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ANALYSIS OF DENSE MEDIUM BENEFICIATION OF DANDOT COAL FOR USE IN CEMENT INDUSTRY IN PAKISTAN

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ABSTRACT

This research entails the extent of up-gradation of Dandot coal, using conventional gravity based sink-float separation techniques, to make it techno-economically acceptable for the cement industry as a partial substitution of imported coal. In this research, various sizes of run-of-mine coal samples were subjected to specific gravity based sink-float test and resultant fractions were analyzed. Experimental results of sink-float analysis showed that the size fraction of -50mm to +2mm at a specific gravity of 1.75 produces a product which is techno-economically acceptable and simultaneously qualifies the quality parameters established by the cement industry i.e., Cumulative Yield, Ash and Sulphur of 68%, 14% and 2.82% respectively. The product is suitable for substituting around 40% of the imported coal in the local cement industry that can save substantial foreign exchange i.e., approximately 240 million USD per annum.

Key Words: *Cumulative Yield, Run of Mine, Sink-floats separation techniques, Techno-economical, Up-gradation.*

INTRODUCTION

Coal is a useful fossil fuel that has long been in demand for a variety of household and industrial purposes. Coal washing is a routine process in most of the countries where coal reserves are in abundance. Although Pakistan has one of the largest reserves of coal, but this coal is not being optimally utilized because of its relatively lower grade and inconsistent quality. This is primarily due to non-availability of coal processing and washing industry and secondly, underdeveloped and primitive mining methods in vogue in the country. Coal is mostly used in the power generation and cement industry as a cheaper source of energy. Primarily, cement industry in Pakistan had been using furnace oil and natural gas till the year 2002. However, in order to economize the cement production process, the industry at present is using approximately five to six million tons of imported coal. Pakistan Energy Year Book 2009 (2010) represents the country's current energy mix structure and coal consumption by sector in the following pie-charts (Figures 1 and 2).

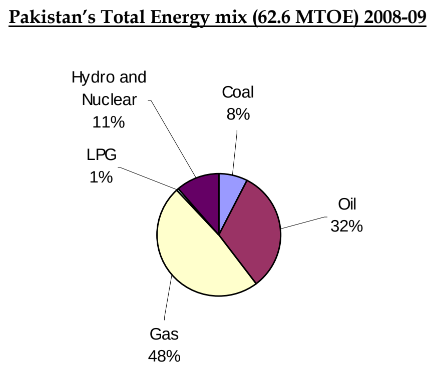


Figure 1: Pakistan's Total Energy Mix

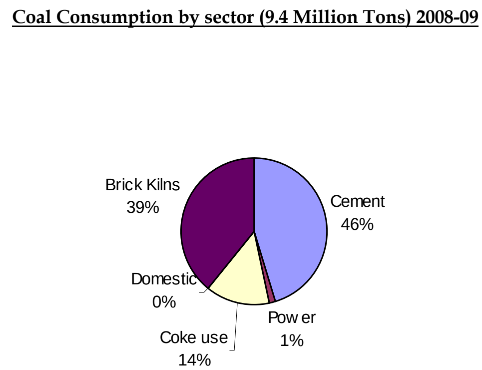


Figure 2: Coal Consumption by Sector

It is pertinent to know that indigenous "Run of Mine" (ROM) coal production of approximately four to five million tons is siphoned to low efficiency primitive brick kiln industry. General chemical characteristics of indigenous coal vary widely due to primitive mining methods i.e., Ash 20-50%, Sulphur 4-10%, Gross Calorific Value (GCV) 3,500-5,000 Kcal/kg. On the other hand, the imported coal that meets the techno-commercial demand of cement industry is processed and contains approx.1.5% Sulphur (dry basis) and Ash content of less than 20% that corresponds to a Gross Calorific Value (GCV) greater than 5,500 Kcal/kg.

Table 1: Coal Reserves of Pakistan

Province	Sind	Baluchistan	Punjab	NWFP	Azad Kashmir	Total
Coal Reserves (Million Tons)	185,457	217	235	90	9	**186,007**

Reference: Pakistan Energy Year Book 2009 (2010)

Substituting imported coal with the processed or consistent quality local coal is of great importance in Pakistan's perspective. Even after having 186 billion tons of coal reserves (Table 1), only 4 to 5 million tons is being mined annually and even this is not utilized by the process industry and is consumed in low efficiency brick kiln industry. Substituting around

40% of imported coal i.e., 2.4 million tons, with local processed or upgraded coal can save substantial foreign exchange i.e., approx. 240 million USD per annum at $100/ton landed cost of imported coal, making country more self reliant in terms of energy. Moreover, local up-graded coal will be available at a minimum of 20% lesser cost as compared to imported on equivalent energy basis, saving approx. 40 million USD per annum only in the cement industry which will increase with the increase in cement production. In order to use indigenous coal in process industry, a proper washing or processing industry is required and also, scientific wash-ability investigation of coal is a prerequisite for evaluating the techno-commercial feasibility of processing industry project. The main problem associated with this coal is the inconsistent and relatively higher total Sulphur and the Ash contents in the ROM coal.

It was found necessary and worth considering to undertake a preliminary study in order to identify the techno-commercial needs of cement industry i.e., in terms of Product Quality Specifications and Yield Requirements, before actually conducting coal Specific Gravity (S.G.) based sink-float analysis. Through cement industry experience of blending local coal with imported, during this preliminary study, it was found that processed coal with Ash content of less than 20%, G.C.V. of less than 5500 Kcal/kg and Sulphur content of less than 3.50% would be the minimum acceptable quality requirement of cement industry to substitute up to 30% of imported coal. With this Sulphur level, total Sulphur in the blend remains below 1.5% as it is obvious in the Table-1. From burner firing to clearance in the kiln and heat transfer cyclones, the operations report was found satisfactory and manageable. Moreover, a Yield of minimum of 65% was envisaged in order to address economic considerations. Additionally, it was found that Sulphur is the most crucial quality parameter that decides the percent substitution of imported coal, as maximum acceptable limit of coal Sulphur is 1.5% at the cement kiln burner. Taking the South African imported coal average Sulphur as 0.70%, various combinations with local processed coal were tried to make Sulphur, in the blended sample, less than 1.5% and the following Table 1.1 represents the calculated possible blending percentages and Figure 3 is the graphical representation of this.

Table 1.1: Various blending ratio options for substituting imported coal with processed indigenous coal

Option	Sulphur (%)		Blending (%)		Sulphur (%)
	Local processed coal	Imported coal (Average)	Local processed coal	Imported coal	Blended coal
1	3.5	0.7	29	71	1.5
2	3	0.7	34	66	1.5
3	2.5	0.7	44	56	1.5
4	2	0.7	60	40	1.5
5	1.5	0.7	100	0	1.5

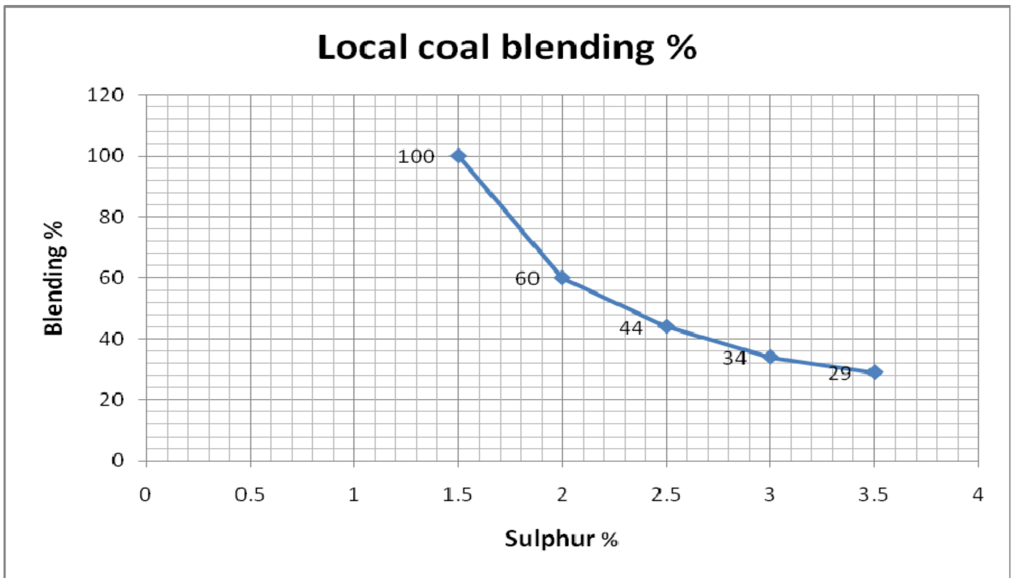


Figure 3: Graphical Representation of Table 1.1

Additionally, it was found that fine coal fraction i.e., -2mm is desirable fuel product for brick kiln industry and can be directly sold to them. Therefore, it was decided to conduct sink-float study of +2mm to 50mm for two reasons i.e., to meet the existing demand of brick kiln industry and to simulate the real situation.

After establishing the required parameters, a full scale detailed sink-float study of various screened fractions of Dandot coal (Punjab, Pakistan) was conducted in order to find out exactly the extent of up-gradation and impact of particle size on liberation properties of impurities. The Coal Beneficiation processes (which are also known as coal up-gradation, coal cleaning, coal preparation or coal washing) are used to enhance certain desirable coal properties by reducing the level of impurities. Fixed impurities (also known as intrinsic impurities) and free impurities (also known as extrinsic impurities) are two types of impurities which occur in coal. Fixed impurities originate from parent coal forming plant and such impurities cannot be separated by coal washing, and coal contains hardly 1% of these impurities by weight, so it does not pose unnecessary problems during coal burning. Free impurities adhere to the surface of coal seam and consist mainly of dirt band and rock properties which can be removed by coal washing.

Various gravity methods of separation are used to clean the coal and exploit density difference between the coal and gangue material. Among the gravity methods of separation, dense media separation is the most efficient process for the removal of impurities from Run of Mine coal. This is because it has the ability to make sharp separations at any required density, with a high degree of efficiency even in the presence of high percentage of near density material. For this, heavy liquids normally organic in nature, having density in between the clean coal and impurities are used. Clean coal having density lower than the liquid will float while impurities having higher density will sink. Wash-ability data obtained after experimentation consists of three variables; density or S.G., Weight Fraction or Yield and Ash content. The cumulative weight and Ash content of float fraction is used to approximate the recuperations of clean coal and gangue at each relative density level.

Liquids of the exact S.G. can be made through various methods. The most common type of liquid used in float or sink testing is the solution of zinc chloride. Nearly all the S.G. values that are needed in coal wash-ability work can be produced by changing the concentration of zinc chloride.

METHODOLOGY

A coal sample of gross weight of around 350 Kg was collected from Dandot area coal mines according to standard sampling procedures (ASTM D 6883). Sample was crushed using a laboratory Jaw Crusher at top size of 50mm. Then complete sample was screened in to five fractions of -50 to +25mm, -25 to +12.5mm, -12.5 to +6mm, -6 to +2mm and -2mm. Sink-float analysis was performed on former four screened fractions (ASTM D4371) using zinc chloride solution of different specific gravities.

The gravities used for the Dandot coal were; 1.30, 1.35, 1.40, 1.45, 1.50, 1.55, 1.60, 1.65, 1.70 and 1.80. The first step in wash-ability testing was to prepare the heavy liquid. Various suitable amounts of zinc chloride were dissolved in water to produce the desired S.G. The S.G. of these liquids was measured using a hydrometer. Wash-ability was carried out in different vessels for different size fractions. For all the material float and sink was performed in standard baths. The float and sink tests were conducted as follows;

The first heavy liquid was created with S.G. of 1.30. The entire sample was put into this liquid slowly and gradually in batches, allowing sufficient time for coal and gangue material to separate. The material of S.G. less than 1.30 floated on top of the liquid and everything heavier sank to the bottom. The light material (referred to as the "float") was removed and washed with water to remove zinc chloride and then set aside to dry. Then, the heavier material (referred to as the "sink") was removed and washed with water to remove the zinc chloride solution and set aside to dry. Once the "sink" material was dry, it was placed into another liquid of slightly higher S.G. of 1.35. The entire process was repeated until the entire matter was separated into the desired S.G. classes. In order to have a complete picture of the coal wash-ability, all relevant size classes were studied using the sink-float procedure. The individual S.G. classes were then weighed and analyzed for Ash and Sulphur content.

RESULTS

To prepare samples for conducting wash-ability tests at various coal particle size ranges, crushing of ROM coal samples was done using a laboratory Jaw Crusher at 50mm jaw opening. During crushing, a range of size fractions was obtained. Four sets of samples having sizes from -50 to +25 mm, -25 to 12.5 mm, -12.5 to +6 mm and -6 to +2 mm were screened. Generally, the following Tables 2.1, 2.2, 2.3, 2.4 and Table 2.5 show fractional and cumulative wash-ability results of the above four samples respectively. In these tables, the fractional data represents the properties such as, Ash, Sulphur and Yield of a particular coal float fraction (sink of previous S.G.) at certain S.G. In other words, fractional data shows that if sinks of S.G 1.40 are put into a solution of S.G. 1.45, its float fraction will have a fractional Yield of total sample with Ash and fractional Sulphur. Whereas, cumulative data shows that if whole of the sample is directly (without previously putting into any other S.G. solution) put in a solution of S.G. 1.45, it will show a cumulative Yield of floats of total sample with Ash and cumulative Sulphur.

Table 2.1: Wash-ability data for the size fraction – 50+25 mm

S.G.	Fractional			Cumulative		
	Yield %	Ash %	Sulphur %	Yield %	Ash %	Sulphur %
1.30	18.5	5.7	3.18	18.5	5.7	3.18
1.35	10.4	8.9	3.15	28.9	6.9	3.17
1.40	7.8	14.2	3.12	36.7	8.4	3.16
1.45	5.1	21.4	3.08	41.8	10.0	3.15
1.50	3.6	26.9	3.04	45.3	11.3	3.14
1.55	3.5	31.9	3.92	48.8	12.8	3.20
1.60	1.0	34.3	4.80	49.9	13.3	3.23
1.65	2.6	41.1	5.51	52.4	14.6	3.34
1.70	0.8	40.5	6.22	53.2	15.0	3.39
1.75	4.5	46.8	5.20	57.8	17.5	3.53
1.80	3.8	49.6	4.18	61.5	19.5	3.57
-1.80	38.5	62.1	18.54	100.00	35.9	9.33
Sum	-	-	-	-	-	-

Table 2.1, shows that at S.G. 1.45, sinks of 1.40 S.G. had a fractional Yield (floats) of 5.1% of total sample. Similarly, this 1.45 S.G. fraction had a fractional Ash and Sulphur of 21.4% and 3.08% respectively. Whereas, cumulative washability data in these tables, represents all the three fractional properties i.e., Yield, Ash and Sulphur, the data has been accumulated with respect to their weighted averages i.e., at S.G. of 1.45. Fractional Yields of S.G. 1.30, 1.35, 1.40 and 1.45 were added to give a cumulative Yield of 41.8% (of total sample). S.G. -1.80 represents the sinks or discard of 1.80 S.G. Whereas, cumulative data of -1.8 S.G. shows the characteristics of original sample as all floats and final sink fractions have been accumulated in it.

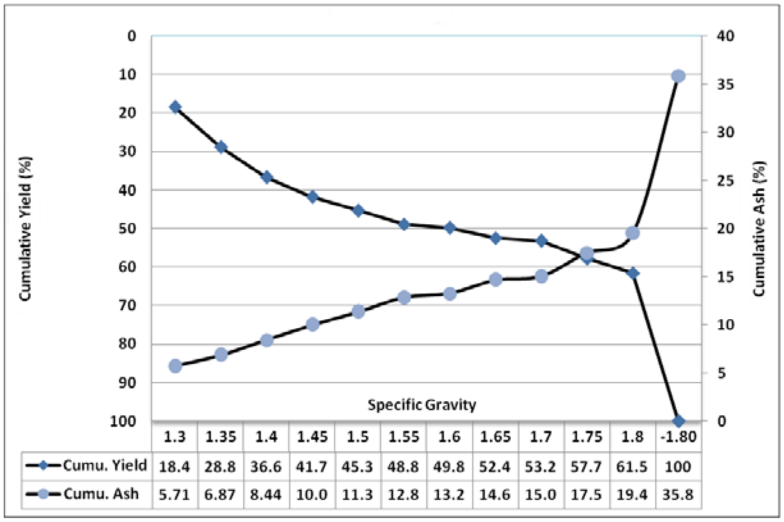


Figure 4: Coal Washability and Ash Reduction for the Size Fraction –50+25 mm

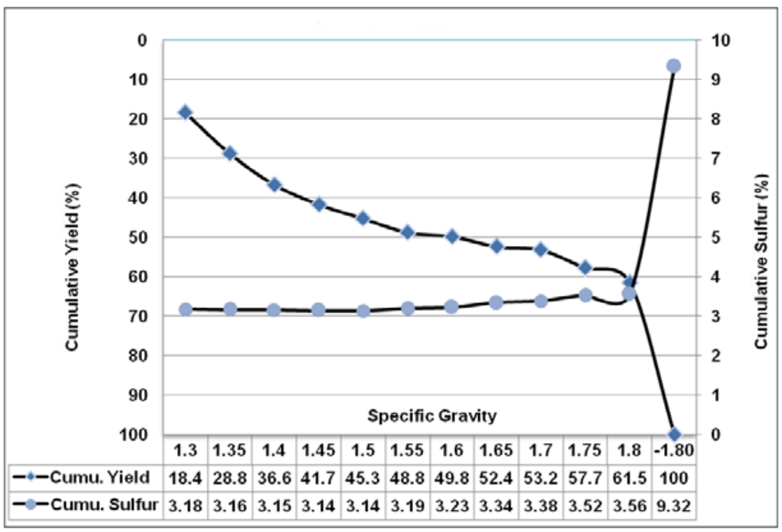


Figure 5: Coal Washability and Sulphur Reduction for the Size Fraction –50+25 mm

It is obvious from the Figure 5 that for the coarser size range i.e., -50 to +25 mm, liberation of impurities such as mineral matter and Sulphur is not very effective. For maximum possible Yield of clean coal, coal fraction is 58% at a high S.G. of 1.75 with cumulative Sulphur content of 3.52%.

Table 2.2: Washability data for the size fraction – 25+12.5 mm

S.G.	Fractional			Cumulative		
	Yield %	Ash %	Sulphur %	Yield %	Ash %	Sulphur %
1.30	43.8	8.4	2.09	43.8	8.4	2.09
1.35	7.5	11.5	2.47	51.3	8.9	2.14
1.40	4.5	15.9	2.84	55.8	9.4	2.20
1.45	3.4	20.6	3.32	59.1	10.0	2.26
1.50	2.2	26.0	3.80	61.3	10.6	2.32
1.55	1.7	31.9	3.82	63.0	11.2	2.36
1.60	3.0	35.4	3.83	66.0	12.3	2.43
1.65	1.5	40.3	3.56	67.5	12.9	2.45
1.70	1.8	44.0	3.28	69.3	13.7	2.47
1.75	1.7	47.9	3.49	71.0	14.5	2.50
1.80	2.6	52.0	3.70	73.6	15.9	2.54
-1.80	26.4	63.5	14.97	100	28.4	5.82
Sum						

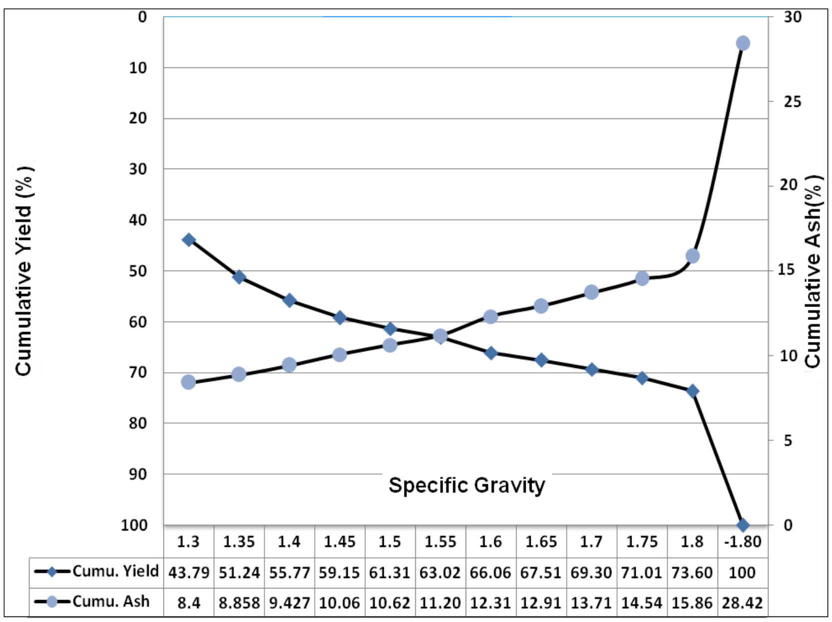


Figure 6: Coal Washability and Ash Reduction for the Size Fraction – 25+12.5 mm

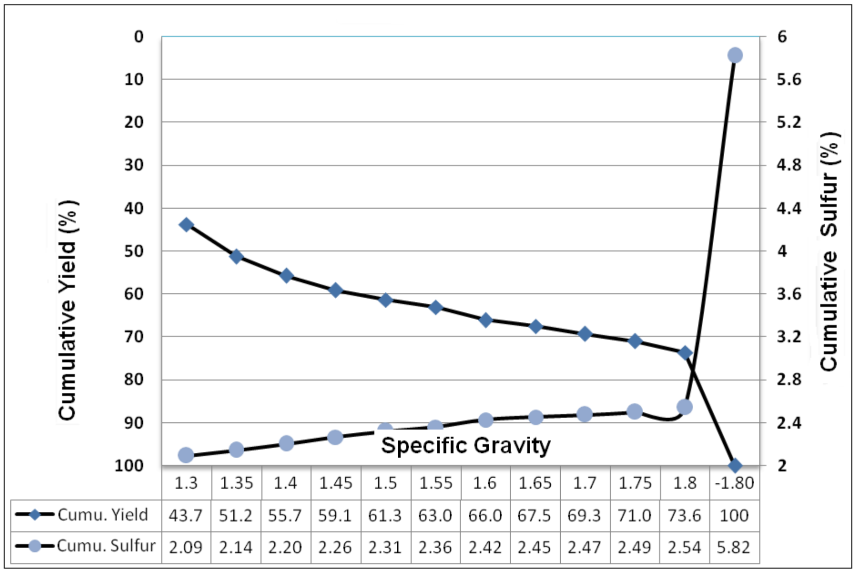
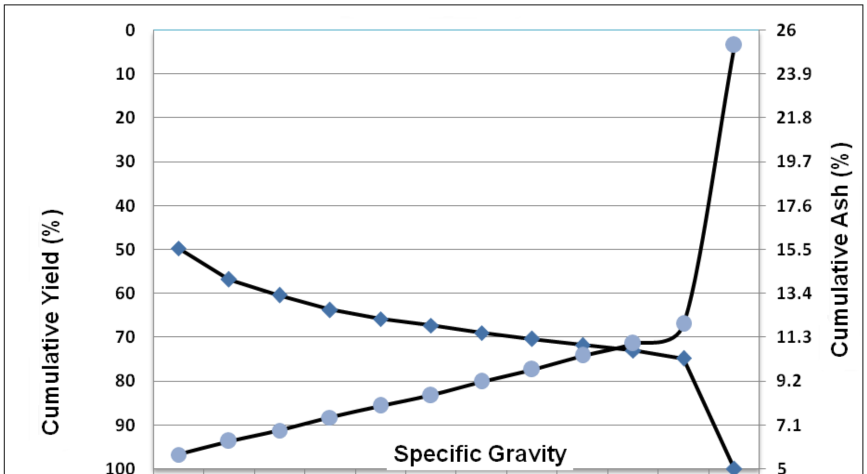


Figure 7: Coal Washability & Sulphur Reduction for the size Fraction – 25+12.5 mm

Figure 7 represents that with the decrease in particle size i.e., from top size of 50mm to 25mm, liberation of impurities has improved. A Yield of 71% with Ash and Sulphur content of 14% and 2.5% respectively was achieved. Almost 50% Ash forming mineral matter and 57% Sulphur content is liberated and separated during the gravity separation in this size range.

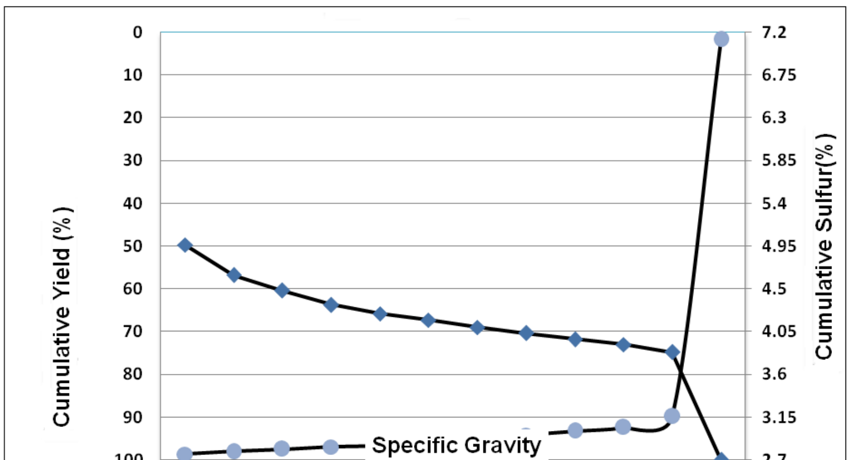
Table 2.3: Coal Washability data for the Size Fraction – 12.5+6 mm

S.G.	Fractional			Cumulative		
	Yield %	Ash %	Sulphur %	Yield %	Ash %	Sulphur %
1.30	49.7	5.7	2.76	49.7	5.7	2.76
1.35	7.0	10.8	2.98	56.8	6.3	2.79
1.40	3.6	15.1	3.20	60.4	6.8	2.81
1.45	3.3	18.8	3.26	63.7	7.5	2.84
1.5	2.0	25.3	3.33	65.8	8.0	2.85
1.55	1.5	30.2	4.04	67.3	8.5	2.88
1.6	1.7	35.0	4.76	69.0	9.2	2.92
1.65	1.3	39.5	4.89	70.3	9.8	2.96
1.7	1.5	42.2	5.02	71.8	10.4	3.00
1.75	1.2	46.0	5.19	73.0	11.0	3.04
1.8	1.8	50.0	7.98	74.8	11.9	3.16
-1.8	25.2	64.9	18.88	100	25.3	7.12
Sum	100					



	1.3	1.35	1.4	1.45	1.5	1.55	1.6	1.65	1.7	1.75	1.8	-1.80
Cumu. yield	49.7	56.7	60.3	63.7	65.7	67.2	69	70.3	71.7	72.9	74.7	100
Cumu. Ash	5.68	6.31	6.84	7.47	8.02	8.51	9.17	9.76	10.4	10.9	11.9	25.2

Figure 8: Coal Washability and Ash Reduction for the Size Fraction – 12.5+6 mm

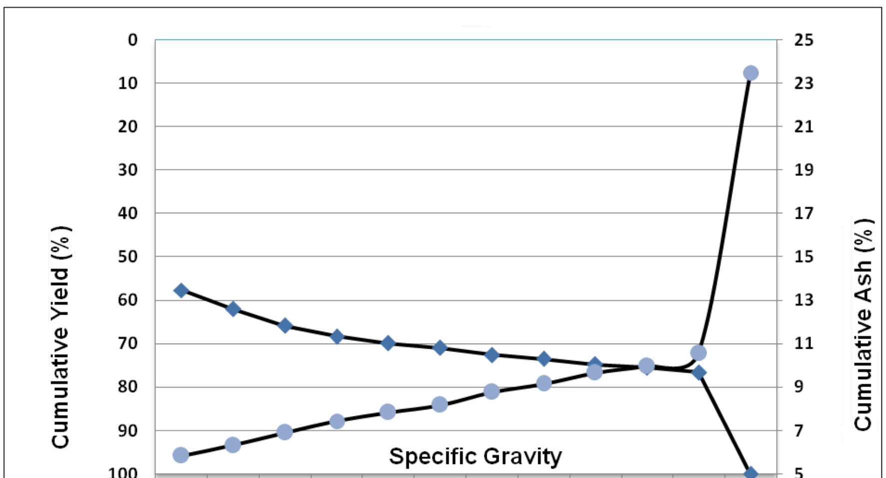


	1.3	1.35	1.4	1.45	1.5	1.55	1.6	1.65	1.7	1.75	1.8	-1.80
Cumu. yield	49.7	56.7	60.3	63.7	65.7	67.2	69	70.3	71.7	72.9	74.7	100
Cumu. Sulfur	2.76	2.78	2.81	2.83	2.85	2.87	2.92	2.96	3.00	3.03	3.15	7.12

Figure 9: Coal Washability and Sulphur Reduction for the Size Fraction – 12.5+6 mm

Table 2.4: Coal Washability data for the Size Fraction – 6+2 mm

S.G.	Fractional			Cumulative		
	Yield %	Ash %	Sulphur %	Yield %	Ash %	Sulphur %
1.30	57.7	5.8	1.98	57.7	5.8	1.98
1.35	4.4	12.6	2.43	62.0	6.3	2.01
1.40	3.7	16.6	2.87	65.8	6.9	2.06
1.45	2.5	21.2	3.15	68.3	7.4	2.1
1.50	1.6	26.0	3.43	69.9	7.8	2.13
1.55	1.1	30.5	3.42	71.0	8.2	2.15
1.60	1.6	34.3	3.41	72.6	8.8	2.18
1.65	0.9	38.4	3.45	73.5	9.2	2.19
1.70	1.2	40.7	3.48	74.8	9.7	2.22
1.75	0.7	41.7	3.91	75.5	10.0	2.23
1.80	1.1	49.8	4.33	76.6	10.6	2.26
-1.80	23.4	65.9	10.18	100	23.5	4.11
Sum						



	1.3	1.35	1.4	1.45	1.5	1.55	1.6	1.65	1.7	1.75	1.8	-1.80
Cumu. Yield	57.6	62.0	65.8	68.3	69.9	70.9	72.6	73.5	74.7	75.4	76.6	100
Cumu. Ash	5.84	6.31	6.90	7.42	7.84	8.18	8.77	9.15	9.67	9.97	10.5	23.4

Figure 10: Coal Washability and Ash Reduction for the Size Fraction – 6+2 mm

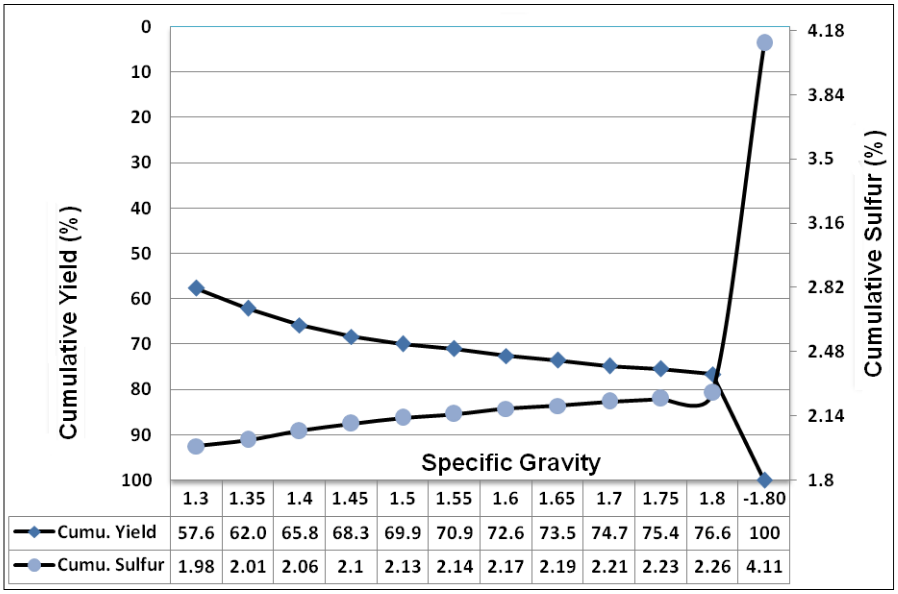


Figure 11: Coal Washability and Sulphur Reduction for the Size Fraction – 6+2 mm

It can be observed that with further decrease in the size of coal i.e., from top size 25mm to 12.5mm, Ash forming minerals liberation has further improved. Reduction in Ash and Sulphur is reported to be 58% and 46% respectively.

Table 2.5: Cumulative Coal Washability data for the Size Fraction – 50 mm+2 mm

S.G.	Cumulative		
	Yield %	**Ash %**	**Sulphur %**
1.30	38.49	6.7	2.36
1.35	46.45	7.4	2.46
1.40	51.75	8.1	2.52
1.45	55.58	9.0	2.57
1.50	58.09	9.8	2.60
1.55	60.26	10.6	2.64
1.60	62.19	11.4	2.68
1.65	63.93	12.2	2.73
1.70	65.24	12.8	2.76
1.75	67.64	14.0	2.82
1.80	70.27	15.3	2.86
-1.80	100.00	29.6	7.11
Sum			

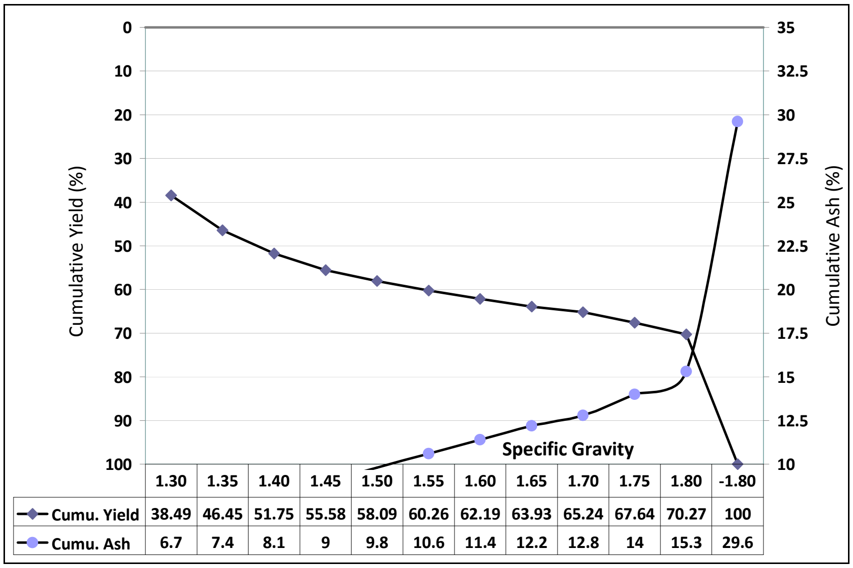


Figure 12: Coal Washability and Ash Reduction for the Size Fraction – 50+2 mm

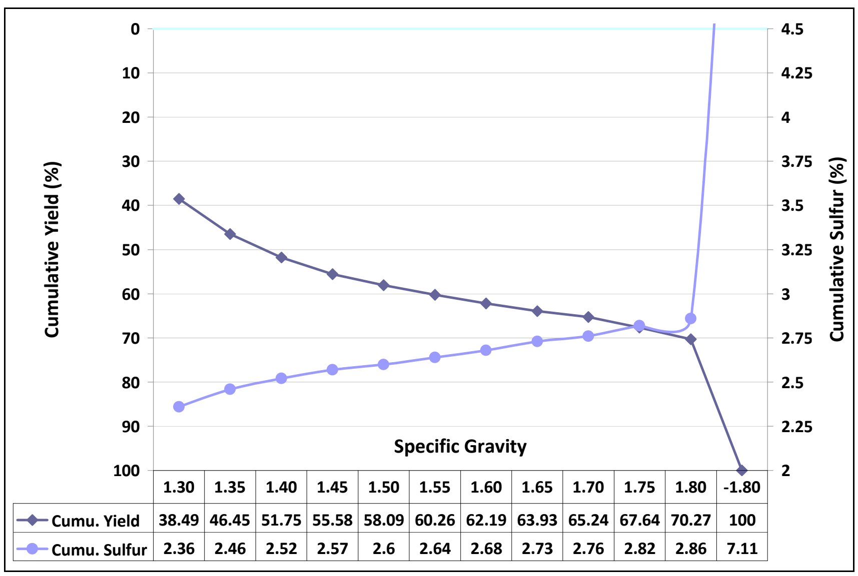


Figure 13: Coal Washability and Sulphur Reduction for the Size Fraction – 50+2 mm

Table 2.5 represents the washability data for all the four fractions that was mathamatically added up and acuumulative washability data for -50 to +2mm was generated. It was observed that lower Yield and higher Sulphur content of -50 to +25mm has been compensated by virtue of addition of other size fractions of better quality. Total of 68% Yield with

14% Ash and 2.82% of Sulphur can be achieved, if all four size fractions are washed together in dense media separator at a S.G. of 1.75.

DISCUSSION

The results of individual fractions as well as their accumulated effect were studied. Washability results clearly depict that liberation and separation of Ash forming mineral matter and Sulphur compounds is directly related to the top size of coal particle. Better liberation and separation was observed with smaller coal particle top size, i.e., 58% Yield, 17% Ash and 3.53% Sulphur for -50 to +25mm fraction as against 76% Yield, 10% Ash and 2.23% Sulphur for -6 to+2mm size fraction at separation S.G. of 1.75. Yield, Ash and Sulphur parameters of all the size fractions other than -50 to +25mm were found to be within acceptable limits of established techno-economic parameters as determined in the preliminary study i.e., at S.G. of 1.75 Yield remained well above 65%, Ash and Sulphur remained well below 20% and 3.5% respectively. These results are also in line with the quality requirement parameters established for application in the cement industry.

However, at size fraction of -50 to +25mm Yield, Ash and Sulphur content are 58%, 17% and 3.53% which does not meet the established techno-economic minimum requirements for substituting imported coal for the cement industry of Pakistan. Comparing the data, Yield of this fraction, is 58% as against 65% of minimum requirement and Sulphur content of 3.53% is also higher than the required maximum acceptable limit of 3.50%.

Results suggest that the size fraction -50 to +25mm is not suitable for washing if processed alone; however, if data for all four fractions is accumulated as shown in Table 2.5, results suggest that a Yield of 68% having Ash and Sulphur of 14% and 2.82% could be achieved at a S.G. of 1.75. This result is within the acceptable limits of established parameters. The study concludes that washing of Dandot coal for the size range of –50 to +2 mm at a S.G. 1.75 is techno-economically viable for substituting approx. upto 40% imported coal in the cement industry of Pakistan. Therefore, the indigenous coal with above mentioned specifications can be utilized in the cement industry.

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