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Up-gradation of the local coal of Cherat area, Khyber Pakhtunkhwa, for cement industry

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Abstract

Every passing day prices of furnace oil and natural gas are increasing, so coal is getting importance especially in Pakistan in the current scenario of energy shortage. Cement industry is also a big consumer of coal. Only 10 percent of the total demand of cement industry is being fulfilled by local coal while remaining 90 percent is imported from foreign countries in Pakistan. About 2.5 million tons coal is being imported per year because our local coal possesses higher values of sulfur and ash, thus causing wastage of foreign exchange. Froth flotation, hydrocyclone classification and pneumatic classification methods are mostly applied for coal washing/up-gradation. These methods were adopted in present research to upgrade indigenous coal. In the raw coal ash content was observed to be 45.01% and sulfur content was 3.86%. After analyzing the test products it was found that the results of Froth flotation process were more encouraging than the hydrocyclone and pneumatic classifications. Froth flotation test results show higher reduction in sulfur and ash, give maximum calorific value along with higher percent recovery of upgraded coal. Ash reduction in Froth flotation, hydrocyclone and pneumatic classifications is 44.78%, 35.16% and 19.73% respectively. Sulfur reduction in Froth flotation, hydrocyclone and pneumatic classifications is 44.48%, 29.41% and 14.80% respectively while the recovery of upgraded coal is 40.35% in the case of froth flotation, 30.25% by hydrocyclone classification and 23.64% by pneumatic separation.

Keywords: Froth flotation; Hydrocyclone classification; Pneumatic classification; Ash; Sulfur; Coal recovery.

1. Introduction

There are vast resources of coal in all four provinces of Pakistan and in Azad Jammu and Kashmir. Locations and names of major coalfields and coal occurrences of Pakistan are given in Table1. According to rough estimates, the total coal resources of Pakistan are more than 186 billion tonnes. Coal reserves, together with heating values (as on moisture mineral matter free basis), of all the four provinces and Azad Kashmir are shown in Table 1.

The detail of the Khyber Pakhtunkhwa coal reserves are shown in Table 2.

Cherat Coalfield is located in district Nowshera having coal reserves of 7.74 million tonnes. In past literature, coal in Cherat area was placed in Patala Formation, however it is now considered in the Hangu Formation. The coalfields of this area are Shah Kot, Shekhai, Jabba Khattak, and Bakhtai in Cherat Range. Here, the sulfur is for the most part pyritic with some organic sulfur. Coal is connected with calcareous argillites, demonstrating lagoonal environment (Malkani, 2012).

For the local coal to be utilized in cement industry the sulfur and ash need reduction to 1 percent and 15 percent respectively. Cement

Table 1. Coal reserves of Pakistan and Azad Kashmir (Malkani, 2012).

Province	Reserves in million tonnes	Calorific value (btu/lb)
Sindh	185457	5219-13555
Baluchistan	459	9637-15499
Punjab	235	9472-15801
KPK	122.99	9386-14217
AJK	8.72	7336-12338
Total	**186282**	

Table 2. Khyber Pakhtunkhwa coal reserves (Malkani, 2012).

S.No	Coal field	Reserves in million tonnes
1	Hangu/Orakzai	81
2	Cherat	7.74
3	Gulakhel	30
4	Shirani	0.5
5	Dar Adam Khel	3.75
Total		**123**

properties and its manufacturing process are severely affected due to high sulfur and ash contents of coal. Portland cement contains $3CaO.SiO_2$ (50-70%), $2CaO.SiO_2$ (20-40%), $3CaO.Al_2O_3$ (3-17%) and $4CaO.Al_2O_3F$ (5-15%). These are the constituents of lime stone i.e. the raw material of cement. Coal sulfur and ash; however upset this composition thus restricting the use of coal in cement manufacturing process.

Sulfur varies in coal depending upon the depositional conditions of coal beds. Coal containing less than 1% sulfur is contributed by parent plant material. Coal having sulfur 1 to 3% is considered as high sulfur coal. High sulfur in coals comes from two major sources (i) sulfate of sea water which flooded peat swamps (ii) Parent plant material (Chen-Lin, 2012). Pakistan cement industry has high potential for converting to use coal as a fuel. However Pakistani coals have high ash contents, so low heating values along with significantly high sulfur contents (in the range of 5 to 6 percent), thus poses problems to the local cement industries (A., 1884). High quantity of ash (non-combustible minerals) present in the coal disturbs the clinker required composition. Operational problems are created by high sulfur i.e. encrustations of sticky hard material coatings in pre-heater. Due to high sulfur content in coal, cement quality is also adversely affected (Huska, 1984).

It is determined in United Kingdom that sulfur emissions are reduced almost 20 to 30% by coal washing. It is of high importance to note that pyritic sulfur in coal can be easily removed by washing techniques. Effective communition of coal makes it further possible to have increased/ high pyrite liberation but question arises that whether or not after the increased operational cost and size reduction the final product will remain marketable (B. Ambedkar, 2011).

Coal burning produces sulfur oxides and there are several methods to control these emissions; some methods are used after the combustion, some during and some before combustion. Flue gas scrubbers are used after combustion to remove sulfur oxides from plant gas emissions. During combustion limestone ($CaCO_3$) is added to the combustor to absorb sulfur oxides (Emad Abkhoshk, 2010).

2. Experimental work

2.1. Materials, methods and equipments used

10 representative samples of weighing 100 kg as a whole and about 10 kg of each were collected in bulk size and compact form from the different location of Shah Kot-1mine at Cherat village, district Nowshera for test work. The 10 samples were crushed, grind, blend and prepared in the size range of -250+90μm. After blending of coal sample the coning and quartering techniques were used to get homogeneous coal sample and the same sample was used in the whole research work.

Different equipment's are used for reduction of ash and inorganic sulfur which include hydro cyclones, jigs, flotation cells, pneumatic classifiers and shaking tables etc. The equipments and testing facilities used in research are presented in Table 3.

Table 3. Equipment and testing facilities used.

S.No	Equipment	Purpose of use	Laboratory/Organization
1.	Jaw Crusher & Roll Crusher	Crushing coal lump samples	Mineral Testing Laboratory, Hayatabad Peshawar
2.	Rod Mill, Model D.R , AMDEL Australia, Sr.No	Grinding of crushed coal to desired size	-------------do-------------
3.	Vacuum Filter Model B52208, Sr. NO 31441, UK.	Dewatering of flotation ,and Hydro cyclone test products	--------------do-------------
4.	Sieve Shaker, Model ACTAGON 200, UK	Sizing of ground ore	--------------do-------------
5.	Denver Laboratory Flotation machine, Model D-12,Process Equipment Limited , England, UK	Flotation Tests	--------------do-------------
6.	PH Meter , Model HI 8424m, Singapore	For PH measurement in flotation	--------------do-------------
7.	Electric Oven , Model A-9VC, UK	Drying the wet sieving and flotation test products	--------------do-------------
8.	Hydro cyclone Classifier KHD Humboldt Wedag AG, Germany	For classification of coal sample	Department of Mining Engineering, UET Peshawar
9.	Pneumatic Classifier KHD Humboldt Wedag AG, Germany	For c lassification of coal sample	Department of Mining Engineering, UET Peshawar
10	Muffle Furnace, Model FM-38, Serial No. 306472R, Voltage AC 220V, Current 9A, Frequency 50Hz, Yamato, Japan	Combustion of coal sample in order to find the moisture, volatile and ash content	Department of Mining Engineering, UET Peshawar

2.2 Analysis of raw coal

The proximate analysis of the raw coal sample was conducted using the air dried basis of analysis and the results presented in Table 4.

2.3 Pneumatic classifier tests

10 samples of 200gm each in the size range -250+90µm were prepared and processed in pneumatic classifier. The pneumatic classifier sort material by utilizing differences in shape, size and density of minerals (Wills, 1992). Coal particles were collected as overflow and refused/ tailings as underflow. Percent ash reductions, percent sulfur reduction, calorific value of overflow and recovery of overflow have been given in Table 5.

2.4 Hydro cyclone tests

10 samples of 200gm each in the size range -250+90 µm were processed in hydro cyclone. The coal sample was fed into hydro cyclone in slurry form of pulp density 20%. The hydro cyclone gave two products i.e. overflow and underflow (tailings) on the basis of difference in shape, size and density of minerals. Percent ash reduction, percent sulfur reduction, calorific value of overflow and recovery of overflow is recorded as shown in Table 6.

2.5 Froth flotation tests

Froth flotation is one of the important beneficiation techniques widely used for the separation of valuable particles from gangue particles based on the phesio-chemical surface properties (Qu et al., 2013; Wills, 1992). The froth flotation techniques is nowadays considered beneficial to use for the processing of coal, because of low capital cost and it gives high recovery as compared to other processing techniques (Murat Erol, 2003). Froth flotation test gives two products i.e float (concentrate) and tailing In case of coal processing, the concentrate particles are hydrophobic in nature and attached to bubbles and start to float while the tailing particles are hydrophilic in nature and accumulate at bottom of flotation cell. The float particles are collected from the surface of flotation cell and the gangue particles collect from the bottom of flotation cell. The recovery in flotation test is a time dependent, means the recovery increases when the flotation time increases since the cumulative recovery of a component in concentrate is proportional to flotation time (Shah and Abott, 2002). Froth stability determines the separation performance of froth flotation such as product grade and throughput (Crawford, 2000; Qu et al., 2013).

Table 4. Analysis of raw coal sample.

Sample Serial no.	Ash Content (%)	Sulfur Content (%)	Volatile Matter (%)	Moisture Content (%)	Fixed Carbon (%)	Calorific Value (btu/ lb)
1	44.67	4.03	16.04	3.84	35.40	8,298.69
2	43.00	3.87	18.13	4.02	34.90	8,187.85
3	44.05	4.41	16.73	3.72	35.70	8,316.45
4	45.10	3.74	16.41	3.12	35.17	8,281.65
5	46.74	4.22	13.20	4.02	36.10	8,325.41
6	46.21	4.10	13.80	3.68	36.25	8,331.52
7	43.15	3.55	17.71	4.47	34.83	8,105.73
8	45.64	3.75	15.54	4.35	34.31	8,091.17
9	44.52	3.97	15.76	3.46	36.22	8,285.52
10	47.04	3.05	14.96	3.17	34.88	8,068.41
Average values	**45.01**	**3.86**	**15.83**	**3.785**	**35.38**	**8,229.24**

Table 5. Results of Pneumatic classification.

Coal Sample Serial no.	Ash reduction (%)	sulfur reduction (%)	Calorific Value (b tu/ lb)	Recovery (%)
1	23.21	19.35	9,613.84	20.30
2	14.53	11.88	9,580.18	23.70
3	15.66	28.79	9,503.21	21.55
4	15.07	4.54	9,409.63	23.75
5	17.84	13.03	9,395.11	26.85
6	25.77	15.85	9,596.47	27.00
7	17.38	3.66	9,561.52	24.00
8	23.09	5.86	9,575.41	22.75
9	21.49	20.15	9,582.73	20.60
10	23.25	24.91	9,571.78	26.25
Average	**19.73**	**14.80**	**9,538.98**	**23.67**

Table 6. Results of hydrocyclone.

Coal Sample Serial no.	Percent Ash reduction	Percent sulfur reduction	Calorific Value (b tu/ lb)	Recovery (%)
1	33.24	31.43	10,092.56	32.34
2	34.85	28.07	10,120.20	24.56
3	31.37	30.67	10,055.24	29.22
4	36.26	29.50	10,201.30	29.55
5	36.82	29.43	10,445.34	33.43
6	37.74	27.05	10,005.67	31.20
7	35.67	30.00	10,567.00	31.43
8	31.54	31.45	10,435.90	30.34
9	36.60	26.45	10,468.50	28.67
10	37.53	30.09	10,314.70	31.80
Average	**35.16**	**29.41**	**10270.64**	**30.25**

Ten flotation tests were conducted on the coal samples having 20% pulp density, and at the following floatation parameters as presented in Table 7.

Percent ash reduction, percent sulfur reduction, calorific value of concentrate and recovery of concentrate are given in Table 8.

3. Comparison with the standard coal used in cement industry

Coal used in the cement industry should not have ash and sulfur more than 15% and 1% respectively. After performing tests on equipment, average values for ash and sulfur have been taken for concentrate/ overflow and compared with coal used in cement industry. Table 9 and Figure 1, Table 10 and Figure 2, and Table 11 and Figure 3, shows difference in values both numerically and graphically for pneumatic classification, hydrocyclone classification, froth flotation respectively. Table 12 and Fig. 4 and shows the comparison of methods used for up-gradation of the coal.

Table 7. Froth flotation process parameters.

Process	**Parameter**	**Reagent Dosage/Value**
Froth Flotation	Feed particle size	-250 +90 µm
	Pulp density	20%
	Conditioning time for reagents	5 minutes
	PH value of the pulp	6 - 7
	Depressant	Nil
	Collector	Kerosene oil, 12 to 15 drops
	Frother	Pine oil, 5 to 6 drops
	Froth collection time	10 minutes

Table 8. Results of froth flotation parameters.

Coal Sample Serial no.	**Percent Ash reduction**	**Percent sulfur reduction**	**Calorific Value (btu/lb)**	**Recovery (%)**
1	42.35	43.90	11,688.12	42.50
2	41.16	45.22	11,732.52	42.00
3	43.92	54.42	11,765.81	40.50
4	44.9	44.65	11,754.33	41.50
5	48.43	50.00	11,805.94	38.50
6	43.17	48.05	11,520.21	46.00
7	45.77	38.60	11,875.72	35.00
8	47.52	44.26	11,831.10	38.00
9	41.37	44.58	11,591.44	44.00
10	49.29	31.15	11,845.12	35.50
Average	**44.78**	**44.48**	**11,741.03**	**40.35**

Table 9. Comparison of standard coal used in cement and pneumatic classification overflow.

	Standard coal used in cement		**Pneumatic classification overflow**	
	Ash (%)	Sulfur (%)	Ash (%)	Sulfur (%)
Average values	15.00	1.00	36.10	3.29

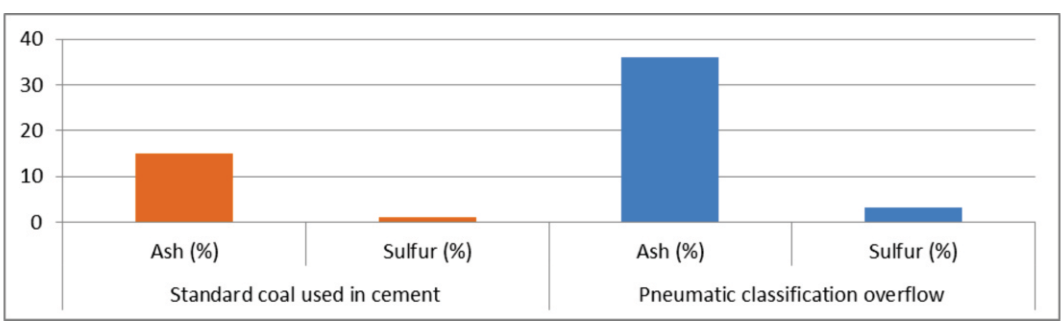

Fig. 1. Comparison of coal used in cement industry and pneumatic classification overflow.

Table 10. Comparison of standard coal used in cement and Hydrocyclone classification overflow.

	Standard coal used in cement		**Hydrocyclone classification overflow**	
	Ash (%)	Sulfur (%)	Ash (%)	Sulfur (%)
Average values	15.00	1.00	29.45	2.73

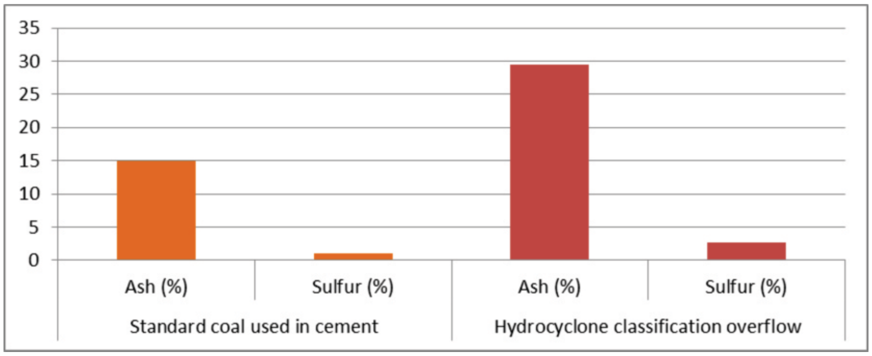

Fig. 2. Comparison of coal used in cement industry and hydrocyclone classification overflow.

Table 11. Comparison of standard coal used in cement and froth flotation concentrate.

	Standard coal used in cement		**Froth flotation concentrate**	
	Ash (%)	Sulfur (%)	Ash (%)	Sulfur (%)
Average values	15.00	1.00	24.82	2.12

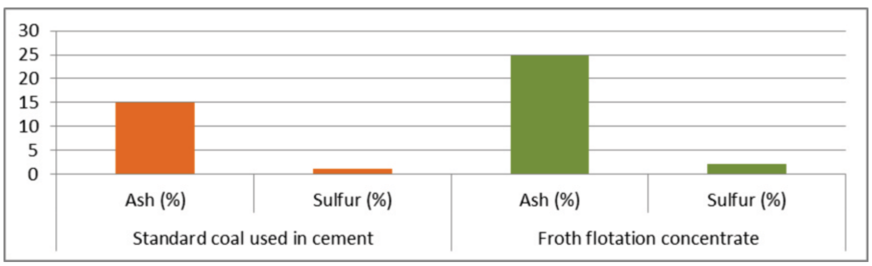

Fig. 3. Comparison of coal used in cement industry and froth flotation concentrate.

Table 12. Comparison of methods used for up-gradation of coal.

Pneumatic classification results			**Hydrocyclone classification results**			**Froth flotation results**		
% Sulfur reduction	% Ash reduction	% Recovery	% Sulfur reduction	% Ash reduction	% Recovery	% Sulfur reduction	% Ash reduction	% Recovery
14.80	19.73	23.67	29.41	35.16	30.25	44.48	44.78	40.35

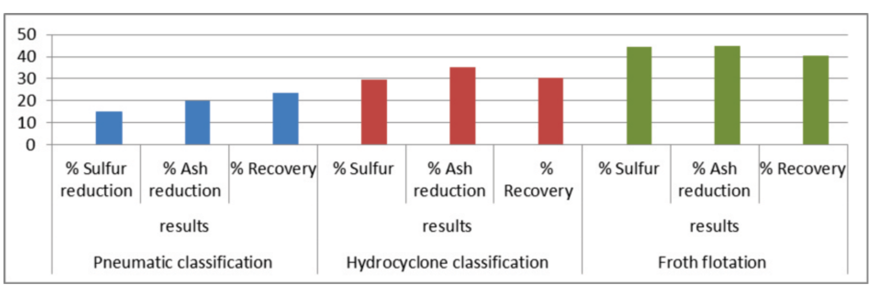

Fig. 4. Comparison of results obtained from methods used for up-gradation of the coal.

4. Conclusions and suggestions

Froth flotation test results show higher reduction in sulfur and ash, maximum calorific value increase and higher percent recovery of upgraded coal as compared to pneumatic and hydrocyclone classification. Ash reduction in froth flotation, hydrocyclone and pneumatic classifications is 44.78%, 35.16% and 19.73% respectively. Sulfur reduction in froth flotation, hydrocyclone and pneumatic classifications is 44.48%, 29.41% and 14.80% respectively while recovery of upgraded coal is 40.35% in the case of froth flotation, 30.25% by hydrocyclone classification and 23.64% by pneumatic separation. It is observed that the calorific value of coal also increases in pneumatic, hydrocyclone classifications and froth flotation respectively but it is highest in froth flotation method.

More improved results can be obtained if tailings are used again in flotation i.e. two or three stage flotation. Comparing these methods on economic basis; further experimental work can be done because in froth flotation the cost of chemicals is high then hydrocyclone and pneumatic classifications where no chemicals were used.

Pulverized coal is used in cement industry which is an additional advantage of adopting froth flotation process for coal washing, where desired feed size is very fine.

References

A., N. S., 1884. Use of Pakistan coals in industry . The first Pakistan national coal conference , 347.

B. Ambedkar, T. C., 2011. Feeasibility of using ultrasound-assisted process for sulfur and ash removal from coal. Chemical engineering and processing , 50, 236-246.

C.L. Shah. J.A. Abott, N. M., 2002. Sulfur reduction evaluation of selected high sulfur chines coal. Fuel , 81, 145-152.

Chen-Lin, C., 2012. Sulfur in coal: A review of geochemistry and origin. International journal of coal geology , 100.

Crawford, J., 2000. Imortance of pulp density, particle size and feed regulation in flotation of coal. Transactions of the metallurgy society of A.I.M.E , 119-150.

Emad Abkhoshk, M. K., 2010. A study on the effect of particle size on coal flotation kinetics using fuzzy logic. Expert system with applications , 37, 5201-5207.

Huska, P.K., 1984. Converting cement rotory kilns to coal firing. The first Pakistan national coal conference , 358.

Malkani, M.S., 2012. A review of coal and power resources of Pakistan. Science, technology and development , 202-218.

Murat Erol, C. C., 2003. The effect of reagents and reagent mixtures on froth flotation of coal fines. International Journal of Mineral Processing, 131-145.

Qu, X., Wang, L., Nguyen, A. V., 2013. Correlation of air recovery with froth stability and separation efficiency in coal flotation. Minerals Engineering, 41, 25-30.

Wills, B. A. 1992. Mineral Processing Technology. (5th Ed.) England: Camborn school of mines.