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An Assessment of Cleaning Amenability of Salt Range Coal Through Physical Cleaning Methods

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Abstract. Representative coal samples from the eastern salt range (Modern Engineering and Kishor coal mines, Pakistan) and the central salt range (Punjmin coal mine, Pakistan) were collected and examined for their chemical composition. The chemical characteristics indicate that the salt range coal belongs to sub-bituminous category. Washability analysis on selected coal samples (6.70 × 0.212 mm) using zinc chloride solution with a specific gravity from 1.3 to 1.7 were executed. The results classify the central salt range coal as easily washable while, the Eastern salt range coal as moderately difficult to wash. Jigging, shaking table and spiral techniques were applied to check the cleaning amenability of the salt range coal through these techniques. Among these techniques, shaking table revealed the most promising results for all the three coals. Punjmin coal showed the maximum rejection of ash of 55% and that of total sulphur of 74% with a recovery of 46%.

Keywords: coal washability, physical processing, gravity concentration, salt range coal, coal cleaning

Introduction

Coal is black or dark black combustible rock that contains carbon, hydrogen, oxygen and smaller amounts of sulphur, nitrogen and other trace elements in chemical combination. It is the single largest source of energy for the world economy (Sanders *et al.,* 2002). Coal not only plays an important role in fulfilling the energy requirements of the world, but is also traded in huge volumes for use as a fuel in cement industry and many other industries like fertilizer, glass and ceramic, sugar and brick firing etc. It is also used as a source of domestic heating and as a source of production of coke which is extensively utilised as reducing agent in metallurgical processes (Nawaz *et al.,* 2009).

Chemical properties and heating value of coal have prime importance in the end use of coal. High ash and sulphur contents in coal create problems in terms of slagging and fouling, clinker formation and corrosion of equipment due to SO_2 production during combustion of coal in boilers. Presence of large amounts of ash in coal produce slag along walls of furnace and around burner regions which reduce the heat transfer to water wall and cause damage to the burners (Hatt, 1990; Hatt and Rimmer, 1989). The use of poor quality coal as an energy source also create environmental problems due to emission of harmful gases such as CO_2 and SO_2 which in turn, causes global warming and health problems (Oteyaka *et al.,* 2008).

Salt Range coal is characterised by large amount of mineral matter especially pyrite, which restricts its use in power generation and local industry. Most of the salt range coal is consumed in brick making sector for the benefit of construction industry. In order to use it in power generation, cement industry and other manufacturing industries, there is a need to clean it from impurities.

Washability analysis is generally required to assess the liability of coal for cleaning and for the design and optimisation of coal processing plants as well as for monitoring coal preparation plant performance (Callen *et al.,* 2008; 2002). Galvin (2006) reviewed various techniques available for acquiring coal washability data, including float-sink, water fluidisation, jigging, water pycnometry, displacement pycnometry, and *in-situ* measurement of partition curves. Image analysis and release analysis are also gaining inspiration in determining washability characteristics of fine coal (Adel and Wang, 2005).

Normally, sink-float tests are carried out in the laboratory on the representative coal samples to generate useful information relating to amenability of coal cleaning. Washability curves are usually drawn to anticipate the theoretical yield and ash contents of clean coal at different specific gravities (Majumdar and Barnwal, 2004). The

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basic coal washability technique, float-sink technique involve the use of dense medium (organic liquid, salt solution or suspension). Several issues need to be addressed while selecting a dense medium including occupational safety, health, recoverability, chemical interaction and economy (Galvin, 2006). Salt solutions such as zinc chloride offer noteworthy advantages in terms of toxicity, safety, health and environmental standards.

Today various physical cleaning techniques like gravity concentration, flotation, electric and magnetic separation and oil agglomeration, are in use for the beneficiation of coal (Chen, 1998). Among these, gravity concentration processes enjoy the advantages of being cheaper, simple in operation and convenient (Shahzad, 2012) and are used extensively for coal cleaning (Wills and Napier-Munn, 2006). Gravity concentration entails a variety of techniques such as water-only cyclone, dense medium separators, jigs, shaking tables and spirals etc.

Jigs are primarily used for coarser size particles, in which a bed of particles is pulsated with a current of water, resulting in the assortment of particles on the basis of different densities (Xie and Kawn, 2004). Peng *et al.* (2002) have enlisted various modern jigging units. They applied packed column jig for the cleaning of coal in the size range from 1.18 mm to 150 μm which produced a clean coal concentrate corresponded to 90-98 % ash rejection with combustible material recovery of 75-85%. Shaking tables operate within the size range of – 5 mm to 0.5 mm (Anastassakis, 2004) while spirals are normally applicable for cleaning 1 × 0.15 mm fraction of coal feed (Honaker *et al.,* 2007). Cicek *et al.* (2008) found shaking table efficient at 15% and higher ash ratios.

The aim of this study is to evaluate the cleaning amenability of coal of selected areas of salt range through washability analysis and gravity concentration techniques including jigging, shaking table and spiral.

Materials and Methods

Coal samples. Representative coal samples, which weighed above 50 kg each, were collected from three Pakistan coal mines: (i) Modern Engineering, (ii) Kishor and (iii) Punjmin. Modern Engineering and Kishor coal mines are located in the eastern salt range in the areas of Ara and Mahinwal-Basharat, respectively while Punjmin coal mine is situated in the area of Badhrar in the central salt range (Fig. 1). The head sample of each coal mine was crushed to minus 18 mm using laboratory scale Denver Jaw Crusher and mixed properly.

Equipment. Jigging tests were carried out by using laboratory scale Denver coal Baum jig while the tabling tests were performed on a Wilfley laboratory scale shaking table. Spiral tests were conducted on Humphrey coal spiral.

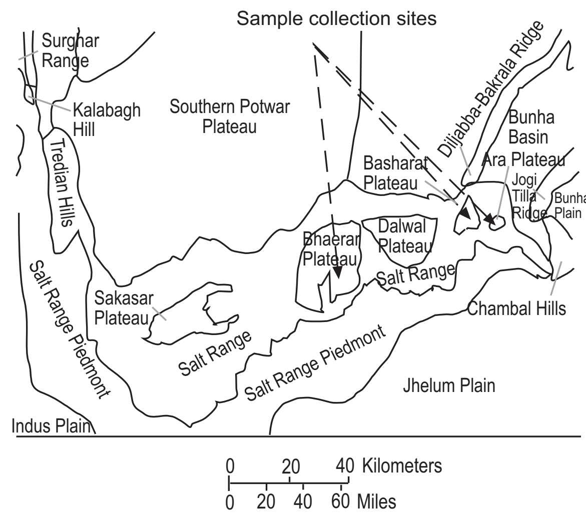

Fig. 1. Location map of sample collection mine sites: Modern Engineering coal mine (Ara), Kishor coal mine (Basharat) and Punjmin coal mine (Badhrar). (Source: Warwick, 2007).

Results and Discussion

Proximate analysis. One coal fraction of each coal mine was ground to - 0.150 mm using disc mill and proximate analysis (ASTM D 3173, 3174, 3175) were carried out on these powdered fractions. Total sulphur was determined by using Eschka method (ASTM E 775-87). Calorific values were determined by using Bomb calorimeter. The results of proximate analysis are presented in Table 1. These results categorize Modern Engineering and Punjmin coal to sub-bituminous C class, while Kishor coal to sub-

Table 1. Results of proximate analysis of Modern Engineers, Kishor and Punjmin coal

Properties	Modern Engineering coal	Kishor coal	Punjmin coal
Specific gravity	1.43	1.49	1.38
Moisture contents (%)	4.5	3.7	4.7
Volatile matter (%)	38.6	40.2	28.7
Ash contents (%)	25.0	25.5	26.0
Fixed carbon (%)	31.9	30.6	40.6
Sulphur contents (%)	4.139	5.071	9.336
Calorific value (Kcal/kg)	5266.00	5435.00	4753.00

bituminous B class (ASTM D 388). The results also show that all the three coals contain higher amounts of ash and sulphur in them.

Sink-and-float tests. A representative sample from each product with a particle size range from 0.670 to 0.212 mm was subjected to float-and-sink test. Zinc chloride solution was prepared and used as heavy medium with specific gravities of 1.4, 1.5, 1.6 and 1.7. The results of washability analysis for Modern Engineering, Kishor and Punjmin coals are presented in Fig. 2-4, respectively. Three other related curves, namely: clean coal curve for ash and sulphur and specific gravity/yield curve are also drawn along with primary washability curve for these three coals.

According to coal washability data established for Modern Engineering coal, clean coal with 16 % ash, 2.65 % sulphur and 70 % recovery can be obtained at a medium specific gravity of 1.57. Similarly, for Kishor coal, 17 % ash and 3.30 % sulphur can be acquired with theoretical clean coal recovery of 80 % at a specific gravity of 1.51. In case of Punjmin coal, the values of ash, sulphur and weight recovery of clean coal at a specific gravity of 1.54 were found to be 8, 2.40 and 70 %, respectively.

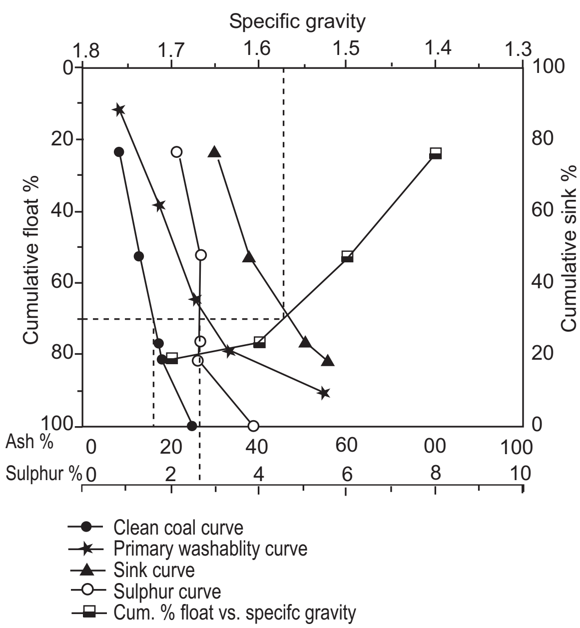

Fig. 2. Washability curves for Modern Engineering coal.

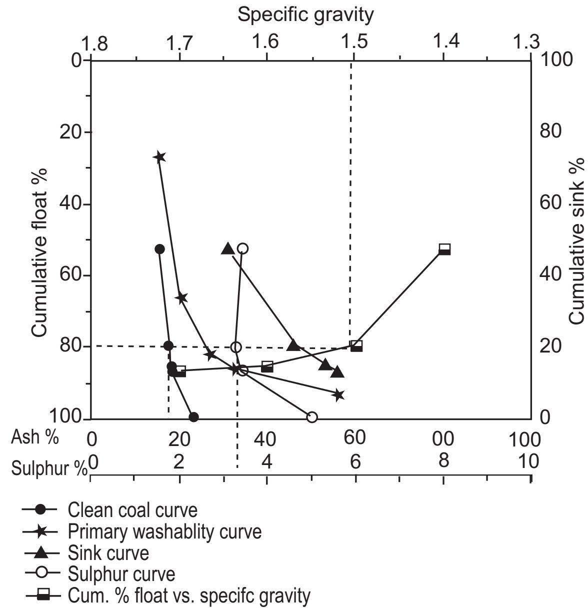

Fig. 3. Washability curves for Kishor coal.

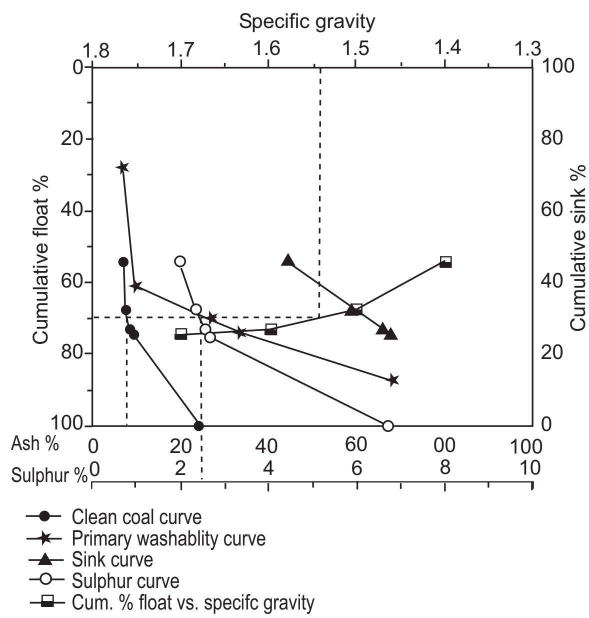

Fig. 4. Washability curves for Punjmin coal.

Generally, the ease or difficulty of washing of coal is judged by the shape of primary washability curve. The more the shape approximates the letter L, the easier the cleaning process will be (Lin *et al.,* 1999). According to washability curves drawn for salt range coal, Punjmin coal is found to be easily washable while Modern Engineering and Kishor coals can be classified as moderately cleanable coals.

Moreover, it is also shown by the clean coal curves for sulphur that most of the sulphur of Punjmin coal is associated with mineral matter, probably in the form of pyrite. In case of Modern Engineering and Kishor coals, it appears that a certain portion of sulphur is attached with the mineral matter while, relatively larger portion of it is bound to organic material in the form of organic sulphur.

Gravity concentration tests. Gravity concentration techniques including jigging, shaking table and spiral were employed to check the cleaning susceptibility of the salt range coal. The feed size was kept in the range of -1.18 + 0.60 mm, - 0.833 + 0.295 mm and – 0.600 + 0.212 mm for jigging, shaking table and spiral, respectively. The solid concentration for the jigging and shaking table operation was kept at 35% while it was maintained at 40% for the spiral concentrator. Water flow rate for jig, shaking table and spiral was managed at 15, 8 and 20 gallon/min, respectively. The speed and stroke length of the shaking table was maintained at 260 strokes/min and 20 mm. The slope (length) and tilt (cross) of the shaking table were kept at 15 mm and 20 mm, respectively. The average values of ash, sulphur and weight recovery of the concentrate obtained from gravity concentration tests are presented in Table 2.

Table 2. Results of gravity concentration tests conducted on Modern Engineering, Kishor and Punjmin coal samples

Concentration techniques	Concentrate Average (%)		Concentrate Rejection (%)		Average recovery
	Ash	Sulphur	Ash	Sulphur	
Modern Engineers coal					
Jigging	17.7	2.781	29.2	32.82	31.89
Shaking table	16.8	2.621	32.8	36.67	45.43
Spiral	20.7	3.772	17.2	8.87	5.71
Kishor coal					
Jigging	22.3	4.951	12.55	2.36	64.03
Shaking table	20.7	4.337	18.82	14.47	74.58
Spiral	23.1	3.957	9.41	21.97	10.22
Punjmin coal					
Jigging	13.2	2.456	49.23	73.7	11.81
Shaking table	11.7	2.43	55	73.98	46.27
Spiral	14.9	2.369	42.69	74.63	10.67

In case of jigging tests, maximum rejection of ash of 49.23 % and that of sulphur 73.70 % was observed for Punjmin coal but recovery was very low. Modern Engineering and Kishor coal exhibit average weight recovery of 31.89 and 64.03 % with ash rejection of 29.20 and 12.55 % and elimination of sulphur of 32.82 % and 2.36 %, respectively.

The results of tabling tests revealed the elimination of ash 32.80, 18.82 and 55.0 % and that of sulphur 36.67, 14.47 and 73.98 % with average weight recovery of 45.43, 74.58 and 46.27 % for Modern Engineering, Kishor and Punjmin coal, respectively.

The results of spiral tests indicate that the recoveries for all the three coals remained very low. Punjmin coal showed maximum rejection of ash (42.7%) and that of sulphur (74.63%) while these values were less for Modern Engineering and Kishor coal.

Conclusion

Following conclusions can be drawn from this study:

1. Salt range coal contains higher amounts of ash and sulphur which make it unsuitable for use in cement industry and power generation.
2. Washability analysis revealed that the Eastern salt range coal (Modern Engineering and Kishor) was found to be moderately difficult to wash while the central salt range coal (Punjmin) was classified as easily washable coal.
3. Shaking table was found the most promising one among the three gravity concentration techniques (jig, shaking table, spiral) for all three coals for the rejection of ash.
4. Spiral was observed to be more efficient than shaking table and jig for the removal of sulphur for Kishor coal and Punjmin coal.
5. Punjmin coal can be used in local cement industry after cleaning through gravity concentration process. In order to use it for power generation, further cleaning of sulphur is required. For this purpose, a combination of shaking table and spiral may prove fruitful.
6. Modern Engineering and Kishor coal need more attention in terms of cleaning prior to their use in local cement industry. Special considerations with respect to their beneficiation are required for their use in power generation.

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