Environmental Impact Assessment of the Thar, Sonda and Meting-Jhimpir Coalfields of Sindh

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Summary: The coal deposits explored so far in the Sindh province include Thar, Sonda, Meting-Jhimpir and Lakhra coalfields. Thar coalfield is the largest coalfield of Pakistan. It has estimated resources of 175 billion tonnes of coal. The Sonda coalfield is located in the deltaic area of lower Indus and is having the total resources of 280 million tones of coal. The Meting-Jhimpir is the second oldest coalfield after Lakhra explored in the District Thatta in the Sindh province. It has about 161 million tonnes of coal resources. The representative coal samples from the Sindh coalfields, especially Thar, Sonda and Meting-Jhimpir coalfields, have been analyzed for the concentration of proximate and ultimate constituents, calorific values and heavy, trace and light elements by using various techniques. The sequential leaching behavior of these coals was also performed by using various solvents. The amount of fixed carbon, ash, hydrogen, carbon, and nitrogen in the Sindh coals are within the permissible limit, however, the sulfur contents, especially in the Sonda and Meting-Jhimpir coals, are above the permissible limit. The sequential leaching analyses suggest that most of the heavy and trace elements are associated with HCl-soluble compounds and also with the insoluble or organic shielded matters. However, iron is generally associated with the HNO_3-soluble disulfides. The leaching behavior of the Sindh coal suggest that there are chances of contamination of the underground water system due to acid drain water during the large scale coal mining in the region. The combustion of Sindh coal may pose threat to the environment of the region as far as the S, Pb, Zn and Ni contents of the Sonda and Meting-Jhimpir coals are concerned. These coals, therefore, need to be cleaned and also the particulate emission level of the power generation plants should be substantially reduced before the use of these coals in the power generation plants and other industries of Pakistan.

Introduction

Coal is likely to remain an important part of the Pakistan energy supply, largely because it is the most abundant domestically available fossil fuel. One of the major concerns related to the use of coal for electricity production is the release of elements during combustion and the resulting coal combustion product (CCPs)-fly ash and bottom ash-to the environment. It is, therefore, necessary to acquire accurate, reliable and quantitative information about the concentration and modes of occurrence of chemical elements, especially heavy metals in feed coal and coal combustion products.

The mining of coal is another cause of environmental degradation of the area, which results in the serious problems related to contaminated mine drainage. Acid mine drainage from closed and abandoned mines (both surface and underground) has far reaching effects on water quality. Naturally occurring radioactive material released by coal combustion is accumulating in the environment along with elements such as mercury, arsenic, silicon, calcium, chlorine, lead and sodium as well as metals such as aluminum, iron, lead, magnesium, titanium, boron, chromium, nickel, zinc, copper which are collectively dispersed in millions of tons of coal combustion by-products [1].

Four major coalfields named as (1) Sonda, (2) Meting-Jhimpir (both in Thatta district) (3) Lakhra (in Dadu district) and (4) Thar coalfield in Tharparkar have been explored so far (Fig. 1). Thar coalfield is situated in District Tharparkar of south-eastern Sindh and is the largest coalfield of Pakistan having an area of about 9000 Km^2. The resource potential of this single coalfield is estimated about 175 billion tonnes [2]. Sonda coalfield is located in the deltaic area of lower Indus, on the National Highway 40 kms from Thatta and 130 kms from Karachi towards

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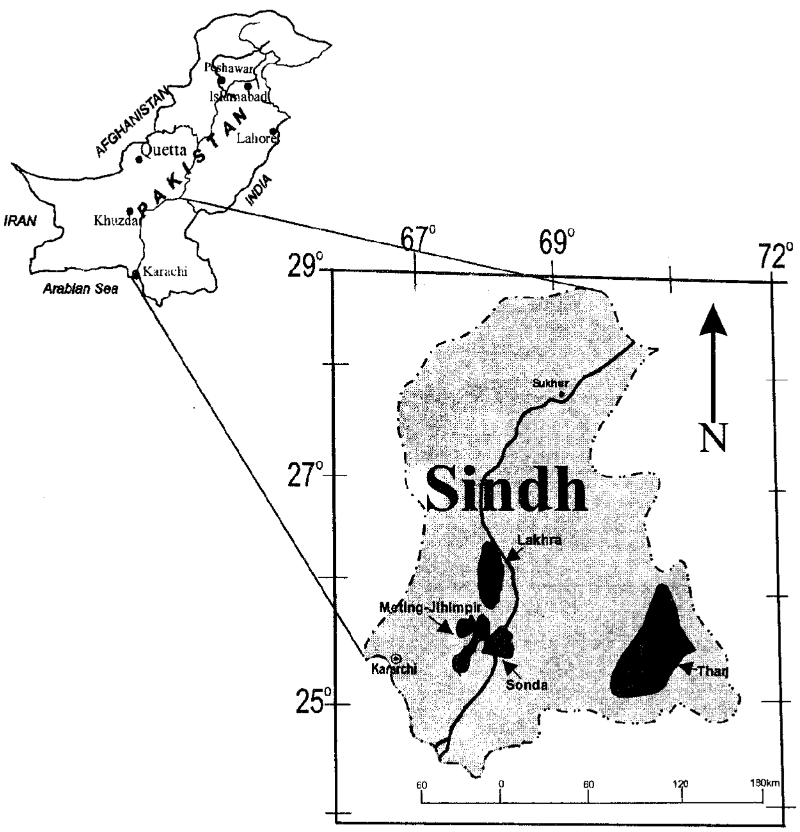

Fig. 1. Location map of the Thar, Sonda, Lakhra and Meting-Jhimpir coalfields of Sindh, Pakistan.

Hyderabad. More than 29 coal seams of varying thickness and continuity occur at different horizons in Sonda coalfield. The total reserves have been estimated as over 295 million tones [3]. The Meting-Jhimpir coalfield lies approximately 125 km east of Karachi in the vicinity of Meting-Jhimpir railway station on the main railway line extending from Karachi to Peshawar. Only one seam with thickness ranging from 0.3 to 1.0 metre is being commercially mined in the area. The total reserves of coal have been estimated as 161 million tones.

Keeping in view the huge deposits of Sindh coal in Pakistan, their future threats to the environment need to be studied. This study is the part of the Ph.D. research of the first author and has been carried out to evaluate the Sindh coals for their use in power generation and other industrial purposes.

Results and Discussion

A total of fifty six drill core samples of the Thar coal (i.e., Block I, II, III) and eleven core samples of Sonda coal were obtained from the core library of Geological Survey of Pakistan, Karachi. Thirteen representative coal samples from the Meting-Jhimpir coalfield have been collected during field work. These samples were analyzed for the proximate and ultimate analysis (Table-1). Among the heavy, trace and light elements, the concentration of Cu, Pb, Zn, Ni, Cr, Co, Cd, Fe, Mn, Ca, Mg, Na and K were determined in these coal samples (Table 2).

Thar Coalfield

Proximate Analysis

Fixed carbon contents of the Thar coal have been given in Table-1. It is ranging from

Table-1: Proximate and ultimate constituents (in percent) and calorific values (btu/lb) of Thar, Sonda and Meting Jhimpir coalfields of Sindh.

Elements	Thar coalfield (N = 56)			Sonda coalfield	Meting-Jhimpir
	Block-I	Block-II	Block-III	(N = 11)	coalfield (N = 13)
Fixed Carbon	33.78-45.21 (38.61)	34.78-48.34 (41.06)	34.56-48.45 (40.76)	39.34-44.78 (41.20)	38.43-45.67 (41.11)
Ash	4.50-6.73 (5.44)	4.76-7.12 (5.79)	4.56-6.23 (5.36)	4.76-6.34 (5.77)	9.52-12.68 (10.77)
Carbon	52.70-70.53 (60.24)	54.26-67.44 (63.00)	53.91-66.23 (61.84)	54.78-67.45 (61.43)	54.78-66.23 (60.20)
Hydrogen	5.34-8.28 (6.68)	5.85-8.76 (7.12)	5.61-7.66 (6.59)	5.88-7.30 (6.90)	5.34-7.34 (6.82)
Nitrogen	0.27-0.41 (0.34)	0.29-0.44 (0.36)	0.28-0.39 (0.33)	0.23-0.40 (0.31)	0.24-0.40 (0.32)
Sulfur	0.98-4.00 (1.55)	0.45-2.56 (1.11)	0.44-2.32 (0.99)	2.00-7.00 (4.33)	2.00-5.20 (3.65)
Calorific value	8445-11303 (9653)	8695-12085 (10265)	8640-12113 (10190)	9835-11195 (10301)	9608-11418 (10143)

N = number of samples; the average values are in parentheses.

Table-2: Ranges and averages of heavy, trace and light elements (in mg/ kg) in the Thar, Sonda and Meting-Jhimpir coalfields of Sindh.

Elements	Thar coalfield (N = 56)			Sonda	Meting-Jhimpir
	Block-I	Block-II	Block-III	coalfield (N = 11)	coalfield (N = 13)
Pb	7-36 (20)	7-56 (33)	32-65 (49)	8-28 (17)	7-39 (23)
Zn	10-36 (22)	8-71 (38)	25-116 (85)	9-75 (44)	12-75 (40)
Cu	8-17 (12)	10-38 (21)	12-31 (21)	6-32 (14)	6-49 (22)
Ni	9-32 (22)	13-65 (41)	31-75 (60)	14-46 (34)	8-41 (23)
Cr	8-21 (15)	8-35 (18)	13-47 (26)	7-18 (11)	8-22 (12)
Cd	0.3-0.5 (0.34)	0.1-0.4 (0.31)	0.2-0.3 (0.29)	0.10-0.40 (0.19)	0.10-0.40 (0.24)
Co	2-8 (5)	7-25 (14)	11-25 (16)	2-4 (3)	0.05-0.55 (0.25)
Fe	3421-7632 (5883)	331-8473 (4150)	2845-8762 (4993)	891-8421 (5867)	724-6834 (4500)
Mn	0.1-1.0 (0.61)	0.17-1.84 (0.75)	0.13-1.37 (0.59)	0.14-0.42 (0.27)	<0.05-0.49 (0.09)
Ca	81-418 (230)	81-470 (254)	151-364 (258)	85-512 (203)	156-390 (241)
Mg	45-75 (62)	28-171 (81)	51-115 (78)	28-68 (43)	40-72 (60)
Na	465-670 (564)	470-925 (680)	290-318 (304)	370-438 (414)	321-681 (515)
K	165-412 (223)	158-290 (229)	110-180 (147)	218-340 (289)	104-440 (252)

N = number of samples; the average values are in parentheses.

33.78 to 45.21 % in the block-I, from 34.78 to 48.34 % in block-II and 34.56 to 48.45 % in the block-III with an average amount of 38.61 %, 41.06 % and 40.76 % respectively. Ash is ranging from 4.50 to 6.73 % in block-I, from 4.76 to 7.12 % in block-II and from 4.56 to 6.23 % in block-III with an average amount of 5.44 %, 5.79 % and 5.36 % respectively.

Ultimate Analysis

Thar coalfield has carbon in the range of 52.70 to 70.53 % (average = 60.24 %) in block-I, 54.26 to 67.41 % (average = 63.00 %) in block-II and 53.91 to 66.23 % (average = 61.84 %) in block-III (Table-1). Hydrogen in the Thar coal is in the range of 5.34 to 8.28 % (average = 6.68 %) in the block-I, 5.85 to 8.76 % (average = 7.12 %) in block-II and 5.61 to 7.66 % (average = 6.59 %) in block-III (Table-3). Nitrogen varies from 0.27 to 0.41 % (average = 0.34 %) in block-I, from 0.29 to 0.44 % (average = 0.36) in block-II and from 0.28 to 0.39 % (average = 0.33 %) in block-III (Table-1). Sulfur contents in the Tahr coal are ranging from 0.98 to 4.00 % in block-I, from 0.45 to 2.56 % in block-II and from 0.44 to 2.32 % in block-III with an average amount of 1.55 %, 1.11 % ad 0.99 % respectively. There is no significant difference on average in the sulfur contents of three blocks of the Thar coalfield. However, the block-I is having relatively high amount of sulfur.

Combustion Properties

The calorific values (CV) of the Thar coalfield are given in Table-1. It is clear from this table that the CV varies from 8445 to 11303 btu/ lb in the block-I, from 8695 to 12085 btu/ lb in block-II and from 8640 to 12113 btu/ lb in block-III with the average values of 9653 btu/ lb, 10265 btu/ lb and 10190 btu/ lb respectively.

Heavy and Trace Elements

The concentration of lead (Pb) is highly variable in all three blocks of the Thar coalfield. The Block-I has maximum lead contents of 36 mg/ kg, Block-II has 56 mg/ kg, and Block-III has 65 mg/ kg with an average lead content of 20 mg/ kg, 33 mg/ kg and 49 mg/ kg respectively (Table-2). It is, therefore, observed that the Block-III has relatively highest Pb concentration on average basis. The concentration of Zn varies from 10 mg/ kg to 36 mg/ kg in Block-I, 8 mg/ kg to 71 mg/ kg in Block-II and 25 mg/ kg to 116 mg/ kg in Block-III of the Thar coalfield. The average concentration of Zn is 22 mg/ kg, 38 mg/ kg and 85 mg/ kg in Block-I, II, and III respectively (Table-2). It is clear from the data that the Block-III of the Thar coalfield has relatively high concentration of Zinc. The concentration of copper (Cu) varies from 8 mg/ kg to 17 mg/ kg in the block-I, 10 pm to 38 mg/ kg in Block-II and 12 mg/ kg to 31 mg/ kg in the Block-III of the Thar coalfield. The average concentration of Cu in Block-I (12 mg/ kg), in Block-II (21 mg/ kg) and Block-III (21 mg/ kg) suggests that the coal of Block-II is relatively high in Copper (Table-2). The concentration of Nickle (Ni) in the Thar coalfield varies from 9 mg/ kg to 32 mg/ kg (average = 22 mg/ kg) in Block-I, from 13 mg/ kg to 65 mg/ kg (average = 41 mg/ kg) in Block-II and from 31 mg/ kg to 75 mg/ kg (average = 60 mg/ kg) in Block-III (Table-2). It is clear from Table-2 that the Thar coalfield is having chromium (Cr) up to 21 mg/ kg (average = 15 mg/ kg) in Block-I, up to 35 mg/ kg (average = 18 mg/ kg) in Block-II and up to 47 mg/ kg (average = 26 mg/ kg) in Block-III. It suggests that the Block-III of the Thar coalfield is relatively more enriched in chromium. Among the heavy metal in Thar coal the concentration of cadmium (Cd) is the lowest and is ranging from 0.1 mg/kg to 0.4 mg/ kg in all three Blocks- (Table-2). However, the Block-I has the highest average concen-tration (0.34 mg/ kg) of cadmium. The concentration of iron (Fe) varies from 3421 mg/ kg to 7632 mg/ kg in Block-I, from 331 mg/ kg to 8473 mg/ kg in Block-II and from 2845 mg/ kg to 8762 mg/ kg in Block-III (Table-2). Block-I has relatively high average contents of iron (i.e., 5883 mg/ kg). The concentration of cobalt (Co) in the Thar coalfield varies from 2 mg/ kg to 8 mg/ kg (average = 5 mg/ kg) in Block-I, from 7 mg/ kg to 25 mg/ kg (average = 14 mg/ kg) in Block-II and 11 mg/ kg to 25 mg/ kg (average =16 mg/ kg) in Block-III (Table-2). Manganese (Mn) varies from 0.10 mg/ kg to 1.0 mg/ kg (average = 0.61 mg/ kg) in Block-I, from 0.17 mg/ kg to 1.84 mg/ kg (average = 0.75 mg/ kg) in Block-II and from 0.13 mg/ kg to 1.37 mg/ kg (average = 0.59 mg/ kg) in Block-III (Table-2).

Light Elements

Calcium (Ca) in the thar coals varies from 81 mg/kg to 418 mg/ kg (average = 230 mg/ kg) in Block-I, from 81 mg/ kg to 470 mg/ kg (average = 254 mg/ kg) in Block-II and in Block-III it is ranging from 151 mg /kg to 364 mg/ kg (average = 258 mg/ kg) (Table-2). The concentration of magnesium (Mg) in the Block-I has relatively low magnesium (45 mg/ kg to 75 mg/ kg) as compared to Block-II (Mg = 28 mg/ kg to 171 mg/ kg) and Block-III (Mg = 51 mg/ kg to 115 mg/ kg). The average concentration of Mg in block I, II and III is 62 mg/ kg, 81 mg/ kg, and 78 mg/ kg respectively (Table-2). The concentration of sodium (Na) varies consider-ably in three blocks. It ranges from 465 mg/ kg to 670 mg/ kg (average = 564 mg/ kg) in Block-I, from 470 mg/ kg to 925 mg/ kg (average = 680 mg/ kg) in Block-II and from 290 mg/ kg to 318 mg/ kg (average = 304 mg/ kg) in Block-III (Table-2). The concen-tration of potassium (K) varies from 165 mg/kg to 412 mg/ kg (average = 223 mg/kg) in Block-I, from 158 mg/ kg to 290 mg/ kg (average = 229 mg/ kg) in Block-II and from 110 mg/ kg to 180 mg/kg (average = 147 mg/ kg) in Block-III (Table-2).

It is clear from the data of the various blocks of the Thar coalfield that the average concentration of all the analyzed heavy metals (i.e., Pb, Zn, Cu, Ni, Cr, Cd, Fe, Co and Mn) and light elements (i.e., Ca, Mg, Na and K) have variable concentration in all the three blocks. These heavy and trace elements have smooth decreasing trend from Fe to Cd (i.e., Fe > Ni > Zn > Pb > Cr > Cu > Co > Cd) and the concentration of these elements gradually increase from block-I to block-III. The block-I is, however, relatively enriched in Fe. Among the light elements the decreasing trend is from Na to Mg (i.e., Na > Ca > K > Mg). However, the concentration of these elements is relatively high in block-1 and II as compared to block-III (Table-2).

Sonda Coalfield

Proximate Analysis

Among the proximate constituents of the Sonda coalfield, fixed carbon and ash contents are given in Table-1. It is clear from this table that the fixed carbon varies from 39.34 to 44.78 % with an average amount of 41.20 % whereas the ash contents varies from 4.76 to 6.34 % with an average amount of 5.77 %.

Ultimate Analysis

Among the ultimate constituents of Sonda coalfield, hydrogen, carbon, nitrogen and sulfur contents are presented in Table-1. It is clear from this table that hydrogen is ranging from 5.88 to 7.3 % (average = 6.90 %), carbon is ranging from 54.78 to 67.45 % (average = 61.43 %), nitrogen is ranging from 0.23 to 0.40 % (average = 0.31 %) and sulfur is ranging from 2.00 to 7.00 % (average = 4.33 %) in the Sonda coals. The Sonda coals are having three times higher amount of sulfur as compared to Thar coals.

Combustion Properties

The calorific values (CV) of the Sonda coals are ranging from 9835 to 11195 btu/ lb with an average value of 10301 btu/ lb.

Heavy and Trace Elements

It is clear from the Table-2 that among the heavy and trace elements of the Sonda coals, Pb is ranging from 8 mg/ kg to 28 mg/ kg (average = 17 mg/ kg), Zn from 9 mg/ kg to 75 mg/k g (average = 44 mg/ kg), Cu from 6 mg/ kg to 32 mg/ kg (average = 14 mg/ kg), Ni from 14 mg/ kg to 46 mg/ kg (average = 34 mg/ kg), Cr from 7 mg/ kg to 18 mg/ kg (average = 11 mg/ kg), Cd from 0.10 mg/ kg to 0.4 mg/ kg (average = 0.19 mg/ kg), Co from 2 mg/ kg to 4 mg/ kg (average = 3 mg/ kg), Fe from 891 mg/ kg to 8421 mg/ kg (average = 5867 mg/ kg), and Mn from 0.14 mg/ kg to 0.42 mg/ kg (average = 0.27 mg/ kg).

Light Elements

Among the light elements in Sonda coal, Ca varies from 85 mg/ kg to 512 mg/ kg (average = 203 mg/ kg), Mg from 28 mg/ kg to 68 mg/ kg (average = 43 mg/ kg), Na from 370 mg/ kg to 438 mg/ kg (average = 414 mg/ kg) and K from 218 mg/ kg to 340 mg/ kg (average = 289 mg/ kg) (Table-2).

By comparing the heavy and trace elements concentration in the Sonda coals (Table-2), it is clear that the Fe has the highest concentration with gradual decreasing trend towards Cd (i.e., Fe > Ni > Cu > Pb > Cr > Co > Mn > Cd). Whereas, among the light elements in the Sonda coals, sodium has the highest concentration with gradual decreasing trend towards magnesium (i.e., Na > K > Ca > Mg).

Miting-Jhimpir Coalfield

Proximate analysis: Fixed carbon is ranging from 38.43 to 45.67 % with an average amount of 41.11 % and the ash contents are ranging from 9.52 to 12.42 % with an average amount of 10.77 % in the Meting-Jhimpir coalfield (Table-1).

Ultimate Analysis

Carbon varies from 54.78 to 66.23 % (average = 60.20 %), hydrogen varies from 5.34 to 7.34 % (average = 6.82 %), nitrogen varies from 0.24 to 0.40 % (average = 0.32 %) and sulfur varies from 2.00 to 5.20 % (average = 3.65 %) in the Meting-Jhimpir coalfield (Table-1). The sulfur contents in the Meting-Jhimpir coalfield are less than the Sonda coalfield but much higher than the Thar coalfield.

Combustion Properties

The calorific values are ranging from 9608 to 11418 btu/lb with an average value of 10143 btu/lb in the Meting-Jhimpir coalfield (Table-1).

Heavy and Trace Elements

Among the heavy and trace elements, the Pb is ranging from 7 mg/ kg to 39 mg/ kg (average = 23 mg/ kg), Zn from 12 mg/ kg to 75 mg/ kg (average = 40 mg/ kg), Cu from 6 mg/ kg to 49 mg/ kg (average = 22 mg/ kg), Ni from 8 mg/ kg to 41mg/ kg (average = 23 mg/ kg), Cr from 8 mg/ kg to 22 mg/ kg (average = 12 mg/ kg), Co from 0.05 mg/ kg to 0.55 mg/ kg (average = 0.25 mg/ kg), Cd from 0.1 mg/ kg to 0.4 mg/ kg (average=0.24 mg/ kg), Fe from 724 mg/ kg to 6834 mg/ kg (average = 4500 mg/ kg) and Mn from 0.05 mg/ kg to 0.49 mg/ kg (average = 0.09 mg/ kg) (Table-2).

Light Elements

Among the light elements Ca varies from 145 mg/kg to 390 mg/ kg (average = 241mg/ kg), Mg from 40 mg/kg to 72 mg/ kg (average = 60 mg/ kg), Na from 321 mg/kg to 681 mg/ kg (average = 515 mg/kg) and K from 104 mg/ kg to 440 mg/ kg (average = 252 mg/ kg) (Table-2).

By comparing the average concentration of heavy and trace elements in the Meting-Jhimpir coal, the iron has the highest concentration with gradually decreasing trend towards manganese (i.e., Fe > Zn > Pb > Ni > Cu > Cr > Co > Cd > Mn). Whereas, among the light elements the sodium has highest concentration in average with gradually decreasing trend towards magnesium (Na > K > Ca > Mg).

The total sulfur contents in the steam coal used for electricity generation should not exceed (0.8-1.0 %) [4], for cement industry a total sulfur content up to 2.0 % is acceptable and a maximum of 0.8% total sulfur content is required for the coking coal, because higher values affect the quality of steel [4]. The studied coals of the Sindh coalfields have high amount of total sulfur (Table-1). However, Thar coal is having relatively low amount (2 %) of total sulfur on average and, therefore, can be used for industrial purposes. But the coals of Sonda and Meting-Jhimpir are having total sulfur contents higher than 2 %. The coals from these coalfields may have higher SO_2 emission as flue gases to the environment and may also cause corrosion and fouling of boiler tubes.

In order to estimate the amount of SO_2 produced daily from the power station, it is necessary to know calorific value, hydrogen and moisture contents of the coal and the power station heat rate [4]. According to World Bank Group [5], a 500 Mwe plant using coal with 2.5 % sulfur, 16 % ash, and a calorific value of 12898 btu/ lb will emit each day: 200t SO_2, 70t NO_2, 500t fly ash, 500t solid waste and 17 (GWh) of thermal discharge. As the Sindh coal on average is having more than 2.5 % sulfur, therefore, the SO_2 release will be more than 200t per day if 500t Mwe of Sindh coals are used everyday in the power generation plant. This suggest that there would be the higher amount of SO_2 release to the atmosphere during combustion of the studied coals. The Sindh coals, especially from Sonda and Meting-Jhimpir coalfields, therefore, need to be desulfurized before their use in power generation plants and also in the other industries of the region.

Nitrogen content of coal is significant particularly in relation to atmospheric pollution. Upon combustion of the coal, nitrogen helps to form oxides (NO_X) which may be released as flue gases and thereby pollute the environment. NO_2 gas has a significant effect on the atmospheres, as it is a stronger absorber of infrared radiation and is considered as major contributor (20 %) to ozone depletion [4]. The coal should not have nitrogen content more than 2 % because of these NO_X emissions [4]. The nitrogen contents of the Sindh coal from all the coalfields (i.e., Thar, Sonda and Meting-Jhimpir) are within the permissible limits (Table-1) and, therefore, have no environmental impact as far as the combustion of Sindh coal and NO_X emission is concerned.

The recommended maximum ash contents for the steam coals are up to 20 % and a maximum of 10-20 % for coking coals [4]. The Sindh coals are having < 11 % of ash in all the three coalfields (Table-1). This coal, therefore, may not have any drastic effects on efficiency of the blast furnace.

Sequential leaching techniques are used to develop models to predict the behavior of elements during combustion of coal and the potential leaching of coal combustion products (CCPs). This requires quantitative data on the modes of occurrence of those elements in the feed coal. Such data can also be beneficial for evaluation of the environmental impacts, technological impacts and economic by-product potential of coal and CCPs. Sequential leaching experiments provide data that determine modes of occurrences of trace elements in feed coal, fly ash and bottom ash [5,6]. The sequential leaching analyses were performed on the Sindh coal and the chemical data were processed to obtain the percentage for each elements leached by four solvents and the results are shown in Table-3 and Table-4. In this experiment sequence of solvent was selected, so that (1) exchangeable cations, water soluble compounds and some carbonates would be removed by $NH_4C_2H_3O_2$; (2) cations associated with carbonates, mono-sulfides, iron oxides and chelated organic compounds would be removed by HCl; (3) elements associated with silicates would be removed by HF and (4) elements associated with disulfides, especially pyrite and marcasite, would be removed by using HNO_3 [6]. The sample residue present following the sequential leaching procedure contains the insoluble elements

Table-3: Elemental concentration data for selected elements from sequential leaching experiments from Sindh coalfield samples.

Elements	Pb	Zn	Cu	Ni	Cr	Cd	Co	Fe	Mn
Original concentration (mg/ kg) Sindh coal feed	29	41	19	37	13	0.22	3	4895	0.45
Percent leached by CH_3COONH_4 Sindh coal feed	0	1	0	5	1	0	1	0	10
Percent leached by HCl Sindh coal feed	80	40	80	20	10	80	40	10	80
Percent leached by HF Sindh coal feed	10	10	10	5	10	10	5	10	5
Percent leached by HNO_3 Sindh coal feed	10	15	10	5	10	10	5	60	5
Percent unleached Sindh coal feed	0	34	0	65	69	0	49	20	0

Note: Original concentration (in mg/kg) are presented on a whole-coal basis; solvent data presented in percent leached by each solvent.

Table-4: Modes of occurrence data for selected elements for feed coal samples from Sindh coalfileds.

Elements	Exchangeable cations, water soluble compounds	Pyrite and other disulfides	Silicates	Carbonates, arsenenates, iron oxides, monosulfides, phosphates and sulfates	Organic association or insoluble and shielded minerals
Pb	0	10	10	80	0
Zn	1	15	10	40	34
Cu	0	10	10	80	0
Ni	5	5	5	20	65
Cr	1	10	10	10	69
Cd	0	10	10	40	40
Co	1	5	5	40	49
Fe	0	60	10	10	20
Mn	10	5	5	90	0

Note: Mode of occurrence data presented in percent leached by each solvent's compounds and (or) mineral association. NH4 = water soluble compounds, some carbonates, and elements bonded onto exchangeable sites; HCl = carbonates, iron oxides, monosulfides, phosphates, and chelated organic compounds; HF = silicates; HNO_3 = disulfides, especially pyrite.

associated with the organic matter and the insoluble or shield minerals [6]. It is clear from the Tables-3 and 4 that 40 percent or more of the elements Pb, Zn, Cu, Cd, Co and Mn are associated with HCl-soluble compounds (Table-3) such as carbonates, mono-sulfides, oxides, phosphate and sulfates where as more than 30 percent of the elements Zn, Ni, Cr, Cd and Co are associated with insoluble phases or organic shielded matter. 60 percent of Fe is associated with HNO_3 soluble compounds while some portions (5-15 %) of all the elements are associated with HF and HNO_3 soluble compounds including clays and other silicates and pyrite and other disulfides. This suggests that Pb, Zn, Cd and Cu in these coals mainly occur in mono-sulfides or oxides and carbonates whereas Co and Mn generally occur as oxides. Fe is mainly occurring in the form of disulfides (i.e., pyrite and marcasite). Ni and Cr generally occur as insoluble organically shielded matters, while Zn, Co, and Fe also occur as insoluble organically shielded matters.

One of the most serious effects of the underground coal mining has been the escape of polluted water from the coal mine workings. These acid and alkaline waters pollute waterways and surrounding land, rendering the area unusable and sterile. The acid mine drainage is the principal cause of contaminated water arising from coal mining. It results from the exposure of sulfide minerals, particularly pyrite, to water and oxygen during and after mining or in piles of mine waste. The presence of pyrite and marcasite (both FeS_2) as expected in the studied Sindh coalfields can cause severe problems during the mining of these coals due to their reaction with atmospheric oxygen.

These may produce the oxidation products such as ferrous and ferric sulfates, sulfuric acid and hydrated ferric oxide. With the exception of ferric oxide, these products are soluble in water and in turn may react with clays and carbonate minerals to form aluminum, calcium, magnesium and other sulfates. This ferruginous water that flow in the presence of air in mine workings may cause the precipitation of ferric oxide which could result in the extensive red / orange staining of walls and equipments in the underground working and may also cause the contamination of the aquifers of the area. There are also chances that acid drain water in coal mining in the Sindh coalfields may excavange various water soluble toxic organic compounds of the heavy and trace metals and hence contaminate the underground water when the underground mining of these coal deposits will start in full swing in future. The contaminated water may cause various type of diseases in the inhabitants, especially those working in the underground mines and living around the Sindh coalfields. Disease known as Balkan endemic nephropathy, a kidney disease that leads to death, has already been reported in the villages situated on alluvial deposits overlaying the lignite coal elsewhere in the world [7].

The concentration of trace elements in ash is dependent upon particle size. Increasing concentra-tions of trace elements are correlated with the decreasing particle size [4]. The trace elements of the feed coal is variably distributed among the bottom ash, fly ash and flue gas in the power generation plant [8]. The fly ash has relatively high concentration of trace and heavy elements, however, chlorine, chromium, mercury, nickel, selenium and sulfur are in high percentage in the flue gas fraction [4, 8]. By considering the ultimate, proximate and heavy and trace elements, with the exception of sulfur, the Sindh coal, especially the Thar coal fields, can be considered as of good quality as far as its use in the power generation plants or in other industries is concerned. However, relatively high concentration of sulfur and certain heavy metals such as Pb, Zn, and Ni may have environmental problems during mining and combustion processes. There are severe health effects associated with S, Pb, Zn, and Ni in coal mining and combustion. Sulfur dioxide produced during combustion has been used as one of the major indices of air pollution. The major physiological response to SO_2 is one of increased airway resistance and causing lower respiratory tract infection, impairment and irritation of eyes, throat and lungs [9, 10]. Pb, Zn and Ni are the elements of greatest and moderate concern during coal mining to combustion process and should be dealt with seriously [11]. These may predominate in small particles emitted from high temperature combustion sources [12]. The environmental problems related with these particulates in Sindh coals can be overcome if the particulates emission level of the power generation plants, which will be running on these coals in future, should be substantially reduced. In this regard necessary measures should be taken by following the guide-lines proposed by World Bank Group [5].

Experimental

The air-dried coal samples were crushed and pulverized to 200 mesh. A known weight of the powdered coal sample was decomposed by concentrated hydrofluoric acid (HF), concentrated nitric acid (HNO_3) and 3N hydrochloric acid (HCl) in the teflon beaker and the final stock solution of 50 ml volume was prepared by using the method of Jeffery and Hutchison [13]. After preparing the stock solutions of all the coal samples, various heavy, trace and light elements (i.e, Cu, Pb, Zn, Ni, Cr, Co, Cd, Fe, Mn, Ca, Mg, Na, K) were determined in these stock solutions by the Perkin Elmer atomic absorption spectrophotometer after the calibration of instrument with the standard solutions.

For determining the leaching behavior of these coals, four different types of leachates were prepared by leaching the representative mixture of Thar, Sonda and Meting-Jhimpir coals of the Sindh coalfields with IN ammonium acetate, 3N hydrochloric acid, concentrated hydrofluoric acid and 2N nitric acid separately [6]. The mixture of coal sample was agitated separately for 18 hours during leaching [14, 15]. The heavy and trace elements in these leachates were then determined by atomic absorption spectrophotometer.

The proximate analyses (i.e., fixed carbon and ash contents) were performed by using the method Harker [16] whereas the ultimate analyses (carbon, hydrogen, nitrogen and sulfur contents) were deter-mined by EuroVector Elemental analyzer. Calorific values of the coal samples were determined with bomb calorimeter.

All the above experiments were carried out by using the facilities of the Geochemistry Laboratory of the National Centre of Excellence, University of Peshawar, Pakistan.

Conclusions

Thar, Sonda and Meting-Jhimpir coalfields of Sindh have highly variable amount of Cu, Pb, Zn, Ni, Cr, Co, Cd, Fe, Mn, Ca, Mg, Na, K, C, H, N, S, fixed carbon and calorific values. The leaching behavior of these coals suggest that Pb, Zn, Cd and Cu are present in the mono-sulfides or oxides and carbonates and Co and Mn are generally present in oxides while Ni and Cr occur as insoluble organically shield matters in these coals. The probable occurrences of pyrite and marcasite may form oxidation products during underground mining, which ultimately cause environmental problem in mining of these coalfields. Thar coal is relatively of better quality as far as the power generation is concerned. However, Pb, Zn, Ni and S in the coals from Sonda and Meting-Jhimpir coalfields may pose health related threats during mining and combustion of these coals.

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