vs. Oxygen Index for the studied samples from Boreholes No. SV-13, VV-04 and VV-14.

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