PETROLOGICAL CONSIDERATIONS FOR BENEFICIATION OF INDIAN COALS

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Abstract

The present paper demonstrates the occurrence of mineral matter as a restraint in coal beneficiation as evidenced through coal microscopy. The Indian Gondwana coals have high ash content because of inorganic mineral matter occurring in high concentration. These minerals occur as 'deep intergrowth', 'massive impregnation', 'superficial mounting', 'filling and depletion of micropores'', 'mechanical cavity filling', and 'fusinitic cavity filling'. It is difficult to liberate all these mineral matters from coal, creating problems during their beneficiation. The conventional techniques which are being followed for the beneficiation of coal in India include hand picking, sizing, blending, pulverizing, washing, dry cleaning, dedusting, dewatering, drying and briquetting and they are not instrumental so far.

Key words

Indian, Gondwana , coals, beneficiation, coal microscopy

Introduction

Nearly sixty percent of the total recoverable coal reserves of the world are located in four Pacific- Asian countries: Australia, China, India, and United States. Coal still continues to be the prime energy resource in India, catering around 57% of the total energy requirement of the country at present. Over 99% of the Indian coals are Gondwana coals and are 'bituminous' in rank. The 'Gondwana Super Group' holds unique position in India owing to their vast occurrence, homogeneity and for preserving the history of the land surface from Early Permian to Early Cretaceous. The Gondwana coals were deposited as thick series of sediments under shallow water fluvio-lacustrine conditions and contain characteristic floral and faunal elements. They are deposited in linear intra-cratonic basin belts in the Peninsular Indian shield aligned along the major river valley systems of the country: Damodar Valley, Son Valley, Mahanadi Valley, Godavari Valley, Wardha Valley, and Rajmahal – Birbhum Valley (Fig.1). These slow sinking grabens, surrounded mostly by crystalline Archean rocks, became the sites for the accumulation of huge thickness of strata along with the huge coal deposits.

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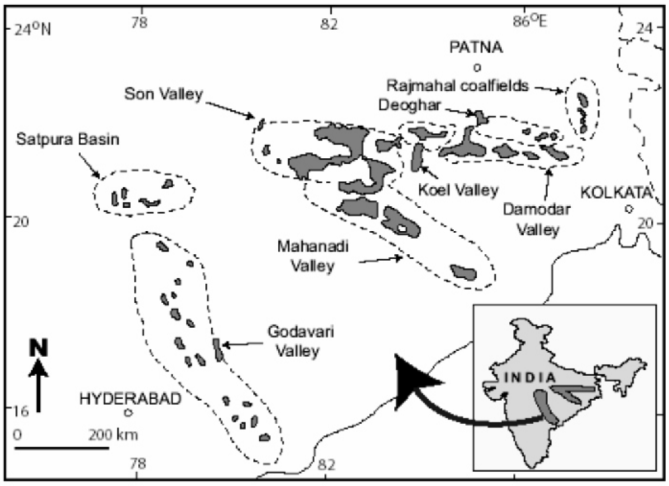

Fig.1. Distribution of Peninsular Gondwana Coalfields of India

India is bestowed with huge resources of coal to the tune of 264 Gt (as on 1.4.2008). Owing to their drift origin, Indian coals generally contain higher mineral matter as an impurity. Over eighty percent of the Indian coals belong to high ash category of E, F, and G grade. Due to depletion of superior grade coals and also due to mechanization of open cast mines, the grade of coal received by the consumers is continuously deteriorating. This increased impurities in coal causes not only reduction in the heat value of coal but also reduces their thermal efficiency. This also leads to increased environmental pollution. The present paper is an attempt to demonstrate coal microscopy as a useful technique to identify the occurrence of mineral matter causing impediments in coal beneficiation. For this purpose, the data generated by the authors and published data of other significant researchers on the Gondwana coals as well as microscopic observations have been taken into consideration.

Methodology

The data on Rajmahal and Deoghar coals have been generated in the 'Coal and Organic Petrology Laboratory', Department of Geology, BHU, Varanasi. The petrographic study of Rajmahal and Deoghar coals was carried out by the author (first author) with polished pellets using an incident light microscope equipped with Wild Photoautomat MPS 45 and Ploemopak with filter block 12/3 having blue excitation filters, suppression filters, and dichromatic mirror.

The SEM study was carried out using high- performance computer- controlled Scanning Electron Microscope. The microstructural relationship of coaly constituents with mineral matter has been studied following recommendations of Singh (1987a & b).

Minerals in coal

To date, there are 316 minerals or mineral groups identified in coals. Many workers have discussed the morphology, genesis, compositions and proportion of these minerals in detail (Hower et al, 2001; Kemezys and Taylor,1964;Stach et al.,1975;Korobetskii and Shpirt,1988; Singh and Singh,1995; Singh,2004;Ward,1989;1991, 1992, 2002; Ward and Taylor, 1996; Ward et al, 1989; Ward et al,1996; Ward et al, 1999; Ward et al, 2001 etc.). The coal mineralogy helps not only in understanding the coal genesis but also in determining the mode of occurrence of trace elements to evaluate the possible environmental effects of coal utilization. Moreover, the problems related to coal utilization is mostly due to the mineral matter incorporated in coal (Gupta et al, 1999).

Contributory studies on the distribution, concentration and the organic-inorganic affinity of the elements in coal and its low and high temperature ash, have been made by Bouska (1981), Kler et al (1987) and Swaine (1990). Kler and Nenahova (1981) discussed the genetic processes and mineral enrichment in coal; providing useful information regarding coal behaviour during combustion and gasification. Vassilev (1992 & 94) has shown that the mode of occurrence of mineral matter affects the coal utilization. Vassilev, (1994) has further discussed that the inorganic matter in coal is composed of:

1. Mineral constituents, present as crystal and grains of different minerals and cryptomere, metamict and gel minerals.
2. Amorphous constituents, present as glass (volcanic and cosmic materials), metamict, metacolloid and gel phases, and
3. Fluid constituents present as aqueous solutions, gas and gas-liquid inclusions.

Genetically, these inorganic matter in coal could be either detrital or authigenic. The detrital particles are transported by water and wind to the mire while the authigenic minerals are formed within the mire due to various biochemical and/ or physico-chemical processes. Depending on the time of formation, the inorganic matter could be Syngenetic (formed during peat formation and also afterwards with rank advancement) or Epigenetic (formed after the coal reached its present maturity level).

Some mineral matter, in coal, may occur as bands, lenticles, and other megascopic masses and are visible at hand specimen scale. They represent permineralized fragments of wood, peat masses and mineral rich laminae (Scott, 1990; Scott et al, 1996). These mineral matters can be removed without much problem during beneficiation. However, a significant level of mineral matter which is intimately associated with macerals, are referred as 'inherent mineral matter' and they cannot be effectively removed by coal preparation techniques (Ward, 2002). They are the unavoidable part of clean coal product. Moreover, the textural relations as shown by coal microscopy may indicate how mineral matter is formed and how will it respond to coal preparation processes (Ward, 2002). The imageries of Scanning Electron Microscope (SEM) have enabled quantitative mineral evaluation in coal (Huggins et al, 1980; Huggins et al, 1982; Birk, 1989; Birk, 1990, and Creelman and Ward, 1996). Singh (1987a & b) and Singh et al, (1986 & 1987) have shown the microstructural relations between the organic constituents of coal and the mineral matter. The syngenetic minerals are generally intermixed with the organic constituents and are deeply intergrown in nature. The epigenetic minerals, however, occupy the micropores, cleats, cracks, tissues, cell lumens and the like ones. Based on SEM studies of Indian Gondwana coals, Singh (1987b) recognized ten types of microstructural relations of mineral matter with coaly substances, viz: (i) Superficial mounting, (ii) Superficial blanketing, (iii) Filling and depletion of micropores (iv) Mechanical cavity filling, (v) Cellular cavity filling, (vi) Deep intergrowth, (vii) Massive impregnation, (viii) Fusinitic cavity filling, (ix) Filling of pitted vessels and (x) Filling of charred cell lumens. He has further shown that types 'vi' and 'vii' are very common and 'i', 'iii', 'iv' and 'viii' are common types in the Indian Gondwana coals. Some of the commonly occurring minerals can be seen in the Gondwana coals of Rajmahal basin as cavity fillings in fusain, as crack fillings and as intimate mixing. The massive replacement of macerals with pyrite and siderite is a common feature while sometimes pyrite also occupies the fissures. Carbonates can also be seen occupying cell lumens.

While studying the Gondwana coals and coals of Northern hemisphere, Stach et al, 1982 have shown that the lithotypes- durain and fusain have maximum contamination while vitrain is the least contaminated one. The study carried out by Singh & Singh (1995) for the coals of Rajmahal basin, corroborates this view. They carried out the ash analysis of individual lithotypes and found that durain has the highest ash content (59.30 to 61.20 %, av. 60.43%) followed by fusain (13.70 to 15.50 %, av.14.47 %), vitrain (11.90 to 13.20 %, av. 12.37 %) and clarain (11.40 to 11.90 %, av. 11.60 %). In general the dull components (mainly durain) of Indian Gondwana coals dominate over others and impart a dull appearance to these coal.

Washability characteristics of Indian Gondwana coals

Clay, sandstone and shale fragments occur as impurities in run of mine (ROM) coal. These constituents are major ash forming entities thereby diluting the combustible content of coal. They cause reduction in the calorific value of coal and also lower the effective capacity of the burning equipment of the Thermal Plant and overall increases the ash handling cost. It is seen that nearly 1% excess ash content in coal is likely to cause 5% loss in its efficiency. The Indian Gondwana coals differ chemically as well as petrographically from other Gondwana coals of the world and thus show different behaviour during their utilization (Sen et al, 2003). Compared to the Carboniferous coals which formed in cold and arid depositional conditions in the rapidly subsiding basins, the Gondwana coals were formed in distinctly warm and humid climate under oxidizing conditions (Chandra & Taylor, 1982; Stach et al, 1982). This caused thick coal seams with intergrown minerals. Thus, a comparatively low vitrinite and high inertinite contents of macerals were formed. A comparison of the petrographic constituents of Indian Gondwana coals to other Gondwana coals of the world has been summarized in table 1. This is based on the study carried out by Snyman (1961), Falcon (1977), Hunt (1984), Queensland Coal Board (1986), Mishra et al (1990), and Mishra and Moitra (1989). Indian coals located at different Gondwana basins, vary significantly with one another and are highly heterogeneous in composition (table-2) as indicated by Mishra et al (1990), Singh & Singh (1996), and Singh et al (2003). This is attributed to the non-uniform conditions of individual basins where differential subsidence rate prevailed and a regional and stratigraphic variation occurred in the morphology of coal quality (Sanders & Brooker, 1986; Mukherjee et al, 1982).

Even though Indian coals do possess some favourable characteristics like low sulphur content, high ash fusion temperature, low chlorine content, yet they are highly interbanded in nature with high ash content ranging 35-45% (Sinha, 2002). He has shown that Indian coals possess extremely difficult washability characteristics on account of (i) Inherent high ash content, (ii) Difficult liberation characteristics, and (iii) Higher proportion of near gravity materials. This view is also supported by Chugh et al (2003) who opine that due to high amount of near gravity or middlings particles in the Indian Gondwana coals, their separation becomes difficult and very efficient cleaning techniques are required. Das et al (2003) carried out similar studies and revealed that Indian coals show difficult to very difficult washability characteristics. Furthermore, Sen et al (2003) have advocated the same view and have given the following reasons causing hurdles during the process of beneficiation of Indian Gondwana coals:

a. Highly inter-banded thick coal seams.
b. The micro-fragmental nature is more and the mineral matters are embedded in core of grains creating difficulty in separating the fines by physico-chemical methods.
c. Coal is inferior with 30-40% ash excluding the dirt bands.
d. The mineral matter intimately mixed with inertinite macerals leading high ash.

Hitherto, before using the coal, it requires being beneficiated and the yield of clean coals and its ash content will affect the economic viability. In view of the notification of Ministry of Environment and Forest (MOEF), Government of India, it is now mandatory for all thermal powerhouses located beyond 1000 km from the coalfields and for those located in polluted and urban areas to use coal with a maximum of 34 % ash content Thus the washability characteristics of the raw coal has an important role to play for beneficiation.

Efforts are being made to remove the non-combustible part of coal. Based on the mineral present in the coal and the nature of distribution of the minerals, various methods are being employed for their removal. Coal preparation involves physical, physico-chemical and mechanical treatment of coal produced from the mines to suit specific utilization. These treatments include hand picking, sizing (breaking, crushing, and screening), blending, pulverizing, washing, dry cleaning, dedusting, dewatering, drying and briquetting, etc.

The mineral matter associated with Indian Gondwana coals occur mainly in the form of deep intergrowth, massive replacement, cracks, fissures and cavity fillings and, therefore, offers a difficult to very difficult washing conditions. In most of the cases they still remain after their beneficiation. It is that part of mineral matter which occurs as superficial blanketing or superficial mounting, may be removed, with ease, from the coal during beneficiation. Generally, while washing coking coals, appreciable part of it is found as middlings which have poor coking nature. Moreover, the existing conventional technologies based on which non-coking coal washeries are being installed in India have not been instrumental so far because, there can not be any single washing scheme that can work economically for the coals of varying washability characteristics to different quality as desired by the consumers.

Conclusions

It is seen that the utilization of coal is highly affected by the mode of occurrence of mineral matter. The dull bands (durain) of Indian Gondwana coals, generally, dominate over the others and are mainly composed of mineral matter. These inorganic matters occur either as detrital or as authigenic component. Generally in Indian Gondwana coals, 'deep intergrowth' and 'massive impregnation' type of mineral occurrence is very common and 'superficial mounting', 'filling and depletion of micropores", 'mechanical cavity filling' and 'fusinitic cavity filling' are common. It is very difficult to liberate these mineral matters from coal and thus create serious problems during their beneficiation.

The existing conventional technologies of coal beneficiation which includes hand picking, sizing (breaking, crushing, screening), blending, pulverizing, washing, dry cleaning, dedusting, dewatering, drying and briquetting based on which non-coking coal washeries are being installed in India have not been instrumental so far.

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Table - 1 Comparison of maceral- group and mineral matter contents of Gondwana coals of India and other parts of the world.

Maceral group/Mineral matter content	South Africa *1	Eastern Australia *2	Western Australia *3	India *4
Vitrinite	Low-high	Low-high	Low-high	Low-high
Mean %	40	59	50	41
Range %	13-72	27-85	12-85	13-79
Ro max % range	0.51-1.50	0.65-2.50	0.32-1.12	0.39-1.67
Liptinite	Low	Low	Low-high	Low-high
Mean %	3	5	8	12
Range %	Tr-5	Tr-13	3-20	2-23
Inertinite	Low-high	Low-high	Low-high	Low-high
Mean %	43	31	36	32
Range %	18-60	9-65	8-85	10-67
Mineral matter	Low-high	Low-high	Low-high	Medium-high
Mean %	14	5	6	15
Range %	4-20	2-13	2-16	10-28

*1 Data from Snyman (1961), Falcon (1977)

*2 Data from Hunt (1984), Queensland coal board (1986)

*3 & *4 After Mishra et al (1990), Mishra & Moitra (1989)

Table - 2 Comparison of maceral group and mineral matter contents of the coals from various Gondwana basins of India

Maceral group/ Mineral matter content	Damodar Valley basins *1		Son-Mahanadi valley basin *2	Pench-Kanhan valley basin *3	Rajmahal Group of coals *4		Deoghar Group of coals *5	
	Raniganj	Jharia			Hura coalfield	Chuperbhita coalfield	Karharbari coals	Barakar coals
Vitrinite	L-H	L-M	L-M	L-H	L-M	L-M	L-M	L-M
Mean %	60	50	42	42	8.4	17.5	-	-
Range %	43-79	13-70	25-58	28-68	0.2-33	6.1-54.5	11.22-30.81	23.13-26.23
Liptinite	M-H	L-H	L-H	L-H	H	H	M	M
Mean %	9	5	14	11	23.9	20	-	-
Range %	6-19	2-20	4-23	2-20	10.8-37.9	3.2-37.6	7.95-11.74	8.92-10.66
Inertinite	L-M	L-H	L-M	L-H	L-M	L-M	L-M	L-M
Mean %	22	35	32	29	35.2	12.1	-	-
Range %	17-33	33-59	17-56	20-67	22.5-50	2.1-34.5	16.18-26.21	10.65-18.17
Mineral matter	M-H	M-H	L-H	L-H	M	M-H	M-H	M-H
Mean %	9	10	12	18	32.6	50.4	50.08	51.60
Range %	6-19	5-18	8-20	2-28	18.2-48.8	12.9-85	41.5-58.9	47.8-55.8

*1,*2 & *3 Data from Mishra et al (1990)

*4 Data from Singh & Singh (1996)

*5 Data from Singh et al (2003)

L-Low, M- Medium, H- High