SUMMARY & CONCLUSION

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The changing patterns of energy used in recent years have focused attention of the scientists, technologists and energy planners to the significance of the world coal deposits, which are the mainstay of our fossil fuel supplies. It is now well realized that till the commercially exploitable alternative sources of energy are abundantly available, coal will continue to dominate the world's energy scenario. This is particularly true for India, since it is endowed with huge reserves of this fossil fuel, sufficient to last for 200 years or so. The deposits of coal, ranging from lignite through sub-bituminous and bituminous to anthracite, belonging to different geological periods, are scattered over different geographical locations in the country. The spectrum of usage of coals ranges from power generation through combustion in boilers, iron and steel making through blast furnace operations, and production of several value added chemicals obtained as by products through pyrolysis in coke ovens used for manufacturing coke. In India, at present coal meets over 70-75 per cent of the energy requirements. It is not merely that coal is a major source of energy supply today, but the energy policy of India is based on the premise that coal will continue to be a primary and single largest source of energy even in the coming several decades. However, most of the coal reserves of India, being of drift origin, are of inferior quality with high ash content. Moreover, reserves of coking coals of the country are also limited and the majority of the coals are non-caking. This implies that our future energy requirements will continue to be met by thermal power generation through large scale combustion of coal, even though it is of low grade. Since the coal reserves in Eastern part of the country (Jharia, Ramgarh, Barakar coalfields in Jharkhand and West Bengal) , Wardha Valley (Nagpur region in Maharashtra), and Bina and Singrauli coalfields in M.P., constitute the major percentage of the total reserves of coal and since the power generation in these States is dependent on the combustion of such inferior grade high ash content coals and also since large number of coal-based industries are coming up in this region, it is rather imperative to have a comprehensive knowledge of their detailed analysis and complete mineralogical characteristics to realize the full utilization potential of these coals in a fuel efficient manner.

The present dissertation concerns itself with the chemical, and mineralogical characterization of some coals of Jharia coalfields (Jharkhand), Wardha Valley-Nagpur region (Maharashtra) and of Jammu and Kashmir Valley coalfields (J & K State), Since the coals of these regions – both existing and new collieries, will be utilized in different industries, particularly for power generation, it is rather highly desirable that they be fully characterised. Moreover, their chemical characteristics, fuel value, and mineralogy are not exactly known, with the result that their utilization potential can not be properly assessed. It was from this viewpoint that the present research work was undertaken. The coals selected for this work were typical representatives of these coalfields and were Lodna and Bhowrah coals from Jharia coalfields; Sauner, Tandsi, and Pathakhera coals of Wardha Valley – Nagpur region, and Metka, Tata Pani and Chakker coals of Jammu coalfields and Kashnir lignite from J & K State. The work comprised essentially the chemical characterization of these coals in respect of proximate and ultimate analyses, evaluation of their fuel value and their mineralogical characterization by employing such complimentary instrumental techniques as X-ray Diffraction (XRD), Infra-red (IR) spectroscopy, Thermal analyses (DTA and TGA) and Scanning Electrom Microscopy (SEM), and, finally, in the light of these characteristics, evaluation of the utilization potential of these coals for different industrial end uses.

The chemical characteristics of the coals comprised of proximate and ultimate analyses. The coals of Jharia coalfields and Wardha Valley, being of 'Drift' origin, belong to Gondwana formation and are typically characterized by their high ash contents. The Lodna and Bhowrah coals of Jharia coalfields are characterized by their high ash content, low volatility and non-coking properties and medium fuel value. The representative Sauner coal of Kamptee coalfields of Nagpur region in general are high moisture, high mineral matter and high volatile matter content coals. On the contrary, Tandsi and Pathakhera coals are low moisture, high mineral matter, and medium volatile matter content coals. The low moisture coals of Tandsi and Pathakhera coalfields are high rank, while the rest of high moisture content coals are of low rank. Also in terms of mineral matter contents, the Tandsi, coals is less inferior in quality than Pathakhera and Sauner coals. The results of the ultimate analysis of these coals reaffirmed the high to higher rank of the coals of Tandsi and Pathakhera coalfield. The sulphur content of Tandsi and Pathakhera coals is within the permissible limit of <0.6 per cent, whereas that of Sauner coal is more than the permissible limit, making it a relatively high sulphur coal, the sulphur content being about 0.9 per cent or more, thereby necessitating their cleaning to bring down its sulphur content within permissible limits (0.5 %).

The fuel characteristics of these coals, as indicated by their heating value, suggest that the calorific values of Tandsi and Pathakhera coals are quite high indicating that these coals are good quality bituminous coals with very high calorific value. Banki coal, having heating value of 7920 Kcal/kg, however, is a less mature coal but with its heating value on the higher side.

Low temperature carbonization assay of a coal being an important criteria for evaluating the yields of various products under carbonisatrion conditions and also to obtain important informations about the nature and rate of evolution of the volatile matter at different temperatures, the low temperature carbonization characteristics of all the 4 coals of Wardha Valley –Nagpur regions were determined and the four main products obtained after carbonization, namely the final semi coke or char; a tar consisting of liquid hydrocarbons; fixed gases; and aquous liquor; were analysed, so as to ascertain their utilization potential. In terms of coke/char yield of these coals, which is in the range of 80-82 per cent for Tandsi and Pathakhera coals and about 75 per cent for Sauner coal of Nagpur region, it can be said broadly that all these coals can well be used for production of good quality smokeless coke. Nevertheless, the Tandsi and Pathakhera coals, bestowed with good coking properties, are advantageously more suitable for metallurgical grade coke making. Furthermore, when tar yield is taken as a barometer, the Tandsi, Pathakhera and Sauner coals are comparatively much superior to other coals of M.P. (e.g. Bina, Banki and Murpar coals) , suggesting thereby that Tandsi Pathakhera and Sauner coals could be a good resource material in carbonization industries for the recovery of tar. In terms of gas yield. However, Tandsi, Pathakhera, and Sauner coals are found to be more productive. And finally, when coke type is reckoned, it is found that while Sauner coals produces 'A' type coke i.e. non-caking char, Pathakhera and Tandsi coals produce 'D' type and 'F' type coke respectively, suggesting amply that Tandsi coal, after beneficiation, can be a potentially good source for metallurgical coke production, whilst Pathakhera coal, because of its typical carbonization behaviour, is more suitable for either domestic coke production or for blending purposes.

In order to assess the clinkering and fouling behaviour of these coals during combustion, their ash analysis was supplemented by studying the fusion characteristics of their ashes, the latter comprising determination of initial deformation temperaure, hemispherical temperature, and fluid temperature. The ash analysis indicates, in most general term, that while the two coals of Nagpur region exhibhit the extream cases of low (58) and high (68) percentages of silica in Murpar and Sauner coals respectively, the coals of M.P. region contain silica in the medium range of 53 per cent. With varying proportions of alumina content in the ash of these coals, their silica:alumina ration also varies accordingly, the ratio being 2.3:1 for Pathakhera coal and 2.7 -2.9:1 for Bina, Banki and Tandsi coals and a high ratio of 3-3.3:1 for Murpar and Sauner coals, which clearly suggests that while Pathakhera coal is least corrosive, Bina, Baki and Tandsi coals are slightly more corrosive and Murpar and Sauner coals are the most corrosive in nature. Iron oxide (Fe_2O_3), which does contribuite substantially to the foulin characteristics of the coals, has a low content of 3.4-4.8 per cent in Sauner and Pathakhera coals, followed by Tandsi, Bina & Banki coals which contain iron oxide in the range of 7.4-9.1 per cent. The highest content of iron oxide (15.6 per cent) is in Murpar coal. Similarly alkalies are the principal causative factors for producing slag during combustion. In terms of alkali contents of the ashes, Pathakhera coal has the lowest alkali content of 1.3 per cent contrasted with 1.8-2 per cent for Bina, Banki, Murpar and Sauner coals, the highest being 4.8 percent for Banki coal. Therefore, considering the iron and alkali contents of the ashes of these coals, it may be generalized that Pathakhera and Sauner coals have low tendency of fouling and Tandsi, Bina and Banki coals are more prone to fouling, with Murpar coal showing highest tendency for fouloing. Furthermore, as to the slagging tendency, Pathakhera coal is seen to be least prone to slag formation whereas Sauner, Murpar, Tandsi and Bina coals have a higher tendency of producing slag and Banki coal the highest tendency of slag formation during combustion.

The clinkering tendency of the ashes was ascertained by determining the ash fusion ranges. The fusion temperature, comprising hemispherical temperature (HT) and flow temperature of all the coals is greater than 1400°C, except Murpar coal of which (HT) is 1290°C and (FT) is 1330°C. These results clearly indicate that while Bina, Banki, Pathakhera, Tandsi and Sauner coals, because of their high Flow temperature (FT) (over 1400°C), will exhibit no tendency for clinker formation, Murpar coal, because of low fusion temperature, will almost certainly have a tendency to form clinker.

The mineralogical characterization of the coals was performed by using instrumental techniques like X-ray diffraction, Infra-red spectroscopy, Thermal analysis (DTA and TGA) and Scanning Electron Microscopy (SEM). X-ray diffraction analysis indicates that α-quartz is the major phase in all the coals., but in some coals Kaolinite is the major phase in association with α-quartz. However, in other coals also Kaolinite is present, albeit in small quantity.. The other minerals present in minor phases in the coals, in general, include $FeSO_4.7H_2O$, pyrite, illite, gypsum, mica etc. Furthermore, astray occurrence of minerals in traces or minor quantities, including anhydrite, ferrosite, $FeSO_4.H_2O$ is also indicated by X-ray Diffractometry. The I.R. spectroscopy has further reaffirmed the presence of kaolinite and α-quartz as major phases in these coals, except in case ofTandsi coal in which kaolinite and gypsum are present in equal proportions as major phase. The presence of quartz and kaolinite together is indicated by the presence of bands in the region 680-800 cm^{-1} and between 800and 1200cm^{-1} characterised by overlapping and broadening of peaks. The ubiquitous presence of montmorillonite as a Nonetheless, gypsum, calcite and hydrite are found to be invariably present in all the coals. The other minor phases present in these coals that could not be detected by XRD- but confirmed by IR spectroscopy, are illite and per sulphate. The iron-bearing minerals, were also detected in the coals to occur in the form of sulphides (pyrites), sulphate (melanterrite, Szmolonkite) clay minerals (illite and mica) carbonates (ankerite, and siderite). Pyrite is seen to be invariably present in all the coals, although its content is more in Tandsi coals. The sulphate content in the form of szmolnokite and melanterite is very less in Tandsi coal, which contains a large fraction of carbonate minerals (siderite and ankerite). . In the LT ashes of these coals, the minerals characterized indicate few significant changes to have taken place during heating. First, the appearance of pyrrhotite, indicates of oxidation of pyrite and second the appearance of magnetite and haematite suggests the decompoisition of clay or carbonate minerals. Quite different from this,Tandsi coal ash is found to contain magnesioferrite Mg Fe_2O_4 phase, implying the reactions between clay and mica minerals to have taken place to form this complex ferrite. This could be possibly due to early softening of the minerals during ashing.

An attempt has made to correlate the mineralogy of Wardha Valley (Nagpur region) with their geolocial formation. The Wardhha Valley coals constitute a real extension of the main Gondwana formation. The Gondwana system coal deposition is believed to have formed from vegetal matter via allochthonous mode or more commonly 'drift' mode. Like other coals of Gondwana formations, Wardha Valley (Nagpur and M.P. region) coals too contain high ash (mineral matter), being as high as 45 per cent, which is due to the incorporation of vegetable matter during drifting, alongwith clay in the coal matter. These coals typically contain simultaneously very low percentage of vitranous matter and thicker duraneous layers. Characteristically *allochthonous* deposits of the extended Gondwana coals of Wardha Valley (Nagpur and M.P. regions) contain not only different kinds of organic components but also the inorganic components of varying nature and proportions. It is believed that the finely devided portion of organic matter formed large proportion of drift materials, intimately associated with fine clay and silt. During the course of sedimentation, the drifted material might have formed bonds or pockets of high ash material in the coal deposits with the result that the minerals got unevenly distributed in different deposits of the coal formation, which satisfactorily explains the varying mineralogical composition of the coals, both in nature and in quantity. The high percentage of silica, in general, in Gondwana coals, of which Wardha Valley (Nagpur and M.P. regions) coals are typical expamle, could be possibly due to the incorporation of silica from the lining or membranes of the plant cells which became colloidally complexed with the coal matter. It could also be possible that some of the grasses that preferentially absorb silica, which got deposited in the cell mass were carried away alongwith the marine water during the process of drifting and eventually got intimately mixed with the coal matter.

The drift material got intimately associated with large proportion of fine clay or silt which eventully got incorporated in the coal matter, whose sporadic pockets appeared unevenly in the bands of coal deposits, which is why some of the coals of the Wardha Vallry - Nagpur region, are found to contain dominant clay and carbonate minerals like in Tandsi,and Sauner coals. The presence of large amounts of iron minerals it explicable on the basis of the decay of leaves rich in iron content, which got incorporated in coal matter during the process of drifting. With the rich iron content in the system and correct pH of the whole system, most of the sulphur of the plants would have released H_2S, which after reacting with iron might have precipitated as ferric sulphate in the upper layer of deposits or ferrous sulphate in the lower layer. During the process of coalification this precipitation might have formed nodule, clusters and veins of iron pyrite (in association with marcasite), while inherent sulphur, in amorphous or colloid form, might have got intimately associated with the coal mass. This very well accounts for the invariable presence of pyrite in all the coals of this extended Gondwana region i.e. Wardha Valley (M.P. and Nagpur regions).

From the chemical fuel, mineralogical carbonization characteristics of the coals of Wardha Valley- Nagpur region, their utilization potential in different industries has been ascertained. In general, the coals of Wardha Vallry - Nagpur . region are medium to high volatile, high ash, low-to-high moisture 'D' to 'F' grade coals. The fuel value of Tandsi and Pathakhera cols is very high, whereas that of other coals is the medium range. In terms of caking property, Tandsi coal is medium caking coal, yielding 'F' type coke contrasted by Pathakhera coal which is a semi-caking coal, yielding 'D' type coke. The medium volatile matter contents of these coals coupled with their caking capabilities (semi to caking), high C.V., low sulphur content, good tar yield and with another plus point of having non-clinkering properties, all taken cumulatively strongly suggest their use for carbonization purposes. These coals are also good as blendable coals for coke making after beneficiation. However, the inferior quality of Sauner coal in terms of high ash content together with their difficult washability characteristics makes its use limited, primarily as feeds for power generation in Thermal Power Plant. Utilizing the excellent caking property of Tandsi coals, they should be better utilized for coke makiing for steel industries. The other non-coking coal, namely Sauner coal is a low grade inferior quality coal, having non-clinkering characteristics, which makes its restricted use only for combustion in thermal power plants and other fuel purposes in different industries

In this way, the present work on the chemical, fuel, carbonization, mineral characterization of the coals of Jharia, and Wardha valley Coalfields is very useful for assessing their utilization potential in different industries including power generation, which in the coming years, will be fully dependent on these coals. Apart from its academic importance, the present work has tremendous industrial impact in the proper selection of coals, according to their fuel, mineralogical and washing characteristics for different industries which are fast coming up in the Eastern and Central India/, and also in other parts of the country.

General Minerology of Jammu coals

From the mineralogical characteristics of Jammu coals and Kashmir Lignite by Chemical analysis i.e. Ash analysis and X-ray diffraction, Infrared spectroscopy, Thermal analysis (DTA, TG) and Scanning Electron Microscopy (SEM), the mineralogy of these coals, in general, is as follows :

a) In most of the Jammu coals, either Kaolinite is predominantly present as the principal mineral or quartz, accounting for the major phase. In some cased (Metka coal and Kashmir lignite) the proportion of these minerals is almost equal. This is clearly inferred from the X-ray diffraction and I.R spectroscopic investigations and also fully supported by DTA TG results.

b) Quartz in all the coals including lignite is in the form of sheet silicate including mica and montmorillonite as revealed by X-ray and more clearly by I. R. studies.

c) These coals also contain substantial quantities of sulphur containing minerals including sulphide (pyrite, marcasite) and sulphate minerals like szmolnokite ($FeSO_4$ H_2O), Melanterite ($FeSO_4$ $7H_2O$) Anhydrite $CaSO_4$ and Jarosite X [Fe_3 $(SO4)_3$ $(OH)_6$], X being Na or K, as indicated by SEM micro photographs and also from the studies of other authors through studies by Mossbauer spectroscopic investigations.

The presence of persulphate, though in minor quantities is noticed in all the coals and lignite.. Likewise, the I. R. studies have confirmed the occurrence of Gypsum ($CaSO_4 2H_2O$) in all the coals and lignite.

d) The other minerals present in minor phase in almost all the coals including lignite are calcite, Illite and occasionally anatase. The presence of pyrrhotite and iron oxides in the LTA of Tata Pani coals and Kashmir Lignite has also been reported by other investigators through Mossbauer spectroscopic study..

The presence of most of these minerals is clearly seen visually in the scanning electron photo-micrographs of some of the L. T. Ashes of these coal including Kashmir lignite. These Photographs represent 1500-6000 times magnification of the original size of the minerals present in the samples. It will be observed from these photographs that in general the low temperature ashing or slow combustion has uncovered the minerals – alumino silicate and other mineral particles. imbedded in the coal surface which now appears in their characteristic shape among the surface pits. Large number of extremely small iron spheres can also be seen clinging to the ash particles. For different magnifications, the different minerals observed the colas and lignite (as seen in Figs. 30,31, and 32), the mixed mineral species namely quartz, clay (thin and elongate particles). Pyrite framboids and kaolinite are clearly identified. In. Fig. 30(A), the pyrite framboids in the form of grey spherical granules and prominent white irregular shaped patch of kaolinite with veins of gypsum on its, meaning thereby its presence in traces and in intimate association with the kaolinite are conspicuously observed. In the SEM photograph (Cf. Fig. 30-A, 31A) the diffused pyrite framboids and dominant kaolinite are unmistakably seen. Likewise in the SEM photograph Fig. 30(B), the iron oxide crystals (in the form of agglomerates of grayish black tiny particles in the centre) in a matrix of other minerals (seen as this elongate particles or flakes, cleat, fissures or veins) are distinctly noticeable, In a similar manner, in the scanning electron pthomicrograph of Metka coal (Fig. 31-A), the presence of calcite from acleat in the form of black veins on the overall surface is clearly visible, while the white patch in the centre of the photograph is that of kaolinite. It will be noticed that on this white kaolinite patch is a black spot which is due to extremely small particles of Iron-oxide crystals. When this kaolinite patch was further examined at a higher magnification, the resulting photograph 31(B) evinced the presence of Gypsum which can be seen as grayish shite or whitish patches on the dominant kaolinite lemins. In the photograph 31(A) the black veins due to calcite on the overall surface and the dominant white lemine representing kaolinite are clearly observed. Examined at higher magnification, the kaolinitic patch further revealed the presence of small quantity of pyrite framboids, as grayish black spot in the centre of the photograph. . The scanning electron photomicrograph of Kashmir lignite Fig.32 shows the presence of a distinctive suite of minerals, such as pyrite framboids (at the bottom left white kaolinitic patch) calcite (seen as grayish black veins or stripes) and small patches of whitish grey on the cleat due to gypsum. This is more clearly observed in photograph Fig.32(B) where in not only the black patch of extremely small particles of iron oxide but also cleats and fissures and flakes of other minerals namely quartz, calcite and gypsum are clearly noticed.