Rajasthan lignite as a source of unconventional oil

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Coal and lignite can be converted to liquid fuel and gas through various processes that involve gasification and/or direct liquefaction. An assessment of lignite for conversion to oil and gas has been attempted based on samples from two mines in the districts of Bikaner–Nagaur and Barmer in Rajasthan. The evaluation, based on organic geochemical studies, indicates that lignite contains a mixture of type II and type III organic matter which can be a source of both oil and gas. The study indicates moderate potential for conversion of lignite to liquid fuel and gas. It justifies a more comprehensive and detailed study of the Rajasthan lignite for production of unconventional fuels in pursuance of clean coal technology options.

Keywords. Lignite, liquid fuel and gas, organic geochemistry, unconventional oil.

IN sedimentary basins where oil and gas are found, organic-rich rocks constitute the primary source of hydrocarbons. Geochemical studies carried out in various basins have indicated that coal can be a source rock for significant quantities of oil and/or gas in sedimentary basins under certain conditions. For instance, studies in the Assam basin have pointed to the Tertiary coal formation as one of the primary sources for the oil found in the basin. It is also widely known that coal can be converted to liquid fuel by the application of suitable technology. Besides coal, carbonaceous shale, which contains significant quantities of kerogen can also be a source of liquid fossil fuels. This is known as an oil shale.

Unconventional fossil fuels are gaining increasing importance as energy alternatives in view of the increasing consumption and unpredictable global oil prices. The more important ones include coal bed methane (CBM), shale gas, oil shale, gas hydrate, underground coal gasification (UCG), and coal-to-oil conversion. In a study carried out by Oil India Limited, Duliajan on the feasibility of conversion of Assam coal to liquid fuel, it was demonstrated that these coals have the required characteristics for conversion to liquid fuel[1].

In the present study, a preliminary evaluation of the potential of lignite from two lignite mines in the districts of Bikaner–Nagaur and Barmer in Rajasthan has been undertaken based on organic geochemical studies.

Lignite is a soft, brown fuel with characteristics that put it somewhere between coal and peat. Because of its high content of volatile matter it is easier to convert lignite into gas and liquid petroleum products than high-ranking coals. The organic matter present in shale and coal/lignite helps us to categorize them as follows: lean shale, < 2% total organic carbon (TOC); rich shale, 2–12% TOC; oil shale, 12–35% TOC and coal/lignite, > 35% TOC.

In India, lignite deposits are found in Tamil Nadu, Jammu and Kashmir, Rajasthan, Gujarat, Kerala and Puducherry. The total reserves of lignite are estimated at about 39 billion tonnes. Lignite occurs in the Barmer–Sanchore and Bikaner–Nagaur basins of western Rajasthan. In the Barmer–Sanchor basin, lignite deposits occur in the Early–Middle Eocene formations and in the Bikaner–Nagaur basin they occur in the Lower Palaeocene to Middle Eocene formations. A generalized stratigraphic column of the western Rajasthan basins is given in Table 1. The total reserves of lignite in Rajasthan are estimated at 4.22 billion tonnes.

The Phanerozoic geological evolution of western Rajasthan involves formation of rift basins in response to global tectonic processes that resulted in the separation of the Indian plate from Gondwana during Jurassic and Cretaceous. The growth and geometry of Mesozoic to Tertiary basins have been largely controlled by NW–SE and NE–SW trending fault systems. The Phanerozoic crustal evolution of western Rajasthan was characterized by the development of three sedimentary basins, the Jaisalmer basin, the Barmer–Sanchor basin and the Bikaner–Nagaur basin[2]. The geological map and the generalized stratigraphy of the basins are presented in Figure 1 and Table 1 respectively[3].

The Akli assemblage is closely comparable to other Upper Palaeocene to Lower Eocene assemblages of western India. It also bears a strong resemblance to Upper Palaeo-

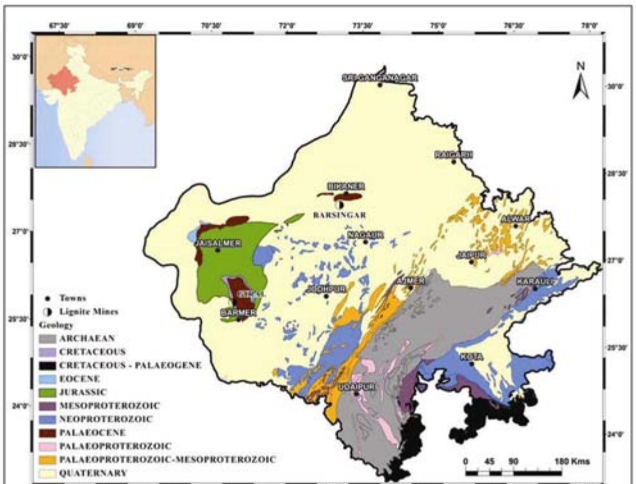

Figure 1. Geological map of Rajasthan showing sample location.

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Table 1. Phanerozoic stratigraphy of western Rajasthan (after Bhandari[4])

Age			Barmer basin	Jaisalmer basin	Bikaner–Nagaur basin
Cenozoic	Holocene		Dune sands, alluvium gravels Utarlai Formation	Shumar Formation	Sand dunes Mar Formation
	Pleistocene				
	Pliocene				
	Miocene				
	Oligocene				
	Eocene	Priabonian			
		Bartonian		Bandah Formation	Jogira Formation
		Lutenian			
		Ypresian	Kapurdi Formation Mataji ka Dungar Formation Akli Formation	Khuiala Formation	
	Palaeocene	Thanetian	Barmer Formation Fatehgarh Formation	Sanu Formation	Marh Formation
		Montain			
		Danian			Palana Formation
Mesozoic	Cretaceous	Santonian			
		Coniacian			
		Turonian			
		Cenomanian			
		Albian			
		Aptian		Harbur Formation	
		Neocomian	Sarnu Formation	Pariwar Formation	
	Jurassic	Tithonian		Bhadasar Formation	
		Kimmeridgian		Baisakhi Formation	
		Oxfordian			
		Callovian	Jaisalmer Formation	Jaisalmer Formation	
		Bathonian	Lathi Formation		
		Lias		Lathi Formation	
	Triassic				
Paleozoic	Permian				Badhaura Formation
	Carbontferous				Bap boulder bed
	Devonian to Ordovician				
	Cambrian		Birmania Formation	Birmania Formation	Nagaur Formation Bilara limestone
Neoproterozoic			Randha Formation	Randha Formation	Jodhpur sandstone
			Malani rocks/ basement complex	Malani rocks/ basement complex	Malani rocks

cene assemblages from the Indus coal region in Pakistan. The studied assemblages indicate that the Akli Formation was deposited in coastal floodplains with a mangrove-dominated vegetation that underwent frequent marine incursions[4]. The abundance of biodegraded terrestrial and amorphous organic matter throughout the succession may be attributed to high microbial activity and overall anoxic burial conditions. Thus, lignite beds contain abundant biodegraded amorphous and pyritized amorphous organic matter, which indicate prevalence of anoxic conditions after burial[4].

In the present study, nine samples of lignite and associated carbonaceous shale were collected from two mines in western Rajasthan. Four samples were collected from the Giral mine in Barmer district and five from Barsingsar mine in Bikaner district.

In the Giral mine, three carbonaceous horizons can be identified – top, middle and bottom, each comprising a number of bands of lignite and carbonaceous clay, besides the greenish-grey clay present as partings. The generalized lithology of a borehole from Giral area is given in Figure 2.

The samples were analysed by Rock Eval 6 pyrolysis for estimation of the hydrocarbon potential. The maximum relative error (standard deviation × 100/mean) was found to be 2.5%. Generally, the relative error was less than or equal to 1.3%. TOC values obtained using Rock Eval gave a good correlation ($r^2 = 0.99$) with the values obtained using other standard methods like Leco analysis[5].

In addition, selected samples were analysed on pyrolysis-GC-MS. Samples were first thermally extracted at 300°C and then pyrolysed at 600°C. GC was programmed from 35°C to 300°C at the rate of 2°C/min. The pyrolysis products were directly swept into GC and separated components were analysed by MS operating in full scan mode in the 50–500 amu mass range[6].

Proximate analysis of lignite broadly shows the following properties (data from Directorate of Petroleum, Government of Rajasthan; unpublished data). (i) Moisture 30–40%; (ii) Ash 15–30%; (iii) Volatile matter 20–25%;

Table 2. Rock Eval analysis results of Giral and Barsingsar lignite and shale

Location	Lithology	TOC (%)	S_1 (kg/t)	S_2 (kg/t)	S_3 (kg/t)	T_{max} (°C)	HI (kg/tonne TOC)	OI (kg/tonne TOC)
Giral 1a	Shale	1.29	0.01	0.55	0.65	424	43	50
Giral 1b	Lignite	51.53	2.3	92.81	21.39	410	180	42
Giral 2a	Shale	0.94	0.06	0.28	0.85	416	30	90
Giral 2b	Lignite	19.13	1.97	93.79	19.64	414	490	103
Barsingsar 1a	Lignite	12.51	0.86	32.61	3.5	421	261	28
Barsingsar 1b	Lignite	48.45	5.16	159.5	11.07	410	329	23
Barsingsar 2a	Shale	3.32	0.45	18.11	2.16	421	545	65
Barsingsar 2b	Lignite	17.42	1.01	69.57	12.07	416	399	69
Barsingsar 2c	Lignite	23.58	1.11	116.22	15.63	414	493	66

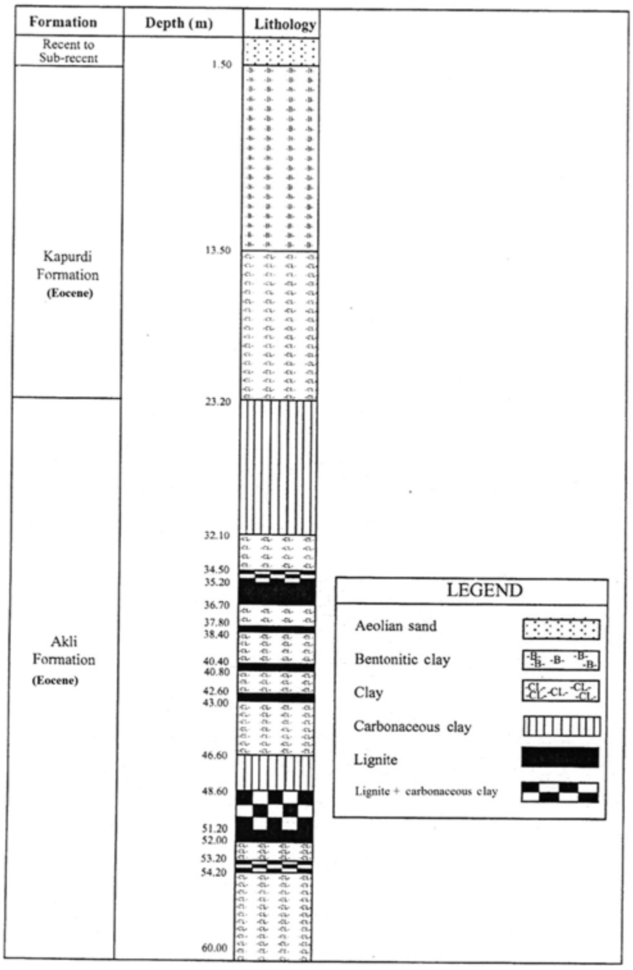

Figure 2. Litholog of a well from Giral area.

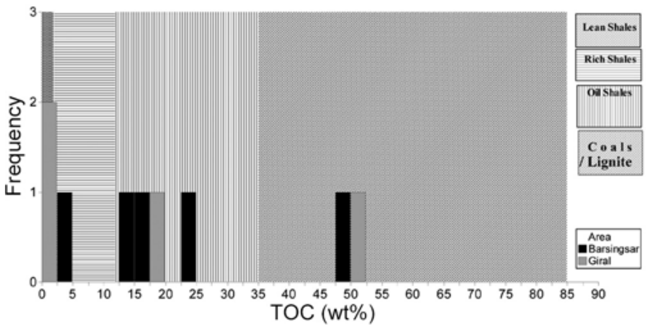

Figure 3. Total organic carbon content of lignite and shale.

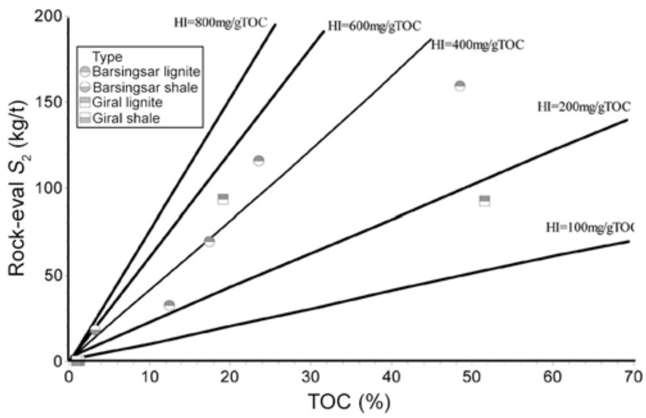

Figure 4. S_2 versus TOC plot for lignite and shale.

(iv) Fixed carbon 15–22.5%; (v) Calorific value 2001–3250 kcal/kg.

Maceral composition of lignite shows huminite content in the range 82.1–88.8%, inertinite content 2.3–3.4% and vitrinite approximately 0.35%.

TOC content varies from 0.9% to 3.3% for shale and from 12.5% to 51.5% for lignite (Table 2 and Figure 3).

Giral shale is organically lean (TOC values of 0.94% and 1.29% respectively) whereas Barsingsar shale is organically rich (TOC value of 3.3%). The Rock Eval parameter S_2, which measures the hydrocarbon generation potential of organic matter is high (32.6–159.5 kg hydrocarbons/tonne) for lignite. This shows that lignite has good potential to generate hydrocarbons. Giral shale has very low hydrocarbon generation potential (S_2 values of 0.28 and 0.55 kg/tonne), while Barsingsar shale has good hydrocarbon generation potential (S_2 value of 18.1 kg/tonne).

Figure 4 shows a plot of S_2 and TOC with boundaries for hydrogen index (HI). Lignite has HI between 180 and 493 kg hydrocarbons/tonne of TOC. Giral shale has very low HI (30 and 43 kg hydrocarbons/tonne of TOC), but Barsingsar shale has very high HI (545 kg hydrocarbons/

Table 3. Oil and gas generation potential of Giral and Barsingsar lignite and shale

Location	Lithology	Gas : oil generation index (GOGI)	Oil generation potential (kg/tonne of rock) (S_2*(1 – GOGI))	Gas generation potential (kg/tonne of rock) (S_2*GOGI)
Giral 2a	Shale	0.82	0.05	0.23
Giral 2b	Lignite	0.09	84.95	8.84
Barsingsar 2a	Shale	0.07	16.80	1.31
Barsingsar 2b	Lignite	0.07	64.92	4.65
Barsingsar 2c	Lignite	0.08	106.34	9.88

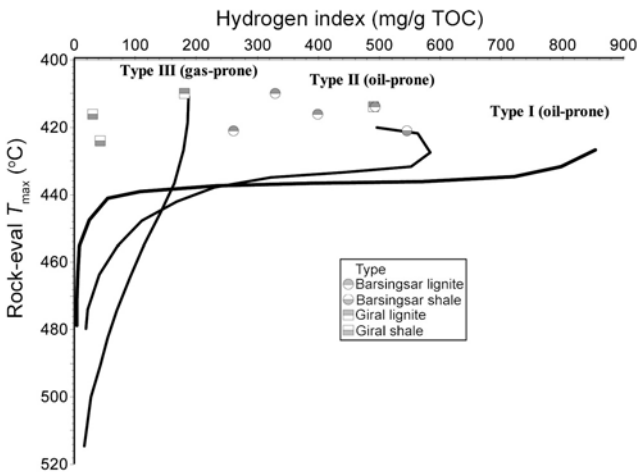

Figure 5. Plot of hydrogen index versus Rock-Eval T_{max} showing organic matter type.

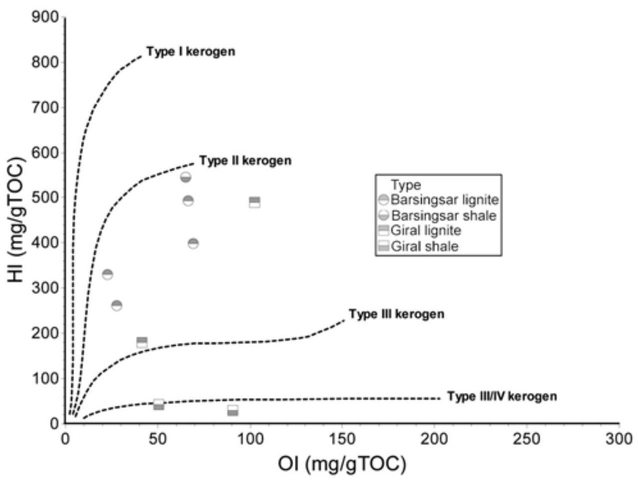

Figure 6. Plot of hydrogen index (HI) versus oxygen index (OI) showing organic matter type.

tonne of TOC). Thus, lignite from Barsingsar and Giral, and shale from Barsingsar are capable of generating both oil and gas, whereas shale from Giral is only gas-prone. Further, HI of lignite decreases with increasing TOC, indicating that lignite is not homogenous and that with increasing organic carbon content, less oil-prone organic matter is being added.

Lignite is a mixture of type II and type III organic matter and consists of both oil and gas-prone organic matter (Figure 5). Giral shale comprises type III organic matter which is essentially gas-prone. Barsingsar shale, however, is oil-prone. The lignite and shale under study are still immature to generate hydrocarbons as their T_{max} is very low (410–424°C). Petrographic analysis shows a mean vitrinite reflectance value in the range 0.27–0.34%, indicating low rank. The oxygen index (OI) of lignite and shale is high (23–103 kg CO_2/tonne of TOC). Thus, lignite and shale have been deposited in terrestrial, oxic environment. Plot of HI and OI (Figure 6) also confirms that lignite from Barsingsar and Giral, and shale from Giral are a mixture of type II and type III organic matter, whereas shale from Giral comprises type III organic matter.

Figure 7 shows mass chromatograms of shale from Giral and lignite from Barsingsar. It can be seen that Giral shale will generate predominantly gas (Figure 7 *a*) and Barsingsar lignite will generate significant amount of liquid hydrocarbons, as evidenced by the presence of alkane/alkene doublets in the mass chromatogram (Figure 7 *b*), in addition to gas.

Distribution of light ($C_{1–5}$), medium ($C_{6–14}$) and heavy hydrocarbons (C_{15+}) shows that lignite from Barsingsar and Giral, and shale from Barsingsar will generate paraffinic–naphthenic waxy oil, whereas shale from Giral will generate gas condensate (Figure 8).

The average gas : oil generation index (GOGI = ($C_{1–5}$/($C_{1–5}$ + $C_{6–14}$ + C_{15+})) for lignite from Giral and Barsingsar is 0.08 (Table 2). Thus, lignite can generate 92% liquid hydrocarbons ($C_{6–14}$ and C_{15+}) and 8% gas ($C_{1–5}$). The average hydrocarbon generation potential of lignite is 94 kg/tonne. Therefore, it is capable of generating approximately 86 kg oil/tonne of lignite.

Barsingsar shale (Barsingsar 2a) has a hydrocarbon generation potential of approximately 18 kg hydrocarbons/tonne of rock and gas GOGI of 0.07. Thus, it can generate approximately 17 kg of liquid hydrocarbons/tonne of rock (Table 3). Giral shale (Giral 2a) has a hydrocarbon generation potential of only 0.28 kg of hydrocarbons/tonne of rock and GOGI of 0.82. Thus, Giral shale will generate only 0.05 kg of liquid hydrocarbons/tonne and 0.23 kg of gas/tonne of rock (Table 3).

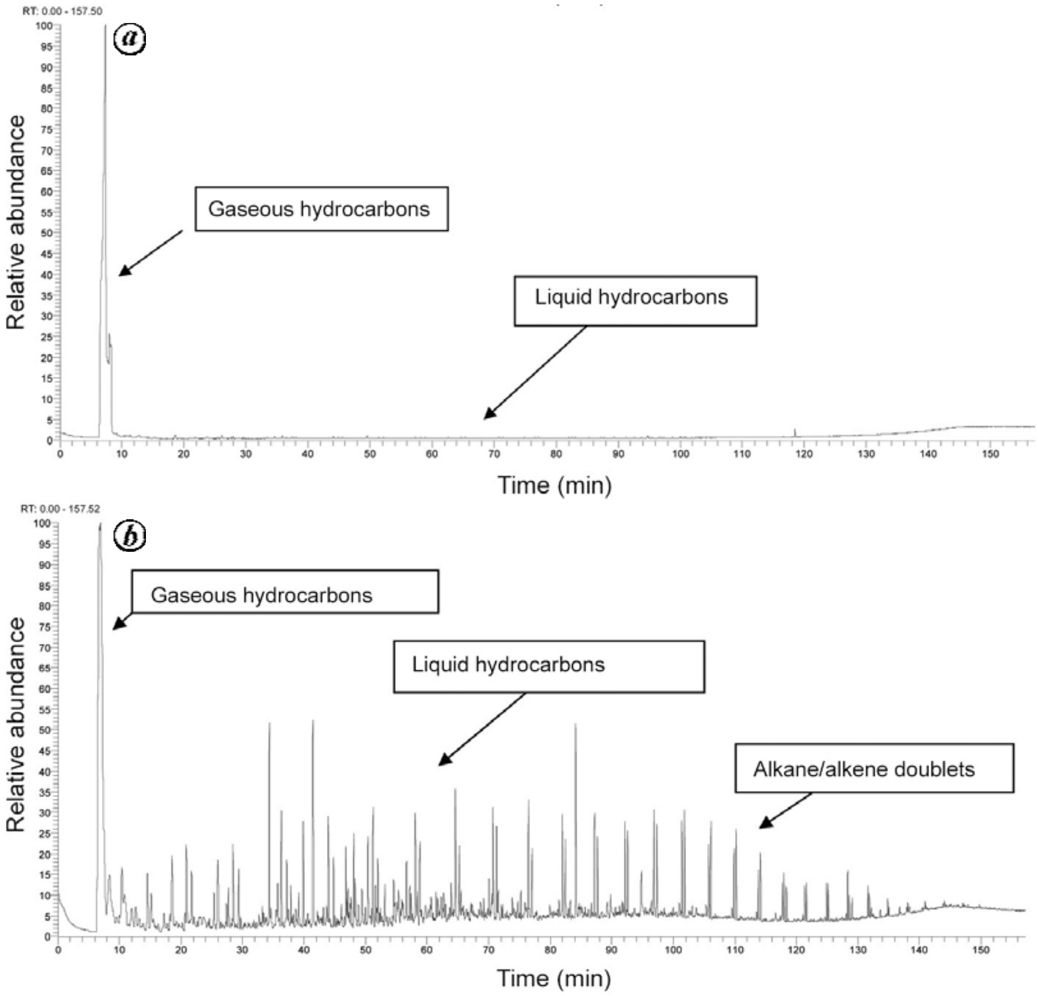

Figure 7. Pyrolysis gas chromatograms of (***a***) shale from Giral (Giral 2a) and (***b***) lignite from Barsingsar (Barsingsar 2b).

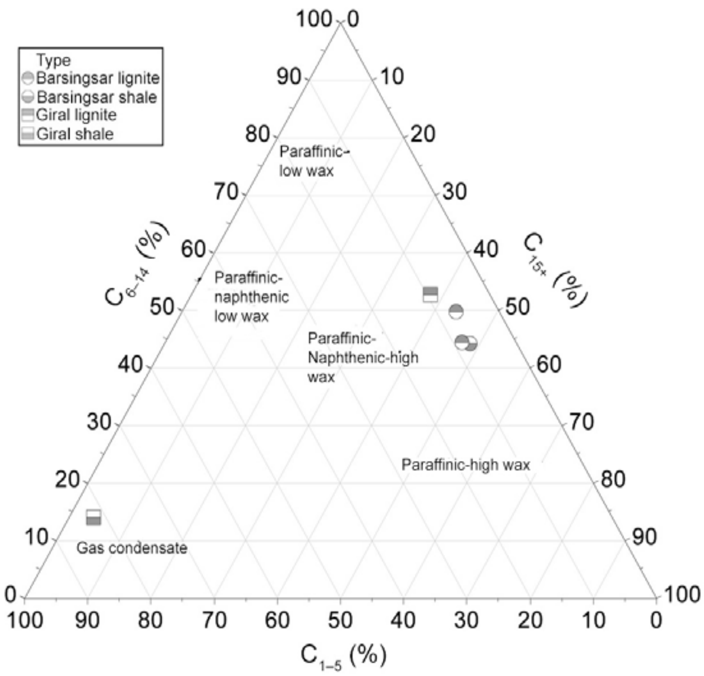

Figure 8. Oil and gas generation potential of lignite and shale based on distribution of light, medium and heavy hydrocarbons.

Because lignite can generate significant amount of liquid hydrocarbons by simple heating in inert atmosphere (pyrolysis), it can be used as a good source of liquid fuel.

We have presented here the results of a reconnaissance study carried out on a limited number of samples. The results indicate moderate potential for conversion of lignite to liquid fuel. Nevertheless, the encouragement received from the preliminary study justifies a more comprehensive and detailed study of the Rajasthan lignite for hydrocarbon generation. Out of the 70,000 sq. km area where Tertiary formations occur, only about 800 sq. km has been explored. There is, thus, tremendous scope for further exploration of lignite in the state both at shallow and at deeper levels. With total lignite reserves of 4225 million tonnes, Rajasthan occupies the second position in India as far as lignite reserves are concerned. The mineable reserves in the Giral and Barsingsar area are of the order of 130 MMT. At present, it is not possible to make an estimation of the total oil potential of lignite in Rajasthan. Nevertheless, based on preliminary studies, assuming an average yield of 90 kg of oil/tonne of lignite, the potential for oil in the Giral and Barsingsar area alone would be about 12 MMT.

Despite significant potential as a source of unconventional oil, the conversion of coal/lignite entails challenges that include environmental concerns and economics of scale. As lignite is a poor-quality coal, extracting energy from it creates particularly high emissions of carbon dioxide. Also, coal-to-liquid fuel plants involve multi-billion dollar investment that necessitates a long-term and large-scale perspective for investors. While these issues are important, a discussion on them is beyond the scope of the present communication.

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Power generation using wind energy in northwest Karnataka, India

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On the backdrop of climate change scenario, there is emphasis on controlling emission of greenhouse gases such as CO_2. Major thrust being seen worldwide as well as in India is for generation of electricity from renewable sources like solar and wind. Chitradurga area of Karnataka is identified as a suitable location for the production of electricity from wind turbines because of high wind-energy resource. The power generated and the performance of 18 wind turbines located in this region are studied based on the actual field data collected over the past seven years. Our study shows a good prospect for expansion of power production using wind turbines.

Keywords: Power generation, plant load factor, turbines, wind energy.

THE concept of harnessing wind energy to generate electricity is gaining momentum around the world. The worldwide installed wind energy capacity was around 194.3 GW by the end of 2010 (ref. 1). In India, the installed wind energy capacity is over 19 GW (ref. 2) and the country ranks fifth in the world. The cost of electricity produced from wind farms in India is at par with the cost of grid electricity. According to the Ministry of New and Renewable Energy guidelines[3], the buyback rate for electricity from wind farms is in the range Rs 3.39/kWh–Rs 5.31/kWh depending on each state, compared to Rs 3.90/kWh–Rs 5.90/kWh for grid electricity. More importantly, using wind to generate electricity emits much less harmful greenhouse gases than during the combustion of fossil fuels that are generously used to generate electricity. It is estimated that there is a saving of 300–500 tonnes of CO_2 emission from a wind farm of 4 MWh electricity generation capacity in India[4].

Currently, about 190 GW electricity generation capacity is installed in India[5], about 11.7% of which is from renewable sources of energy, excluding hydroelectricity. Karnataka has an installed electricity generation capacity of about 11.8 GW (ref. 6) at the end of 2011, out of which about 1.9 GW is from wind energy. Performance assessments of these wind farms are necessary for understanding the wind–energy relationship and possible future improvement in their performance. Most of the wind farms set up in Karnataka are privately owned. Here we

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