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Technical Note:

Preliminary Beneficiation and Washability Studies on Ghouzlou Low-Ash Coal Sample

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ABSTRACT

In the present research, a low-ash coal sample from Ghouzlou deposit in Iran with an average ash content of 12% was subjected to beneficiation experiments such as heavy media separation and flotation. Sieve analysis showed that 62.3% of the coal sample of +2 mm size had around 7.3% ash contents. Also, heavy media tests that were carried out on five size fractions revealed that setting the separation density at 1.4 g/cm³ for the coarse fraction (+1 mm) produced a 5% ash product with more than 70% coal recovery. Samples with lower ash content (<5%) were blended with high-ash coals (>5%) based on the Mayer curves to produce a 5% coal product. Moreover, flotation tests on -1 mm fraction were able to reduce the ash content from 13.2% to 10.4%.

Keywords : *Coal, Heavy media separation, Sieve analysis, Flotation*

1. Introduction

Coals are fossil fuels with complex mixtures of organic and inorganic materials [1]. They can also be defined as sedimentary rocks [2, 3] which are combustible mixture of plant derived organic materials that might have different physical and chemical compositions. They have been merged between other rock layers and diagenesized under the effects of heat and pressure over millions of years [2-4]. The density of the carbonaceous material of coal varies from 1.20 to 1.70 g/cm³ and the density of mineral matter is generally greater than 2.0 g/cm³ [4]. The main component of coal is carbon, it also contains different hetero atoms such as nitrogen, sulfur, chlorine, minerals such as kaolinite, quarts, silica, titania, and various trace elements like W, Mo, alkali metal and toxic elements such as As, and Hg [5]. By removing the inert noncombustible materials from coal, the environmental and operational problems caused by coal usage can be reduced [6]. The presence of high ash content adversely affects the application of coal. Ash is an impurity that does not burn and reduces the handling and burning capacity of coal. Ash negatively affects combustion and boiler efficiencies, increases handling costs, causes clinkering and slagging [2].

Low-ash coal has a wide range of applications ranging from conventional combustion and electrode production to its usage in diesel engines instead of gas oil. Also, in the steelworks, the quality of steel is very important for particular applications. Low-ash coals are needed to reduce silicon levels before dephosphorization of steel. Moreover, the chemical composition of molten iron and slag is greatly affected by the coal ash contents. Another application of low-ash coal is in electrode manufacturing as a low-cost alternative for petroleum coke [7]. In power plants, low-ash coals can generate electricity at a very high efficiency if it is fired directly in gas turbines. It also can be processed to produce a wide range of fuels, chemicals, and materials, which are currently produced from oil and natural gas [8].

Coal cleaning or preparation is a process which removes the inert noncombustible mineral matter from the raw coal. For this purpose, several methods have been introduced such as oil agglomeration, washing cyclones, heavy media separation, froth flotation, and shaking Tables [1, 9]. A necessary stage before cleaning is determination of size distribution [10]. These gravity-based coal cleaning processes are well suited for removing coarse mineral particles from coal [9].

The industry has a long tradition of relying on coal washability data for making decisions. These data are essential for assessing the quality and extent of coal seams, in process modeling, in designing coal preparation plants, and in measuring the separation efficiency of process plants [11]. The aim in coal washability is achieving the maximum possible separation performance for a given coal/mineral matter feed [11].

Dense medium separation is the simplest method among all gravity processes that is able to make sharp separations at any required density and is applied to the pre-concentration of minerals. It is also used in coal preparation, and its accuracy and recovery is higher than jigging [12]. In this method, heavy liquids of suitable densities are used, so that those minerals lighter than the liquid float, while denser particles sink [10].

Froth flotation is widely used in the separation process of fine coals based on the difference in hydrophobicity between coal and minerals [13, 14]. Floatability of coals depend on different parameters such as coal type or rank, coal handling procedure, mining method (strip mining or deep mining), as well as the oxidation time [13]. While bituminous coals used for making coke are very hydrophobic and float easily, low-rank sub-bituminous and oxidized coals float poorly [15].

Mayer curve (M-curve) was introduced in 1950 based on the washability data derived from heavy media experiments. The graphical information of this curve is applied to assess and compare the washability properties of coal samples on a single diagram. The graph can be used to predict the coal recovery in concentrate and middling streams or to blend coal particles from several seams with different ash

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contents and various size ranges to achieve a low-ash product [16, 17].

In this present, a low ash coal sample was subjected to several cleaning stages including sieve analysis, heavy medium separation, and flotation to obtain a high quality coal product which is applicable in specific industries like manufacturing coke, activated carbon, carbon electrodes or black pigment for black paint and ink.

2. Materials and Methods

In PFC, three main components are used for mechanical simulation of material; namely *particle*, *wall* and *bond*. The main component is particle which occupies the volume. The second component, wall, provides the boundary condition for sample generation or applying the velocity boundary condition. The third component is bond which is suitable for simulation of rock materials than cohesionless soil materials and can be employed to study the process of crack initiation and propagation of cemented materials.

2.1. Coal

An Iranian super-bituminous coal sampled from Ghouzlou region, located between East and West Azerbaijan Province. Shahindezh (Saein Ghala) is located 33 kilometers from the excavation tunnel and 78 kilometers from Miandoab. The exploitable mineral reserve of the mine is about 136000 tons, and the probable reserve is estimated to be 450000 tons.

2.2. Coal characterization

Moisture content was determined according to the Australian Standard AS1038.3 by heating 0.5 to 1 g of coal to 110 °C in nitrogen, and calculating the difference between the weight of the initial and dry samples. The ash content of the coal was determined according to the ASTM standard D3174-73 by heating 1-2 g of the sample at 700-750°C. An adiabatic calorimeter was exploited to obtain the calorific value of the samples based on the ASTM D-2015, 1S0 1928 standard. Also, the total sulfur content of the sample was determined using a Leco device (Model 532).

2.3. Sieve analysis

The sieves were arranged in the order of decreasing mesh sizes with the sieve of largest mesh size at the top. Two different methods, wet and dry sieving approaches were used to take 3597g coal sample from the Ghouzlou mine. After dry sieving of the sample, wet sieving was applied for samples which their particle size was under 850 µm and constituted about 250 g of the total sample. Ash analysis was also applied for each size fraction.

2.4. Heavy media separation

In accordance with sieve analysis results, heavy media separation tests were applied on three different fractions, +2-4.75 mm, +4.75-6.35 mm, +6.35 mm, +1-19.05 mm, and +19.05 mm. Dense media were prepared using zinc chloride in the range of 1.20 g cm^{-3} to 1.90 g cm^{-3}.

2.5. Flotation

The flotation cell was filled with 500 g of -500 µm and -1 mm samples, 2 L water, 370 g/ton MIBC as frother, and 420 g/ton fuel oil as collector. Pulp temperature and pH adjusted to 20.4 °C and 6.5, respectively. The rotation speed of impeller was 1500 rpm. Froth collection was carried out in four stages, and the remained tailing of each stage was used for the next stage.

3. Results and Discussion

Washability index shows the separation potential of valuable from gangue particles in coal processing. The efficiency of each separation method is optimum in a specific size fraction. For example, heavy media separation is suitable for particles of - 200 mm size. For particles up to 130 mm, jigging is appropriate [18]. Also, shaking table is the selected method for the size of 500 to 2000 µm, and flotation is used for smaller fractions.

One of the main differences of coal beneficiation in comparison to other minerals is the fact that usually it does not need size reduction. In other words, coal underwent beneficiation with the original particle size obtained from excavation. It is necessary to maintain the coal size distribution in different stages from mine to washing plant, because lowering the feed size increases the processing cost per unit weight of the feed, and probably decreases the recovery.

3.1. Sieve analysis

Table 1 shows the results of sieve analysis. Half of the samples have a particle size of less than 2.9 mm and the rest are larger. According to this table, around 62% of the particles diameter is more than 2 mm, around 25% ranging from 0.5 up to 2mm, and less than 13% of particles diameter is below 500 µm. Therefore, heavy media separation and flotation are suggested for the first and third fractions, respectively. The processing method of the second group will be selected after assessing the results of the first and third fractions. It is also deduced that there is little difference between the ash content of each size fraction. The highest ash is cumulated in the finest size portions (-106 µm) meaning the gangue particle size in these ranges.

Different processing approaches may be applied for different size fractions. For example, heavy media for 4-10 mm, jig for 2-4 mm, shaking table for 500-2000 µm, and flotation for the finer particles. Considering the ash analysis, heavy media was applied on +2-6.35 mm portion, and flotation was performed on -500 µm fraction.

Table 1. Results of dry and wet sieve analysis on the coal sample.

	Particle size (µm)	Weight (%)	Ash (%)	Cumulative undersize (%)	Cumulative oversize (%)	Cumulative ash content (%)
Dry sieve analysis	+6350	22.65	9.1	77.35	22.65	2.06
	+4750-6350	8.59	12.9	68.76	31.24	3.17
	+2000-4750	31.07	13.4	37.69	62.31	7.33
	+1000-2000	17.05	11.8	20.64	79.36	9.35
	+850-1000	1.49	8.7	19.15	80.85	9.47
Wet sieve analysis	+500-850	6.73	11.2	12.42	87.58	10.23
	+250-500	4.48	11.8	7.94	92.06	10.76
	+106-250	3.95	13.6	3.99	96.01	11.29
	-106	3.99	19.5	0	100	12.07

3.2. Heavy media separation

Heavy media separation tests are conducted to investigate the feasibility of gravity methods for heavy mineral dressing. Heavy media tests were conducted on +6.35, +4.75-6.35, and 2-4.75 mm fractions obtained from sieve analysis. Dense media were prepared in 1.2, 1.3, 1.4, 1.5, 1.7, and 1.9 g cm^{-3} densities. Results are presented in Table 2.

It is concluded from the table that the distribution of coal mass and associated ash content in each density is similar for all applied size ranges. Therefore, separation that is based on the size distribution is not effective for obtaining a high quality coal product; however, it is useful for obtaining products with different qualities and size ranges.

It is seen that for all size portions, the ash content increases as the density is increased. Also, Fig. 1 (a-e) which are illustrated based on the data presented in Table 2, revealed the following results for extracting a product with less than 5% ash content.

- According to Fig. 1a, about 33% of the -4.75+2 mm fraction has 5% ash content. In fact, in order to obtain a product with 5% ash content, the separation density should set at around 1.26 g cm^{-3}.

- Considering the -6.35+4.75 mm fraction presented in Fig. 1b, if the separation density is set at 1.28 g cm^{-3}, 30% of the feed is introduced to the coal product with 5% ash content.

- Regarding Fig. 1c, the maximum amount of low ash product (about 82%) is yield from the +6.35 mm fraction by setting the separation density at 1.6 g cm^{-3}.

- 14% of the -19.05+1 fraction has 5% ash content (Fig. 1d). The medium density needed to reach this yield is 1.28 g cm^{-3}.

- It is concluded from Fig. 1e that a high portion (78%) of the particles coarser than 19.05 mm which are lighter than 1.44 g cm^{-3} contains 5% ash.

Finally, considering the above-mentioned facts, it is clear that among all of the mentioned size portions showed in Table 2, the fractions +6.35 and +19.05 mm include the highest percentage of low ash coal. Therefore, it is possible to blend one of these two fractions with high ash coal remained from other three fractions to reach 5% ash products.

Table 2. Results of heavy media separation test on the coal sample.

	Sp. Gr.	Wt%	Ash%	A. pro.	Sep. dens.	Cumulative float (clean)			Cumulative sink (Discard)		
						Wt%	A. pro	Ash%	Wt%	A. pro	Ash%
+2-4.75mm	-1.2	10	3.9	39	1.2	10	39	3.9	90	1199.76	13.33
	1.2-1.3	38.02	6.2	235.72	1.3	48.02	274.72	5.72	51.98	964.04	18.55
	1.3-1.4	30.3	8.8	266.64	1.4	78.32	541.36	6.91	21.68	697.4	32.17
	1.4-1.5	6.36	16.5	104.94	1.5	84.68	646.3	7.63	15.32	592.46	38.67
	1.5-1.7	5.02	24.2	121.48	1.7	89.7	767.78	8.56	10.3	470.98	45.73
	1.7-1.9	2.22	30.9	68.6	1.9	91.92	836.38	9.1	8.08	402.38	49.80
	>1.9	8.08	49.8	402.38	-	100	1238.76	12.39	0	0	0
	total	100	12.39	1238.76							
+4.75-6.35mm	-1.2	0	0	0	1.2	0	0	0	100	1491.18	14.91
	1.2-1.3	36.88	6	221.28	1.3	36.88	221.28	6	63.12	1269.9	20.12
	1.3-1.4	31.72	7.7	244.24	1.4	68.6	465.52	6.8	31.4	1025.66	32.66
	1.4-1.5	5.24	14.4	75.46	1.5	73.84	540.98	7.33	26.16	950.2	36.32
	1.5-1.7	8.34	23.5	196	1.7	82.18	736.98	8.97	17.82	754.2	42.32
	1.7-1.9	4.82	28.9	139.3	1.9	87	876.28	10.1	13	614.9	47.30
	>1.9	13	47.3	614.9	-	100	1491.18	14.9	0	0	0
	total	100	14.91	1491.18							
+6.35mm	-1.2	0	0	0	1.2	0	0	0	100	1113.87	11.14
	1.2-1.3	44.56	3	133.68	1.3	44.56	133.68	3	55.44	980.19	17.68
	1.3-1.4	23.8	3.8	90.44	1.4	68.36	224.12	3.28	31.64	889.75	28.12
	1.4-1.5	10.24	10.7	109.57	1.5	78.6	333.69	4.24	21.4	780.18	36.46
	1.5-1.7	6.65	22.6	150.3	1.7	85.25	483.99	5.68	14.75	629.88	42.70
	1.7-1.9	3.22	30.9	99.5	1.9	88.47	583.49	6.6	11.53	530.38	46.00
	>1.9	11.53	46	530.38	-	100	1113.87	11.14	0	0	0
	total	100	11.14	1113.87							
+1-19.05mm	-1.2	2.31	5.1	11.78	1.2	2.31	11.78	4.75	97.69	1378.59	14.11
	1.2-1.3	14.88	4.7	69.94	1.3	17.19	81.72	5.1	82.81	1308.65	15.80
	1.3-1.4	52.92	5.6	296.35	1.4	70.11	378.07	5.4	29.89	1012.3	33.87
	1.4-1.5	9.78	24.6	240.6	1.5	79.89	618.67	7.74	20.11	771.7	38.37
	1.5-1.6	4.16	23.4	97.34	1.6	84.05	716.01	8.52	15.95	674.36	42.28
	1.6-1.7	3.63	24.9	90.39	1.7	87.68	806.4	9.2	12.32	583.97	47.40
	>1.7	12.32	47.4	583.97	-	100	1390.37	13.9	0	0	0
	total	100	13.90	1390.37							
+19.05mm	-1.2	0	0	0	1.2	0	0	0	100	1010.18	10.10
	1.2-1.3	0	0	0	1.3	0	0	0	100	1010.18	10.10
	1.3-1.4	74.27	4.7	349.07	1.4	74.27	349.07	4.7	25.73	661.11	25.69
	1.4-1.5	11.79	14.9	175.67	1.5	86.06	524.74	6.1	13.94	485.44	34.82
	1.5-1.6	0	0	0	1.6	86.06	524.74	6.1	13.94	485.44	34.82
	1.6-1.7	12.48	35.2	439.3	1.7	98.54	964.04	9.78	1.46	46.14	31.60
	>1.7	1.46	31.6	46.14	-	100	1010.18	10.1	0	0	0
	total	100	10.10	1010.18							

According to Table 2, if the low ash portion of -4.75+2 mm fraction is removed, the remained coal (67%) contains around 16% ash. Referring to the Mayer curves of +6.35 and +19.05 mm fractions which are depicted in Fig. 2, 78 tons of the +6.35 fraction with 4% ash should be mixed with 7 tons of the high ash coal to obtain 85-ton product with 5% ash content. However, it is impossible to blend the mentioned portion with +19.05 mm fraction.

Moreover, it is possible to mix 4 tons of the remained 70% of the second fraction with 18.5% ash and 80 tons of +6.35 portion with 4.5% ash to obtain a 5% ash product.

Another blending possibility is mixing 77 tons of the +6.35 fraction with about 4% ash and 9 tons of the remained coal from the fourth portion with 15% ash content to obtain 86 tons of low ash product.

Assuming that there is a 100-ton pile of +6.35 fraction, 82 tons of the pile has 5% ash. However, the amount of 5% ash product can increase to even 86 tons by using the suggested blending approaches.

3.3. Flotation

In the previous section, heavy media separation studies were performed on the coal particles coarser than 1 mm. In this part, flotation of coal particles finer than 500 µm and 1 mm was investigated.

According to Table 1, the ash content of -1 mm, and -500 µm size fractions are 13.21%, and 14.85%, respectively. Results of the flotation studies show that although a great improvement in ash reduction was observed, unfortunately, it was not possible to achieve a 5% ash concentrate. Nevertheless, if a product of less than 12% ash was required, outcomes were satisfactory. It is obvious from Table 3 that a total coal product of about 10% ash with 75% coal recovery was obtained from -500 µm fraction. Also, the final flotation concentrate gained from -1 mm fraction has 10.4% ash and 90% recovery.

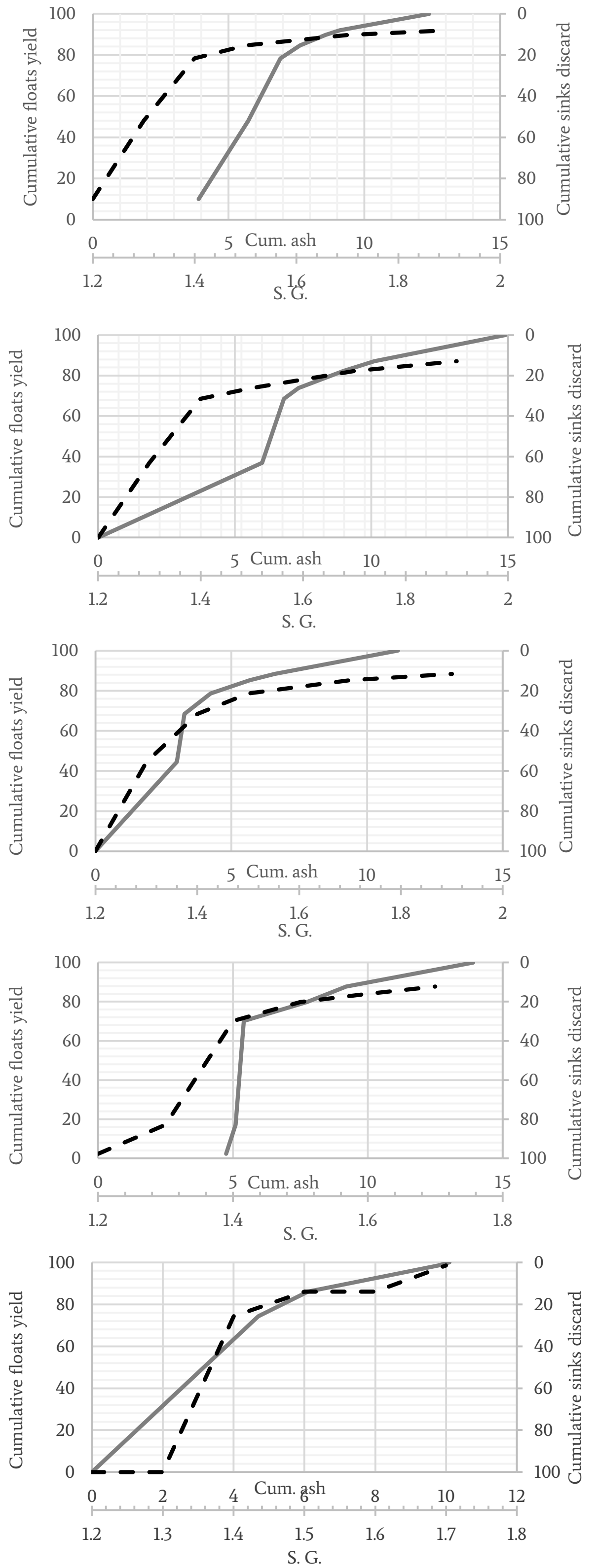

Fig. 1. Washability curves for the (a) 2-4.75, (b) 4.75-6.35, (c) +6.35, (d)1-19.05, and (e) +19.05 fractions. (Solid line: Based on ash content, dashed line: Based on separation density).

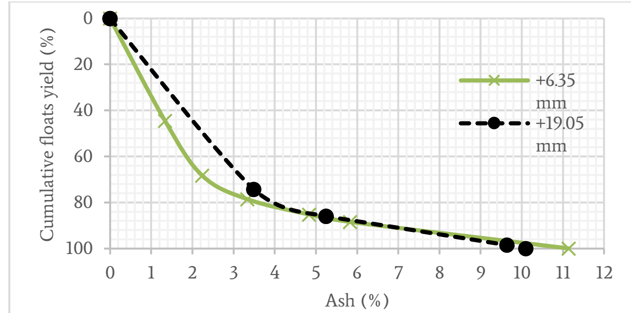

Fig. 2. The Mayer curves of +6.35, and +19.05 mm size fractions.

Table 3. Results of the flotation tests on the coal sample.

	Products	Duration (min)	Weight (g)	Weight (%)	Cum. Weight (%)	Cum. Ash (%)
-500 µm	Conc. 1	1	87.8	18	18	8.2
	Conc. 2	3	138.0	28	45	9.4
	Conc. 3	8	149.1	30	75	9.9
	Conc. 4	14	64.6	13	88	12.7
	Tail	17	57.2	12	-	24.1
	Total	43	496.5	100	-	
-1 mm	Conc. 1	1	89.5	30	30	9.6
	Conc. 2	3	82.5	28	58	11
	Conc. 3	8	56.5	19	77	10.7
	Conc. 4	14	40	13	90	10.4
	Tail	17	30.7	10	-	23.8
	Total	43	496.5	100	-	

Although the flotation concentrates do not meet the expectations for obtaining a 5% ash coal product, blending may be an appropriate solution. Again, regarding Fig. 2, it is deduced that a final product of 5% ash was attainable by blending the +6.35 mm fraction with the flotation concentrates. In fact, if 73 tons of the mentioned fraction was mixed with 13 tons of 9.9% ash or 11 tons of 10.4% ash concentrates, 96 or 94 tons of low ash product will be obtained. Obviously, these tonnages were more than what gained from the +6.35 mm portion itself (82 ton).

Table 4 provides specifications of the feed and final concentrates of the flotation process.

Table 4. Specifications of the coal samples.

Parameters	Total moisture (%)	Volatile matter (%)	Sulfur (%)	Calorific value
Feed	1.93	27.81	4.91	7395
Flotation conc. 1	1.83	29.21	2.51	7509

4. Conclusion

A low ash sample from the Ghouzlou coal deposit was subjected to sieve analysis and washability studies. According to the results of sieve analysis, the total ash content of the sample was around 12% which is acceptable for most of industrial applications. However, as the purpose of the study was to obtain a coal product with 5% ash content, the washability of +1 and -1 mm fractions was investigated through heavy media and flotation methods, respectively. Dense medium fractionation proved that it was feasible to obtain 5% ash products from size portions. Also, it was shown that the efficiency of process could be improved by using the coal blending technique. Furthermore, flotation experiments indicated that obtaining a 5% ash concentrate was not possible. However, the expected product could be gained by blending the flotation concentrates with the low ash size fractions.

REFRENCES

[1] Erol, M., Colduroglu, C., & Aktas, Z. (2003). The effect of reagents and reagent mixtures on froth flotation of coal fines. International Journal of Mineral Processing, 71(1), 131-145.

[2] Babatunde, S.Y. & Adeleke, A. (2014). Froth flotation upgrading of a low grade coal. Petroleum & Coal, 56(1), 29-34.

[3] Palazzi, E., Currò, F. & Fabiano, B. (2013). Accidental continuous releases from coal processing in semi-confined environment. Energies, 6(10), 5003-5022.

[4] Lin, C.L., Parga, J.R., Drelich, J. & Miller, J.D. (1999). Characterization of washability of some Mexican coals. Coal Perparation, 20(3-4), 227-245.

[5] Zhang, Q., Tian, Y., Qiu, Y., Cao, J. & Xiao, T. (2011). Study on the washability of the Kaitai coal, Guizhou Province China. Fuel Processing Technology, 92(3), 692-698.

[6] Ozmak, M. & Aktas, Z. (2006). Coal froth flotation: Effects of reagent adsorption on the froth structure. Energy & Fuels, 20(3), 1123-1130.

[7] Keast-Jones, R. & Smitham, J.B. (1993). Physical Beneficiation to Produce Ultra Low Ash Coal, International Journal of Coal Preparation and Utilization, 12, , 1-14.

[8] Steel, K.M. & Patrick, J.W. (2001). The production of ultra-clean coal by chemical demineralization. Fuel, 80, 2019-2023.

[9] Aktaş, Z., Karacan, F. & Olcay A. (1998). Centrifugal float–sink separation of fine Turkish coals in dense media. Fuel Processing Technology, 55(3), 235-250.

[10] Napier-Munn, T. & Wills, B.A. (2006). Wills' mineral processing technology. Elsevier.

[11] Galvin, K. (2006). Options for washability analysis of coal- a literature review. Coal Preparation, 26(4), 209-234.

[12] Albrecht, M. C. (1980). Coal preparation processes. American Society of Mechanical Engineers Annual Meeting, San Francisco, California, 279-289.

[13] Tao, D., Li, B., Johnson, S. & Parekh, B.K. (2002). A flotation study of refuse pond coal slurry. Fuel Processing Technology, 76(3), 201-210.

[14] Ni, C., Xie, G., Li, Z., Bu, X., Peng, Y. & Sha, J. (2016). Flotation of long flame coal pretreated by polyoxyethylene sorbitan monostearate. Physicochemical Problems of Mineral Processing, 52(1), 317-327.

[15] Patil, D. & Laskowski J. (2008). Development of zero conditioning procedure for coal reverse flotation. Minerals Engineering, 21(5), 373-379.

[16] Habetinejad, H., Jorjani, E. & Sam, A. (2012). Evaluation of Mayer curve validity on feed blending at the Zarand coal washery plant. International Journal of Mining Science and Technology, 22, 19–22.

[17] Thomas, L.J. & Thomas, L.P. (2002). Coal Geology. Wiley.

[18] Fuerstenau, M.C. & Han, K.N. (2003). Principles of Mineral Processing, Society for Mining, Metallurgy, and Exploration.