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Carbon – Science and Technology

ISSN 0974 – 0546

http://www.applied-science-innovations.com

RESEARCH ARTICLE Received: 15/3/2018, Accepted:10/6/2018

Mineral matter characteristics of Samleswari block Ib valley coal field, Odisha, India

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Abstract: In India, coal is one of the important source of energy. Slagging and clinkering of the coal in the process of combustion is the major problem in non-coking coal industries. The purpose of this paper is to thermodynamic assessment of the chemical composition variations and phase transitions in the coal ash during the process of combustion. For thermodynamic analysis FactSage software is used and the coal samples are collected from the Samleswari block Coalfield, Odisha. The predicted data has been matched with the experimental data obtained by XRD. XRD results showed that Quartz and Kaolinite are present in abundance amount. Chemical composition analyses show that there is an abundance of acidic oxides (SiO_2, Fe_2O_3 and TiO_2) in the coal samples. Traces of basic oxides (Fe_2O_3, MgO and CaO) have been observed. High acid-to-base ratios are accountable for the high ash fusion temperatures, which certainly lowers the slagging potential of coal seams studied. The ash fusion temperatures are only an indicator of slag propensity of coal.

Key Words: Proximate analysis, FactSage, AFT and Samleswari block coalfield.

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1. Introduction: The knowledge of mineral composition in coal and structural characteristics of minerals are essential to understand the mineral phases transformation during the process of combustion and gasification. Most common problem of the thermal power industries is the slagging and clinkering of the coal ash. Thermal power plants are adopting technologies to predict the slagging and clinkering behavior based on the ash composition database. Even though, this database cannot give proper information on coal slagging.

There are number of techniques available to provide information on the mineral association in coal, such as mineral-mineral, mineral-coal, mineral-organically associated inorganic constituents etc. [1, 2]. The phase transformations of mineral matter and trace elements in the Chinese coal were studied at various temperatures. The results showed that, for selected trace elements volatization ratios improved with rise in temperature [3]. Chakravarty et al. studied on the Indian coal characteristics like composition, mineral matter characteristics and ash fusion behavior [4]. They predicted the ash fusion behavior and phase transformations in the mineral matter of coal by using the CALPHAD approach, with the help of FactSage software.

In general quartz, kaolinite, illite-muscovite, calcite, chlorite, pyrite etc. are the mineral phases present in the coal ash. Studies of Lopez and Ward on Combodian coal samples mineralogy using low temperature ashing and diffraction techniques shows that kaolinite, illite, quartz and pyrite are the dominant mineral phases present [5].

From the commercial point of view, the quantity, composition and fusibility of coal ash are of prime importance. High ash content in coal matrix diminished the calorific value of coal. Again the quantity of ash is not the only factor for evaluation of the coal properties for fuel engineers, the fusibility of the ash is one of the major parameters to investigate the slagging and clinkering propensity of coal.

Despite considerable research in such areas, the fundamental concept of mineral matter transformation behaviour of high ash Indian coal inside a boiler during coal combustion requires significant appreciation. The primary objective of this investigation is to analyse the mineral phase distribution at different seams of a particular borehole of Samleswari block of Ib valley, Odisha, India. Furthermore, thermodynamic modeling of the phase transitions occur during the ash fusion has investigated.

3. Material and methods

The coal samples collected from the three seams C2 (depth: 27.27 m-27.80 m), C4 (depth: 94.53 m – 95.32 m) and C5 (depth: 143 m – 169.65 m) of Samleswari block Ib valley coal field, Odisha, India. As received coal samples were crushed to -72 mesh size for the ultimate and proximate analysis. Proximate, ultimate and calorimeter analysis were done according to the ASTM D7582-10, ASTM D5373-08 and ASTM D5865 standard methods respectively. Phase analysis of the coal sample was done by using the X-ray diffraction technique by using the Cu-Kα radiation. Ash was prepared by heating the three coals in a muffle furnace at temperature 812 °C for 1 hours. Chemical analysis of the ash was measured by using XRF analysis. Ash fusion temperature of the samples was analyzed according to ASTMD1857 standards. Thermodynamic analysis of the phase transitions and slag formation were carried out by using the FactSage^{TM} software. FactPS, ELEM, FTmisc and FToxide databases were chosen for the analysis.

4. Results and discussion:

4.1 Proximate and Ultimate analysis: Coal samples of 3 different seams at varying depth of a particular borehole of Samleswari block Coalfield were study. Proximate and ultimate analysis of the coal samples is shown in table (1). Table (1) represents the chemical analysis data of coal at 3 different seams, C2, C4 and C5 of Samleswari block coalfield. It appears from Table (1) that the ash content of seam C2, C4 and C5 are in the range of 45.03 % to 45.59 % and moisture ranges from 4.87 % to 5.6 %. The other parameters such as H (%) and N (%) are found to be less. C % of all the three seams are < 40 %.

4.2 Chemical Composition: Table (2) shows the chemical composition of coal ash samples of different seams of Samleswari block of Ib valley. Table (2) also indicates that SiO_2 and Al_2O_3 are the most predominant phases for the coal seam samples and iron, calcium, magnesium, titanium, manganese are minor components present in it. The overall coal quality of all the coal seams of Talcher coalfields studied in this work is identical.

Table (1): Proximate and ultimate analysis of Samleswari block coalfield at different seam.

Seam	Moisture %	Ash %	VM %	FC %	C %	H %	N %	S %
C2	5.6	45.49	25.46	20.31	34.25	3.53	0.81	0.93
C4	5.59	45.03	24.96	21.54	39.83	3.84	0.93	0.88
C5	4.87	45.59	18.77	28	34.76	3.26	0.89	0.7

Table (2): Chemical analysis of ash in percentage.

Seam	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	CaO %	MgO %	MnO %	TiO_2 %	P_2O_5 %	SO_3 %
C2	69.81	5.04	19.44	0.16	0.31	0.07	1.79	0.21	0.76
C4	71.5	4.67	17.44	0.13	0.13	0.02	2.23	0.78	0.78
C5	70.66	4.91	18	0.21	0.03	0.05	2.48	0.47	0.7

4.3 Characterization of mineral species: Phase characterization of the raw coal C2 has shown in Figure (1), it shows that aluminum and silicon are exist in the kalonite form. Quartz, illite and hematite have been also recognized as the common minerals present in the raw coal seams of Samleswari block coalfield (Figure 1) from the XRD patterns. The findings of XRD analyses have been further corroborated by the AFT analysis and FactSage thermodynamic modeling.

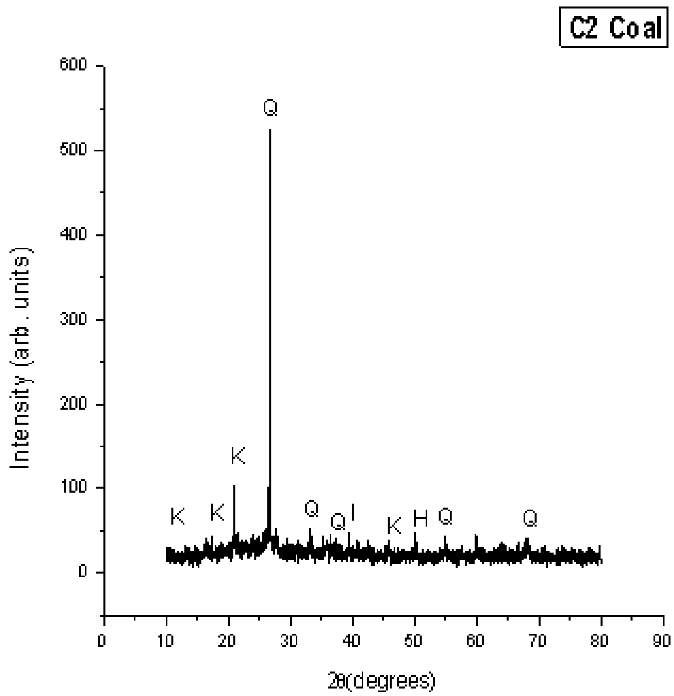

Figure (1): XRD patterns of raw coal. Q-quartz; K-kaolinite I-illite, H: hematite.

4.4 AFT analysis: The behavior of ash fusibility is an important factor for the calculation of efficiency of the boiler plant and gas producers. Ash Fusion Temperature helps in estimating the coal ash slagging behavior. Slagging behavior of the ash depends upon the constituents present in it, which are divided into acidic (SiO_2, FeO, TiO_2), basic (CaO, MgO, Fe_2O_3, Na_2O and K_2O) and amphoteric (Al_2O_3). Higher the presence of acidic compounds in coal ash higher is the melting point. Basic components in coal ash and alkalis have a fluxing effect on SiO_2 and Al_2O_3, hereby reducing the liquefaction point of ash. Ca and Fe play the significant role for ash fusion properties. In present study, it has been observed that the main constituents of ash are quartz and kaolinite with small amount of almandine. Ash fusion temperature tests for the three coal samples shown in the Table (3), it shows fluidize temperature (FT) above 1500 ^oC, which is very promising. The high AFT value indicates the high concentration silica and alumina in all coal ash samples and the corresponding melting temperatures range between 1685 ^oC and 1775 ^oC **[6]**. Table (3) shows a similar range of AFTs for all the seams which suggests similar mineral phase composition in all the seams studied.

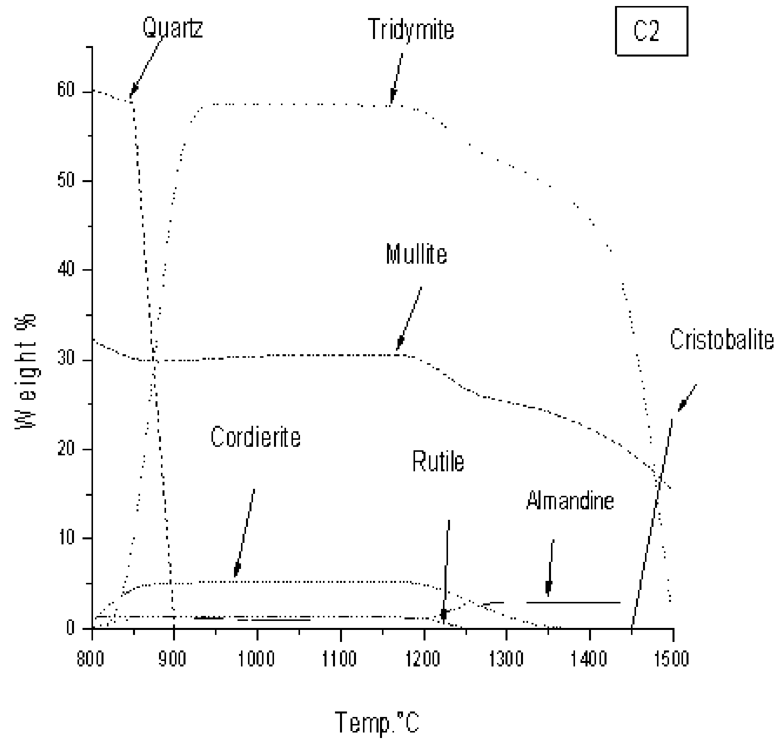

Figure (2): Coal phase variations with temperature.

Table (3): Ash Fusion Temperature of coal ash of different seams of Samleswari block coalfield.

Seam depth (m)	IDT	ST	HT	FT
C2 (27.27 – 27.80)	1115	1167	>1500	>1500
C4 (94.53 – 95.32)	1137	1232	>1500	>1500
C5 (143 – 169.65)	1119	1132	>1500	>1500

4.5 FactSage analysis: FactSage 6.4 software is used for the equilibrium calculations and phase transitions in ash during the coal combustion. For equilibrium calculations, Gibbs energy function for a pure substance has calculated by Meyer and Kelley formula and Redlich-Kister-Muggianu polynomial equation for the solution calculations. The input data used for the FactSage calculations for coal seams C2 sample is from the inferred chemical composition of the raw coal ash data as given in Table (2). The data shows that quartz and mullite are in higher proportions coal ash analyzed along with traces of almandine and rutile. With increase in the temperature there is a transition in the silica from quartz to tridymite phase. Presence aluminium phosphate aid in the rise of liquidus temperature, because of its high temperature stability. Figure (2) shows tridymite (SiO_2) phase occurring at 850 ºC and cristobalite (SiO_2) phase forming after 1100 ºC and 1450 ºC respectively, for coal seam C2. As the temperature increases the phase transformation of coal commences resulting in new phases, cordierite, mullite and tridymite Polymorphism of kaolinite ($Al_2Si_2O_5(OH)_4$) to mullite has been observed with increasing temperature. It shows that final fusion temperature is greater than 1450 ºC. Formation of the mullite phase is the reason for the high temperature stability of ash.

5. Conclusions: The extensive mineral phase study evaluated the chemical compositions of Indian coal seam samples taken from Samleswari block coalfield, Odisha. AFT analysis, elemental composition analyses and FactSage simulation conducted on the samples showed that the concentration of SiO_2 (%), CaO (%), MgO (%), P_2O_5 (%) and SO_3 (%) in coal ash decreases significantly with depth of the seam. Quartz, kaolinite and Tridymite are common minerals in the coal. Ash fusion temperature of C2, C4and C5 is high indicating the appreciable presence of quartz and aluminosilicate.

During combustion the mineral matter present in coal gets transformed to other mineral phases following high temperature phase transformation. From FactSage our study depicts that melting point of mullite and tridymite is high. Furthermore, the quality of coal is sub-bituminous type.

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