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Original Research Paper

Assessment of Relationship Between Raw Coal and Effluent Quality of Zarand Washery Plant, Kerman Province, South East of Iran

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ABSTRACT

The present study has been undertaken to assess the relationship between raw coal and effluent quality of Zarand coal washery plant, Kerman province in southeast Iran. Coal samples, raw coal feed, washed fine clean coal and middling were collected. In washing process, raw water (intake to washery) and effluent samples generated in the washeries, namely, fine coal jig under water and tailing pond water were collected during August-September 2009. In coal samples, trace elements were determined in various fractions of Zarand coal washery. Parameters such as pH, temperature, colour, odour, TSS, oil and grease, COD, and trace and heavy metals were measured in washery processing. TSS, COD and oil and grease were very high in water samples. Trace elements like Cu, Ni, Zn, Pb, Cr, Mn and As were found to be present in the process water indicating that these elements are not released by coal during washing.

INTRODUCTION

Coal is inherently a "dirty" source of energy. Row coal contains non-coal minerals that will be released as polluting discharge during washing. Coal washeries have been implicated as one of the major sources of surface and groundwater pollution (Gurdeep Singh 1986, Bandopadhyay 1987, Gupta Ravi & Gurdeep Singh 1993). Washing principal of coal is mainly based on the differences in specific gravity between coal and its impurities, the different processing techniques depend on the washability characteristics of particular coal. Preparation of coal by physico-chemical methods is known washing/beneficiation. The waste characteristics from coal washing plant are highly dependent on raw coal utilized and the final product. With the continuing increasing demand of coking coal in conjunction with the exhaustion of good quality coking coal, especially, d2 to d5 seams in Pabedana coalfield, it has been necessitated to mine lower seams coking coal. Coal washing is a generic term that is used to designate various operations performed on run-of-mine (ROM) coal to prepare it for specific use.

Water is most common medium for transporting crushed material in coal washing plant and hence, most coal separations take place within this medium. Perhaps, the greatest and the most long-standing problem in coal washery is the disposal of effluents which contain a suspension of fine solids (Bandopadhyay 1995). Regulations of government of Iran severely restrict the methods of disposal of effluent loaded with fine material, usually produced in the form of slurry and normally referred to as tailings.

In the present study, we discuss the geochemical characterization of raw coal feed with fine clean coal and middling productions during processing of coal washery and relationships these coals with discharge waters from raw water (freshwater), fine coal jig water and tailing pond water. Finally, assessment of pollution is produced by coal washery in surrounding area.

MATERIALS AND METHODS

Coal, water tailings and water effluent samples were collected from the Zarand coal washing plant during August-September 2009 to study geochemistry of water tailing and relationship between the coal being washed and the effluent being generated. The raw coal samples from coal washery were collected, namely, blended raw coal feed to the washery, washed fine clean coal and middling production. The coal samples were collected from belt conveyors before coal feeding unite in washery plant. Coal samples collected from 3 points raw coal feed with fine clean coal and middling productions. Besides, water samples were collected from the coal washery at three points: feeding (raw water), fine coal jig water, slurry pond water (8 samples). Water samples were stored in 1000mL polyethylene bottles, which were rinsed three times with the water being collected at each site. The bottles were completely filled and capped in the water to avoid contamination. The pH and EC were measured at each site by dipping electrodes directly into the stream. Water samples were transported to the laboratory and stored in refrigeration. The water samples were filtered through 0.45 μm Supor-450 membrane filters. Finally, the filtered water was acidified to pH < 2 with trace-metal-grade HNO_3^- and stored in a dark room until it was analysed.

Parameters outlined in Iran Environment Protection Organization and Zarazma Company in Tehran were determined in both coal samples and water/washery effluent samples to assess the potential pollutants being transferred from the coal being washed to the effluent being generated. Nitrogen and sulphur were assessed in coal samples to relate with the nitrate and sulphate (prescribed in the standard) present in water/effluent samples. Other parameters analysed were colour, odour, total suspended solids (TSS), chemical oxygen demand (COD); total dissolved solids (TDS), acidity or alkalinity (pH), temperature, oil and grease, chloride and heavy metal contaminants.

RESULTS AND DISCUSSION

Relationship between raw coal and effluent: Processing of coal and minerals involves transfer of potential pollutants from one component of the environment to others. This change occurs in water quality during coal beneficiation. Processing results essentially in production of huge quantities of suspended material, beside other pollutants in the effluent generated. Hence, study on relationship between raw coal and effluent from washers is essential.

Physico-chemical characterization of washery effluent: During dry operation of washing process huge amount of coal fines and noncoal mineral matters are generated, which are mixed with process of wet washing and constitute the effluents. Most of the washeries used wet washing process. The wet process in particular and other unit processes in general are responsible for effluent generation. The physico-chemical analysis of washery samples collected from three points (i) raw water (freshwater), (ii) fine coal jig water and (iii) tailing pond water is given in Table 1. Raw water had total suspended solids of 87 mg/L, but the washery effluents had high quantities of suspended solids ranging from 202 to 8410 mg/L in Zarand coal washing plant. Coal being friable in nature, lot of fines are generated during the washing process.

The concentration of suspended solids/fines generated depends upon the washing operation of the coal being subjected. In fine coal jigs, the coal is subjected to abrasive forces that generate maximum fines observed in coal washing. In waters from the fine coal jig in the washery, the concentration of suspended solids were 8410 mg/L. The tailings from the coal washery are pumped to settling/slurry ponds, in which all the fine solids gradually settle and reasonably clear overflow water is discharged into a natural water course. The concentration of suspended solids in the slurry pond varies depending upon the settling rate. In the present study, it was found to be 202 mg/L in Zarand coal washery. The over flow from settling ponds at times contains huge amount of fines. This may be either due to inadequate retrieval or due to retrieval before complete sedimentation takes place in the tailing pond. Thus, along with the drainage from the slurry ponds also at times contributes to pollution of the natural water course. Hence, an attempt is made in the washeries to maximize water recycle in order to reduce the quantity of effluent discharged outside.

The other technology used to remove suspended material is mechanical dewatering and sedimentation. For this, thickeners are used which play the dual role of clarifying process water and thickening of fines as described earlier. The underflow from the thickener is pumped to vacuum or pressure filters, centrifuged and finally to the setting ponds. Dissolution of minerals or salts can significantly affect the properties of water. Some minerals and salts, such as chlorides and sulphates of the alkali and alkaline earth metals, readily dissolve in water and thus can significantly affect the pH (Osborne 1988). The increasing of pH was observed in Zarand coal washery, the pH was seen to come down from 7.2 (that of raw water) to 8.12 (that of tailing pond water) (Table 1). When NaOH is added in the flotation cell, the slurry is subjected to a pH increase. Such changes in pH can cause precipitation of metal species which affects the flotation behaviour of the particles. The concentrations of dissolved Fe, Al, Ca and Mg decrease as the pH is increased, with the mode of alkali addition being irrelevant. As the pH increases during coal processing, there will be precipitation of metal ion species, whereas if the pH decreases, there will be dissolution of mineral species. Temperature varies from 25.5°C in raw or freshwater to 26.7 °C in tailing pond water, the relative increase can be due to intense interaction between raw coal and water during coal washery processing. However, temperature is not exceeded 5°C above the receiving temperature in three points, raw water, fine coal jig water and tailing pond water.

Oil and grease content was observed from below detection limit (raw or freshwater) to 15.89 mg/L, and it was generally exceeded the permissible limit of 10 mg/L. Increasing of oil and grease can be due to distribution of these materials as a collector and co-collector for hydrophobe suspended material in flotation process unit of coal washery plant.

Trace and major elements: The term 'trace elements' refers to chemical elements present in a natural material at concentration < 0.1% wt, besides the minor elements (0.1-1% wt) and the major elements (> 1% wt). A sub-class of trace elements is the 'heavy metals' such as Cd, Pb, Hg, Zn and Cu with a density of approximately 5000 kg/m^3 or higher. However, besides the reduction of mineral matter in coal,

Table 1: Water quality characteristics at various sampling stations of Zarand coal washery.

Parameter	Raw water	Fine coal jig water	Tailing pond water	Below detection limit	MOEF-Schedule VI Class standards
Colour and odour	Acceptable	Acceptable	Acceptable	-	Acceptable
Total suspended solids	87	8410	202	< 5.0	100
pH	7.2	7.7	8.12	< 0.01	5.5-9
Temperature (°C)	25.5	26	26.7	-	Shall not exceed 5°C above the receiving temperature
Oil and grease	BDL	8	15.89	< 1.0	10
COD	65	849	302	< 25.0	250
Arsenic	BDL	BDL	0.004	< 0.005	0.2
Mercury	BDL	BDL	BDL	< 0.001	-
Lead	0.004	0.004	0.005	< 0.0005	0.1
Cadmium	BDL	BDL	BDL	< 0.0005	2
Chromium	0.005	0.006	0.007	< 0.0005	2
Copper	0.01	0.01	0.012	< 0.001	3
Zinc	0.05	0.07	0.08	< 0.001	5
Selenium	BDL	BDL	BDL	< 0.001	0.05
Nickel	BDL	BDL	BDL	< 0.001	3
Fluoride	0.36	1.05	1.25	< 0.05	2
Manganese	BDL	0.6	0.5	< 0.05	2
Iron	0.89	0.89	0.97	< 0.001	3
Nitrate nitrogen	0.43	0.66	0.79	< 0.01	10
Sulphate	57	155.3	141.25	< 0.5	1000
Chloride	41	99	74.44	< 0.2	-
Calcium	126	418	509	< 0.05	-
Magnesium	174	393	200	< 0.01	-
Sodium	190	345	350	< 0.01	-
Potassium	12.5	15.66	18.82	< 0.05	-

All parameter in mg/L unless specified, BDL = below detection limit, MOEF = Ministry of Environment and Forest of India

the concentration of several trace elements was found to decrease through the beneficiation process (Swaine 1990).

Trace elements are generally decreased by beneficiation, the extent being variable for different elements and coals. In general, those elements associated with the mineral matter are more readily removed than those that are mainly organically bound. In commonly used coal washing methods, many trace elements are concentrated in the heavy fraction (sink). Thus, although it is advantageous to remove some trace elements, especially those of environmental significance, from some coals, which can lead to increasing concomitant materials in the rejects of washing process. Extensive studies have been carried out in the US (Karr 1978) and in India also (Banerjee et al. 2000) to show the distribution of trace elements in various specific gravity fractions of coal.

The problem of release of metals from coal into water has been reported in earlier studies. The metals reported in coal were Al, Ca, Co, Cu, Fe, Mg, Mn, Ni, Pb and Zn. When the metals are listed in order of leaching rate the following series emerged - Mn>Ca>Mg>Zn>Pb>Fe>Ni>Cu>Co>Al (Vlado 1983). In the present study, amongst the parameters analysed, the maximum value was observed for Fe (0.97 mg/L) in tailing pond water. Similar results were also reported by Arora et al. (2006).

In coal samples collected, the concentration of iron vary from 6500 mg/kg in fine clean coal sample to 16750 mg/kg in raw coal feed to the washery which have highest concentration of trace elements. The concentration of calcium varies from 3100 mg/kg in fine clean coal sample to 8944 mg/kg in middlings. The concentration of magnesium varies from 842 mg/kg in fine clean coal to 3280 mg/kg in raw coal feed to the washery. The content of sodium varies from 618 mg/kg in fine clean coal to 2180 mg/kg in raw coal feed to the washery. The concentration of potassium varies from 117 mg/kg in fine clean coal to 514 mg/kg in raw coal feed to the washery.

The values of sodium, potassium, calcium and magnesium were also in the range of 117 mg/kg (K concentration in fine clean coal of Zarand washing plant) to 8944 mg/kg (Ca concentration in middlings of Zarand washery). The concentration of manganese was in the range of 84.30 (fine clean coal) to 135.78 mg/kg in raw coal feed to the washery (Table 2). Hence, metals contents in coal are Fe>Ca>Mg>Na>K>Mn>Zn>Cr>Pb>Cu>Ni>As>Hg>Se>Cd. Relationship between Na, Ca, K and Mg elements in coal samples collected from different points of coal washing plant show Na,

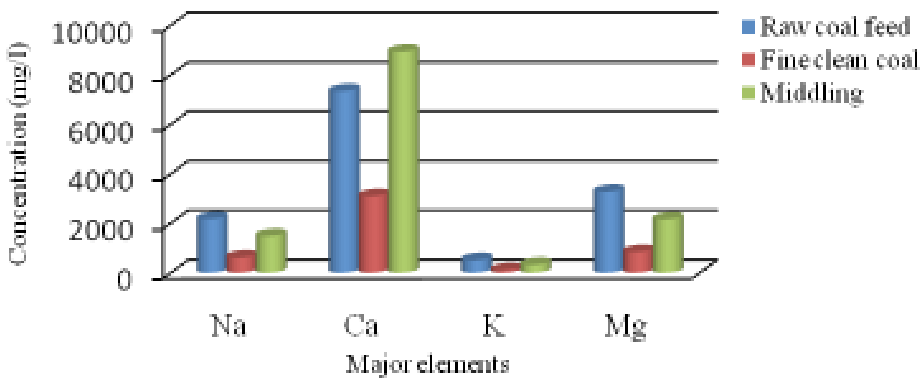

Fig. 1: Major elements analysis of coal samples collected at different stages of coal washing plant.

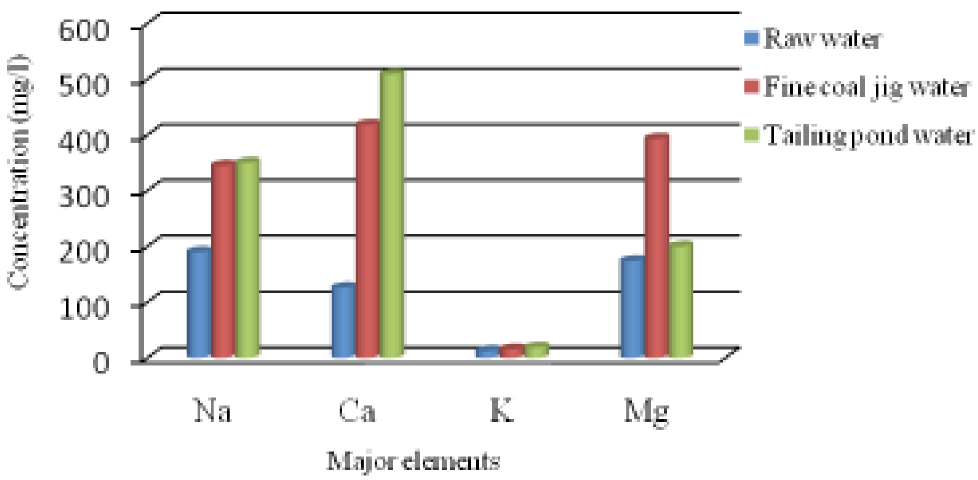

Fig. 2: Major elements analysis of water samples collected at different stages of coal washing plant.

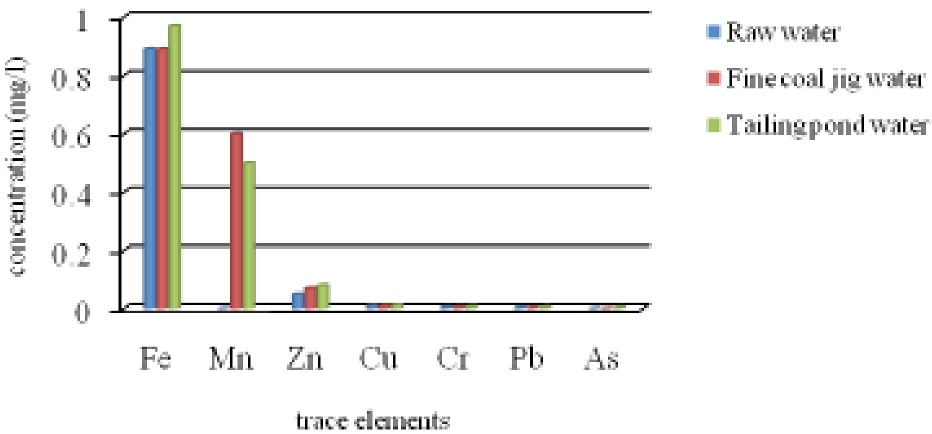

Fig . 3: Trace elements from water samples collected at different stages of coal washing plant.

Table 2: Trace elements in coal samples of Zarand coal washery.

Sl. No.	Parameters	Raw coal feed to the washery	Fine clean coal	Middlings
1	Manganese	137.78	84.30	101.24
2	Copper	29.04	12.20	12.40
3	Nickel	17.23	11.05	10.13
4	Zinc	84.5	51.72	53
5	Lead	29.42	14.40	24.30
6	Chromium	33.71	25.60	25.25
7	Cadmium	0.26	0.08	0.15
8	Arsenic	3.22	BDL	BDL
9	Selenium	1.05	0.88	0.85
10	Mercury	1.25	0.96	0.96
11	Sodium	2180	618	1490
12	Potassium	514	117	331
13	Calcium	7350	3100	8944
14	Magnesium	3280	842	2165
15	Iron	16750	6500	13490
16	Sulphur	0.88	0.65	0.68
17	Chlorine	0.14	0.08	0.1
18	Phosphorus	0.05	0.05	0.05

All parameter in mg/kg, BDL = below detection limit

K and Mg contents decrease in middlings except of Ca (Fig. 1). The metals in tailing pond water are listed in order of leaching rate, and the following series emerged: Ca>Na>Mg>K>Fe>Mn>Zn>Cu>Cr>Pb>As. Other metals in tailing water were below detection limit. Na, Ca, K and Mg elements in water samples collected from different points of coal washing plant show Na, K and Mg elements during water process increased in tailing pond water (Figs. 2 and 3).

The concentration of magnesium was found to be more in the process water than the concentration found in the raw intake water. Magnesium present in raw water intake in Zarand washery was < 0.02 mg/L, whereas in process water, i.e., in effluent from the fine coal jig, it was 393 mg/L, in effluent from the tailing pond water it was 200 mg/L, which is higher than the permissible limit of 100 mg/L. The concentration of sodium varies from 190 mg/L in raw water to 350 mg/L in tailing pond water (Table 1). Calcium content varies from 126 mg/L (raw water) to 509 mg/L (tailing pond water). The concentration potassium varies from 12.5 mg/L (raw water) to 18.82 mg/L (tailing pond water). Sodium, calcium and potassium in coal have also been found to dissolve in water (Orhan 1994). Thus, Na, Ca, K and Mg contents in the process water of coal washery were also higher than those present in the raw water intake of Zarand coal washery.

Fluoride: The concentration of fluoride in case of Zarand washery was higher in the process water. There is maximum concentration of fluoride in tailing pond water (1.25 mg/L). Fluorapatite and fluorine may be present in some coals.

Clay minerals kaolinite, illite and montmorillonite may contain varying amounts of fluorine. Reduction in the concentration of fluorine has been confirmed in washed coal samples from different seams (Swaine 1990). However, the fluorine in coal samples collected could not be assessed.

Sulphate and chloride: The concentration of sulphate and chloride was much higher in the process water. The sulphate content varies from 57 mg/L (raw water) to 155.30 mg/L (fine coal jig water). The concentration of chloride varies from 41 mg/L (raw water) to 99 mg/L (fine coal jig water) in Zarand coal washery. Chlorine is probably organically and inorganically bound to coal (Swaine 1990). The inorganic chlorides are slightly water-soluble and their removal during preparation is dependent on size of coal, Cl content of the original coal and wash water, and the duration of washing. Freshwater flushing of coal is generally effective for Cl reduction (Vlado 1983). The increase of values in the process water may be due to minerals and salts present as chlorides and sulphates of the alkali and alkaline earth metals, which readily dissolve in water (Leonard 1979).

CONCLUSION

Coal being friable in nature, lots of fines are generated during the washing process which increase the turbidity, total suspended solids (TSS), chemical oxygen demand (COD) and also oil and grease. These parameters are very high and exceed of permissible discharge limit. Major elements in coal namely Na, Ca, K and Mg and minor elements in coal namely Mn, F, SO_4 and Cl were found to be higher in concentration in process water than in raw water indicating that these elements are transferred from coal to the water in washeries. Trace elements such as Cu, Ni, Zn, Pb, Cr, Mn and As were found to be present in the process water, besides Fe, which is a major element. Heavy metals like Hg, Cd and Se, though found to be present in coal, were absent in the process water indicating that these elements are not released by coal while washing and thereby will not cause water pollution. The pH of the process water was found to be higher than the raw water.

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