Characterization and Evaluation of Thur Coal for Different Mineral Contents

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Summary: A coal sample, obtained from Thur (Sindh, Pakistan) coal mine was analyzed for various parameters such as moisture, volatile matter, ash, fixed carbon, chlorine, total sulfur, sulfatic and pyretic sulfur. Fixed carbon (27.19%) was found low as compared to volatile matter (45.92 %), which is an indication of a young coal suggesting its rank between peat and lignite. Elements such as iron, zinc, nickel, copper, lead and chromium, determined in the coal ash suggest that the concentration of iron was highest where as the concentration of chromium was lowest among the metals studied.

Introduction

Coal is abundantly present in nature and use as a source of energy in various industries as well as for domestic use. However, environmental pollution is associated with the combustion of coal because it contain carbon, sulfur, chlorine, nitrogen and mineral matter which are converted into oxides of carbon, sulfur, chlorine, nitrogen and causes global warming, acid rain, smog formation and also contaminate water reservoirs. Extensive research is going for the identification and removal of mineral matter from coal. Ishaq *et al* [1, 2] characterized and determined mineral matter in Khusab and Hangu coal samples. Zubkova *et al* [3] studied the influence of mineral matter on transport of coal plastic mass and on volume of coal charge during carbonization. Wells *et al* [4] studied the nature of mineral matter in a coal and the effects on erosive and abrasive behaviour. Franklin *et al* [5] studied the effects of minerals on the rapid pyrolysis and hydropyrolysis of a bituminous coal and also on yields of char, tar and light gaseous volatiles. Wang *et al* [6] leached ashes and chars in order to study transformations of trace elements during coal combustion and pyrolysis. Liu *et al* [7] studied the effect of inorganic matter on reactivity and kinetics of coal pyrolysis. Lu *et al* [8] studied the volatilization behavior of Pb, Cd and Cr in Yima coal during fluidized-bed pyrolysis. Baruah *et al* [9] determined the concentration of Na, K, Mg, Cr, Mn, Fe, Co, Ni, Cu, Zn, and Cd in sub-bituminous Assam coals. Mukherjee [10] studied the effect of leaching high sulphur sub-bituminous coal by potassium hydroxide and acid (HCl and HNO_3) on removal of minerals and sulfur. Cui *et al* [11] studied the effects of remained catalyst and enriched coal minerals on devolatilization of residual chars from coal liquefaction. Suarez-Fernandez *et al* [12] analyzed major, minor and trace elements in coal by radioisotope X-ray fluorescence spectrometry.

The present study concerns with the characterization and evaluation of mineral contents determination in the ash of Thur coal of Pakistan.

Results and Discussion

The proximate analysis of the coal sample is provided in Table-1. The data indicate the moisture, ash and volatile matter are high while fixed carbon is low, which indicate that the coal is young and can be ranked between peat and lignite. The low fixed carbon mean that the coal is low rank and also lower will be its calorific value. The high ash content in coal is undesirable because it not only reduce the calorific value but also deactivate the catalyst and have deleterious effect on the coal utilization process such as liquefaction, combustion and gasification. Moreover, the ash content causes operational problem of agglomeration and corrode the metallic parts of the combustion appliances [2]. The level of total sulfur, chlorine, sulfatic sulfur and pyretic sulfur

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Table-1: Determination of moisture, ash, volatile matter and fixed carbon in virgin coal.

Parameters	Level (%)
Moisture	5.94
Volatile matter*	45.92
Ash*	15.5
Fixed carbon	27.194

*dmf basis

Table-2: Determination of chlorine, total sulfur, sulfatic sulfur and pyratic sulfur in virgin coal.

Parameters	Level (%)
Total sulfur	3.28
Chlorine	1.06
Sulfatic sulfur	0.23
Pyretic sulfur	0.07

in the coal sample is presented in Table-2. The data shows the concentration of total sulfur (3.28%), chlorine (1.06%), sulfatic sulfur (0.23%) and pyretic sulfur (0.07%), which is high. The high concentration of chlorine and total sulfur is undesirable in coal because it not only reduce the fuel quality and deactivate the catalyst but also causes corrosive effect on the metallic parts of appliances and acid rain during combustion [1,13].

Mineral elements in the ash of coal sample were determined by atomic absorption spectrophotometer. Figure 1 shows mineral elements in the ash of coal sample, which was digested with various concentrations (1-5 M) of HCl solution. The data show higher amount of iron (2071.44 μg/g) and least amount of chromium (23.94 μg/g) in the coal sample. The results also indicate that the dissolution of iron decreases with an increase in the concentration of HCl solution, while the digestion of zinc, copper and lead increase up to 4 M and then decrease as the concentration increases. Figure 1 also indicates that the amount of nickel increases with increases in the HCl concentration (even up to 5 M) while in case of chromium, maximum amount was obtained from 4 to 5 M.

Figure 2 presents mineral elements in the ash of Thur coal sample that was digested with various concentrations (1-5 M) of HNO_3. The results indicate that the solubilization of iron, zinc, nickel, copper and chromium increased up to 3 M and then decreased with an increase in the concentration of HNO_3. In case of lead maximum amount was obtained with 1 M HNO_3, which was decreased further with an increase in the acid concentration.

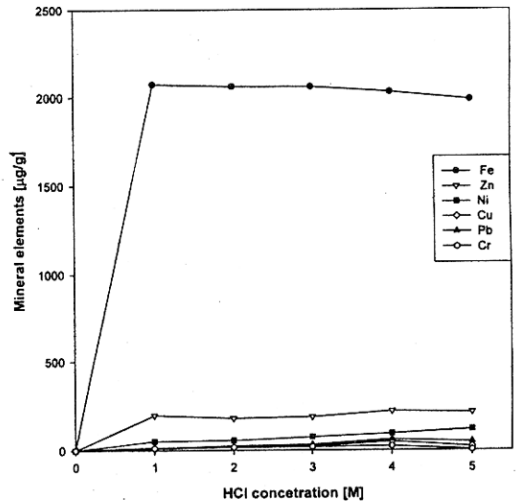

Fig. 1: Effect of HCl concentration on the determination of mineral elements in the ash of coal sample.

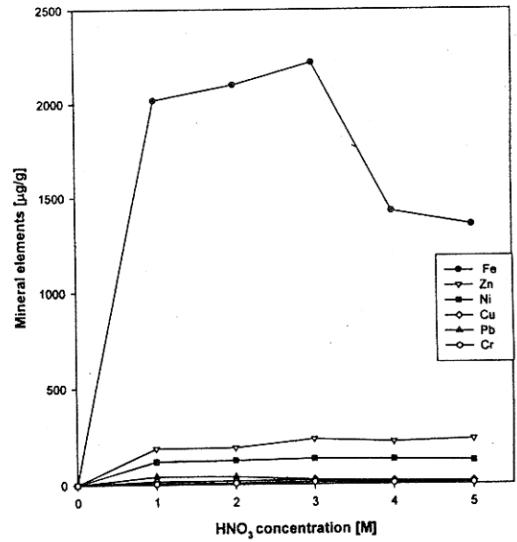

Fig. 2: Effect of HNO_3 concentration on the determination of mineral elements inthe ash of coal sample.

The results of the ash in coal sample, which was digested with acid mixture (H_2O + HNO_3 + HCl + HF) for determination of iron, zinc, nickel, copper, lead and chromium are shown in Figure 3. The results indicate that acid mixture dissolve iron (2090.34 μg/g), zinc (416.43 μg/g), nickel (85.68

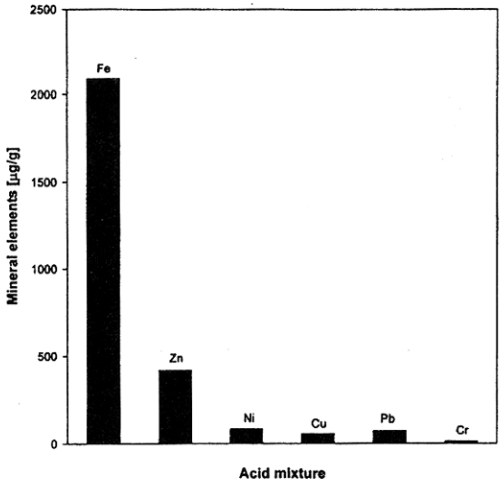

Fig. 3. Amount of mineral elements determined in the ash of coal sample, digested with acid mixture.

µg/g), copper (56.7 µg/g), lead (71.82 µg/g) and chromium (13.23 µg/g).

The data in Figures 1-3 indicate that the coal sample contain higher amount of iron compared to other mineral elements, in all three cases. This may be due to pyrite, which is generally important iron bearing mineral in coals [15]. While comparing the digestion efficiency of HCl, HNO_3 and acid mixture for the aforementioned mineral elements, it was observed that maximum amount of iron was digested with 3 M HNO_3, least with HCl solution and intermediate in case of acid mixture.

In case of zinc, appreciable amount was dissolved with acid mixture (416.43 µg/g), while using HCl and HNO_3, the amount of this element was 219.87 and 233 µg/g, respectively. Higher amount of nickel was observed using 3 M HNO_3 followed by HCl (5 M) and very small amount with acid mixture. Appreciable amount of copper and lead was digested with acid mixture compared to HCl and HNO_3 while higher amounts of chromium was determined using HCl (4-5 M).

Comparison with other Pakistani Coals

Table-3 shows the comparison of Thur coal moisture, ash, volatile matter, fixed carbon, total sulfur, sulfatic sulfur and pyratic sulfur with other Pakistani coals. The results indicate that Thur coal

Table-3: Comparison of Thur coal proximate and elemental analysis with other Pakistani coals (%).

Parameters	Thur	Khushab	S. Waziristan	Hangu
Moisture	5.94	4.75	4	2.78
Volatile matter	45.92	33.75	27	28.76
Ash	15.5	20.4	48	18.2
Fixed carbon	27.19	41.13	16	50.26
Total sulfur	3.28	2.98	5.3	----
Sulfatic sulfur	0.32	0.214	0.25	----
Pyretic sulfur	0.07	0.08	0.1	0.08

contains higher moisture contents (5.94 %) compared to other Pakistani such as Khushab (4.75 %), South Waziristan (4 %) and Hungu (2.78 %). The volatile matter also higher in the Thur coal (45.92 %) than Khushab (33.75 %), South Waziristan (27 %) and Hungu (28.76 %) coals, while the concentration of ash in Thur coal (15.5 %) is lower than Khushab (20.4 %), South Waziristan (48 %) and Hungu (18.2 %) coals. The amount of fixed carbon in Thur coal (27.19%) is low compared to Khushab (41.13 %) and Hungu (50.26 %) while higher than South Waziristan (16 %) coals. The concentration of total sulfur (3.28%) and sulfatic sulfur (0.23 %) in Thur coal is higher than Khushab (2.98 %) and (0.214 %) while lower than South Waziristan (5.3 %) and (0.25%) coals, respectively. The content of pyretic sulfur in Thur coal is 0.07%, which is lower, compared to South Waziristan (0.1%) and Hungu (0.08%) coals [1, 2, 13].

The mineral elements found in the Thur coal sample was also compared with the other Pakistani coals, as presented in table 4. Among the various investigated metals, iron was found to be the higher one (2216.34 µg/g), but its amount is lower compared to Makarwal (3530 µg/g), Degari (5850 µg/g), Sharigh (15200 µg/g) and Sore-rang (2970 µg/g) while higher than South Waziristan (1632 µg/g) coals [14].

Table-4: Comparison of Thur coal mineral elements with other Pakistani coals (µg/g).

Coal samples	Fe	Zn	Ni	Cu	Pb
Thur	2216.34	416.43	188.37	56.7	61.11
Makarwal	3530	185	----	23	----
Degari	5850	27	----	2	----
Shahrigh	15200	1022	----	20	----
Sor-range	2970	45	----	28	----
South Waziristan	1632	13	8	9	41

The amount of zinc in Thur coal (416.43 µg/g) is lower than Makawar (185 µg/g) but higher than Degari (27 µg/g), Shahrigh (1022 µg/g), Sore- range (45 µg/g) and South Waziristan (13 µg/g) coals.

Higher amount of copper was found in the Thur coal sample (56.7 μg/g) compared to Makarwal (23 μg/g), Degari (2 μg/g), Shahrigh (20 μg/g), Sore-range (28 μg/g) and South Waziristan (9 μg/g) coals. The amount of lead (61.11 μg/g) and nickel (188.37 μg/g) was found higher in the Thur coal than the South Waziristan (41 μg/g) and (8 μg/g) coal, respectively [13,14].

Experimental

Sample collection and preparation

The coal sample was collected through PMDC (Pakistan mineral development corporation) according to the standard methods of sample collection from Thur (Sindh, Pakistan) coal mine. The coal sample was crushed, ground and sieved through screen mesh size below 212 μm and used for further study.

Proximate Analysis

The proximate analysis and sulfur determination in coal sample was performed according to the standard ASTM methods [16].

Determination of mineral elements

Samples for mineral elements determination were prepared in such away that 1 g coal was taken separately in different crucibles and heated in an electric muffle furnace at 750 ± 10 ^{0}C until carbon is converted to CO_2. The ash contents were cooled and digested in 50 mL of different molar concentration of HNO_3 and HCl solutions by heating at 100 ^{0}C for a time duration of 2 h with occasional stirring, cooled and then filtered. The filtrates were collected, made up its volume and then stored in polyethylene bottle for the analysis of mineral elements by using atomic absorption spectrophotometer (Polarized Zeeman Hitachi-2000).

The same procedure was adopted for acid solution made of distilled water, concentrated nitric acid, hydrochloric acid and hydrofluoric acid in the ratio of 10:5:1:1 by volume, respectively [14].

Conclusions

It is concluded that Thur coal has high amount of moisture, volatile matter, total sulfur and chlorine while low amount of fixed carbon, which indicate that this coal is young and of low rank and could be used for metallurgical proposes. Among the various investigated mineral elements, higher concentration of iron and very low concentration of chromium were found in the Thur coal. Comparing this coal with other Pakistani coals, it is deduced that the Thur coal contains lower amounts of iron and zinc and higher amounts of nickel, copper and lead.

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