JME

Journal of Mining & Environment,
Vol.2, No.1, 2011, 61-68.

Processing of Alborz Markazi coal tailings using column flotation

Z. Bahri[1], S.Z. Shafaei[1, 2], M. Karamoozian[1*]

1. Faculty of Mining, Petroleum and Geophysics, Shahrood University of Technology; Shahrood, Iran
2. Professor, School of Mining, College of Engineering, University of Tehran, Tehran, Iran

Received 24 Jul 2011; received in revised form 28 Sep 2011; accepted 30 Oct 2011
**Corresponding author: m.karamoozian@shahroodut.ac.ir*

Abstract
Investigations were carried out on coal tailings by conventional cell and column flotation techniques. Tests were conducted to assess processing coal tailings of Alborz Markazi coal washing plant in Iran by column flotation. The effects of reagent type/dosage were investigated with conventional flotation and their results were used in the performance of column flotation. Also the effects of the air rate, the feeding rate, the wash water rate, the frother concentration, the collector dosage were evaluated with column flotation. These coal tailings have an average of 56% ash. This paper used factorial design to optimize grade and recovery of coal tailings. The column flotation results indicated concentrate produced under optimum conditions, kerosene, 2909 g/t; superficial air velocity, 0.96 cm/s; feeding rate, 3.6 lit/min; superficial wash water velocity, 0.98 lit/min; frother dosage, 350 g/t having an ash content of 12.11% and a combustible recovery of 28.51% was obtained.

Keywords: *Coal tailings; processing; column flotation.*

1. Introduction

Cleaning of the coal tailing (<0.6 mm) of Alborz Markazi coal washing plant having 56% ash was studied in both a conventional flotation cell (Denver D-12 with 1-litre capacity cell) and a laboratory column flotation. Column flotation cell has different advantages compared with conventional flotation cell as well as in applications where entrainment is a problem [1]. Some of features of column flotation cell include: higher concentrate grade, higher recovery, high availability and lower maintenance costs, minimal moving parts, lower operating costs and improved process control. The better performance of the columns flotation cell is due to: the long retention time of the ore in column; counter current flows of pulp versus air bubbles; and the wash water added on the froth. Since the Alborz Markazi coal washing plant started to work, more than 1.5 million tons of waste in land has been allocated for the waste depot. About 70% Alborz Markazi coal washing plant wastes were related to jig tailings which contain high percentage of coal. The schematic diagram of the processing circuit of the Alborz Markazi coal washing plant setup is shown in Figure 1.

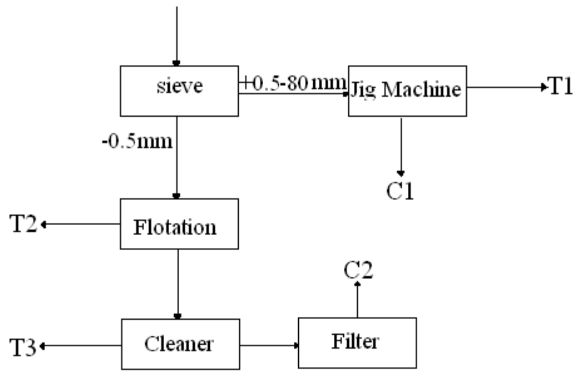

Figure1. Processing circuit of the Alborz Markazi coal washing plant

Also, the presence of these wastes lead to an environmental problem. Pollution waste materials produced by Alborz Markazi coal washing plant has created many environmental problems, when waste material is exposed of atmospheric oxygen and moisture produces acid mine drainage that may seriously affect the water quality and biological life in surface waters [2]. Using the column flotation method for cleaning and utilizing the low rank tails will cause less tails and lower environmental pollution. Also, an increasing consideration is being given to processing of coal tailings, due to increases in energy prices. A number of researchers have investigated the performance of column flotation on separation of coal with high ash content [3, 4, 5, 6, 7, 8, 9 and 10]. Hacifazlioglu et al (2007) processed fine coals the ash content of which was 47.5% using column flotation. Concentrate were obtained with ash content of 15.60%, and the combustible recoveries of 50.92% [9]. Nagui et al (2000) have shown column efficiency to recover phosphates from their wastes with considerable grade and recovery [11].

In order to determine the approximate amount of reagent type/dosage for experimenting with column flotation, the effects of reagents were studied by conventional flotation. As tailing was crushed before, this stage is omitted to make it more economical. The process of column flotation depends on some of the operating parameters. The effect of column flotation parameters such as superficial wash water velocity, superficial air velocity, feeding rate and frother dosage, collector dosage was investigated to obtain optimized clean coal. Experiments were analyzed to evaluate the influence of each parameter and its interactions on the performance.

The schematic diagram of the experimental setup is shown in Figure 2. The aim of this stage is to find the optimized conditions for achieving the desired separation performance of coal and determination of effective factors.

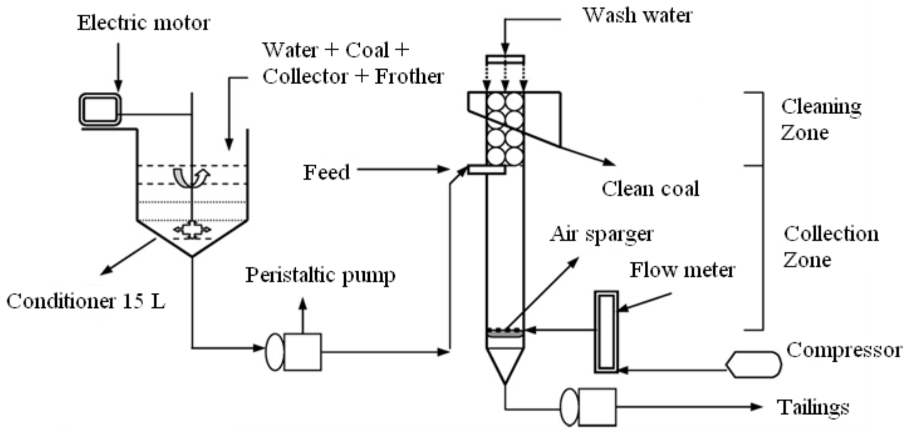

Figure2. Experimental set up for column flotation tests [9]

2. Conventional flotation

The aim of conventional flotation tests was achieving the optimum conditions for three variables (collector dosage, collector type and MIBC dosage) which play a very significant role in the column flotation performance.

2.1. Experimental and modeling procedure

2.1.1. Material and methods

The study sampled about 200 kg from the tailings of the Alborz Markazi coal washing plant in Iran. The material was passed from 0.6 mm sieve. The samples from screening were combined and homogenization. Conventional flotation experiments were carried out in a 1-litre Denver laboratory flotation machine. The percentage of solids in the feed pulp was kept constant at 10% (by weight). To compare the efficiency of reagents type and dosage on the flotation performance, all operating parameters such as impeller speed, pH, conditioning time, flotation time were kept constant for all of the experiments. To perform the tests, gas oil and kerosene as collector and MIBC (Methyl isobutyl carbonyl) was used as frother. The compound of the gas oil and kerosene reagents with a ratio of 1:1 by weight also was studied to evaluate the flotation performance.

2.1.2. Conventional flotation tests and experimental design

Firstly at these tests the slurry was mixed and conditioned in the cell for one minute by the impeller (impeller speed was monitored by the tachometer and kept constant as 1000 rpm in all of the flotation experiments). The specified dosage of collector and frother for each of experiments was then added and conditioned for 120 seconds. Then flotation was carried out by adding the air and the froth collected for 180 second. To obtain the recovery and ash content, the flotation concentrate and tailing were filtered and then dried separately for each of the tests.

In order to study the optimum reagent type/dosage for processing by conventional flotation, general factorial design was applied. The main parameters and their levels are shown in Table 1.

In order to reduce unknown errors, experiments were done randomly. Experiment conditions and their responses are shown in Table 2.

Table 1. Selected parameters and their levels

Name	Main factors	Units	Levels		
A	Collector type	-	Gas oil (G)	Kerosene + Gas oil (K+G)	Kerosene (K)
B	Collector dosage	g/t	2500	3000	
C	MIBC dosage	g/t	150	300	

Table 2. Design of experiment for evaluate the effects of reagent type/dosage on the Coal washing improvement

Run	A	B	C	Response 1: Combustible Recovery (%)	Response 2: Ash Content (%)	Response 3: separation efficiency (%)
1	K+G	3000	300	59.7	28.47	48.69
2	K	3000	150	58.26	28.83	47.59
3	G	2500	150	50.97	28.50	42.93
4	G	3000	300	59.05	29.87	47.52
5	K+G	3000	150	56.86	28.83	46.69
6	K	3000	300	62.06	29.28	49.69
7	G	2500	300	55.41	28.07	46.11
8	K+G	2500	300	59.14	29.82	47.60
9	K	2500	300	55.49	27.54	46.41
10	G	3000	150	49.60	25.21	43.16
11	K	2500	150	59.69	30.16	47.75
12	G	2500	150	56.97	29.33	46.51

2.2. Results and Discussion

To study the effects of reagent type/dosage and their results in the performance of column flotation, the coal separation efficiency was analyzed. Analysis of parameters and interactions was conducted with ANOVA for all response values. Table 3 shows the analysis of variance for the coal separation efficiency data. The results in Table 3 demonstrate that main factors, collector type, collector dosage, MIBC dosage and interactions (collector type x MIBC dosage, collector dosage x MIBC dosage) were effective within 95% confidence interval. Effects of each factor on the separation efficiency are shown in Figure 3.

The effect of collector type on the separation efficiency is illustrated in Figure 3(a). It is observed that kerosene had more effect on separation efficiency. The effect of collector dosage on the separation efficiency of the coal flotation is shown in Figure 3(c). It can be observed that separation efficiency increased with increasing collector dosage. But it is not very significant statistically in the investigated range. The effect of MIBC dosage was evaluated in the investigated range. Changing MIBC dosage from its lower to higher levels causes a considerable improvement in separation efficiency.

The proposed optimum conditions are collector type: kerosene, collector dosage: 3000 g/t, MIBC dosage: 300g/t. Using Design Expert software, the optimum predicted recovery, ash content and separation efficiency were 60.57%, 28.77% and 49.01% with 95% confidence level, respectively.

Table 3. Analysis of variance for coal separation efficiency in the flotation

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	42.011	7	6.00	16.73	0.0081
A	19.70	2	9.85	27.47	0.0046
B	3.04	1	3.04	8.47	0.0437
C	10.79	1	10.79	30.08	0.0054
AC	5.93	2	2.97	8.27	0.0379
BC	2.55	1	2.55	7.12	0.0560
Residual	1.43	4	0.36		
Total	43.45	11			

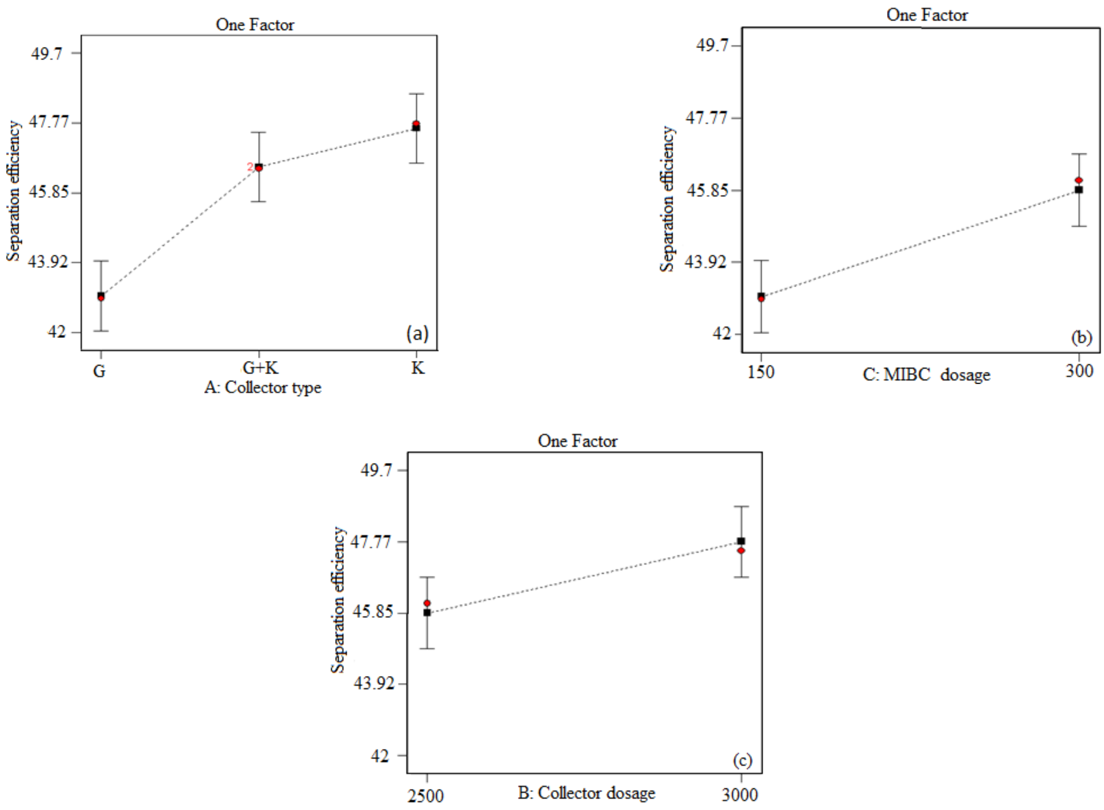

Figure3. The effect of (a) collector type (b) MIBC dosage (c) collector dosage on the separation efficiency

Based on the conventional flotation results, kerosene had better efficacy on the process. Therefore kerosene was selected as collector. And the best results were obtained in the case of using a 3000 g/t kerosene as a collector and 300 g/t MIBC as frother.

It is well known that low rank coals or oxidized coals are generally more hydrophilic. Therefore after conventional flotation tests it was observed that due to low rank of particles even at higher dosage of collector (3000g/t) and frother (300g/t) coal may need more reagents for better efficiency. Thus, to investigate the effects of higher values reagent in separation of coal, they were investigated in the performance of column flotation.

3. Column flotation

3.1. Material and methods

This study used a flotation column having an internal diameter of 10 cm and height of 6 m. The column was initially filled with tap water up to the required level. The pulp was prepared with 5% solid concentration at a 100 litter feed tank and conditioned with Kerosene as collector for 5 min. Then for the froth stability, the amount of MIBC was added to the pulp and conditioned for one minute before feeding the pulp to the column. In the column flotation tests, the pH and the percentage of solid were kept constant 8 and 5% respectively. Gas was generated, using compressed air and entered from the bottom of the column. Both gas and wash water flow rates were adjusted and controlled by using a calibrated glass flow meter to the predetermined rate. At time t=0, tailing pump was automatically adjusted so as to keep the position of the collection zone-cleaning zone interface stable at a height of 20 cm. Therefore for each experiment, froth depth was kept constant by tailing discharge from the bottom of the column using tailing pump. Wash water was added to the froth at a predetermined rate for each of experiments, 10 cm above the top of the column. The pulp was entered to the column through a peristaltic pump (at a point below almost 150 cm from the top) at specified rate to approximately one-third of the total height from the top of the column. When the slurry started flowing into the column, the solid particles move downward against a rising flow of air bubbles. Therefore air bubbles, carrying the hydrophobic mineral particles, rise to the surface of the pulp, while hydrophilic mineral particles remain in the pulp. After column achieved to the steady state, concentrate and tailings were collected separately for 1 or 2 minute; these were subsequently analyzed to obtain their ash content.

3.2. Experimental design

2-level factorial design was used to study the main parameters and their interaction for the coal concentrates from their wastes. Experimental design involved five parameters at two level (2^{5-1}) and two center points. Thus total number of experiments became 18, the optimum range of operating variables depends upon the chemical characteristics of the mineral and also the geometrical of column in use. The main parameters and their levels are given in Table 4.

Thus, to investigate the effects of parameters in separation of coal, three levels of them were selected. The ash content of the coal was considered as the response. In order to reduce unknown errors, experiments were done randomly. Experiment conditions and their responses are shown in Table 5.

Table 4. Selected parameters and their levels

Name	Main factors	Units	Low Level	Center Point	High Level
A	Kerosene dosage	g/t	2700	3000	3300
B	MIBC dosage	g/t	250	300	350
C	Air Rate	cm/s	0.96	1.19	1.42
D	Wash water Rate	Lit/min	0.46	0.72	0.98
E	Feeding Rate	Lit/min	3.6	4	4.4

Table 5. Design of experiment for evaluate the effects of main parameters on the coal washing improvement

Std	Run	A: Kerosene Dosage g/t	B:MIBCl Dosage g/t	C:Air Rate cm/s	D: Wash water Rate Lit/min	E:Feed Rate Lit/min	Response Ash Content
9	1	2700	250	0.96	0.98	3.6	12.76
15	2	2700	350	1.42	0.98	3.6	19.18
11	3	2700	350	0.96	0.98	4.4	14.21
8	4	3300	350	1.42	0.46	3.6	19.88
2	5	3300	250	0.96	0.46	3.6	12.11
13	6	2700	250	1.42	0.98	4.4	13.91
14	7	3300	250	1.42	0.98	3.6	16.33
5	8	2700	250	1.42	0.46	3.6	19.80
10	9	3300	250	0.96	0.98	4.4	13.65
4	10	3300	350	0.96	0.46	4.4	21.25
12	11	3300	350	0.96	0.98	3.6	14.28
1	12	3000	300	1.19	0.72	4	17.13
20	13	3000	300	1.19	0.72	4	17.35
18	14	2700	250	0.96	0.46	4.4	15.17
3	15	2700	350	0.96	0.46	3.6	14.04
16	16	3300	350	1.42	0.98	4.4	27.01
7	17	2700	350	1.42	0.46	4.4	30.75
6	18	3300	250	1.42	0.46	4.4	20.10

3.3. Results and Discussion

Analysis of parameters and interactions was conducted with ANOVA for all response values.

Table 6 shows an analysis of variance for the coal ash content data. The results observed in Table 6 demonstrate that main factors, superficial air velocity, feeding rate, superficial wash water velocity, MIBC dosage, and interactions (Kerosene Dosage x Wash water Rate, Kerosene Dosage x Feeding Rate, MIBC Dosage x Air Rate, MIBC Dosage x Feeding Rate, Wash water Rate x Feeding Rate) were effective within 95% confidence interval.

Effects of each factor on the ash content are elaborated in Figure 4. Figure 4 (a), illustrates the effect of frother concentration on the content ash of coal. Three level of MIBC was evaluated during the flotation experiments. Results in Figure 4 (a) indicate lower dosage have better effects on the ash content, but increasing of this parameter from level 250 g/t to 350 g/t causes a significant increase on the ash content. The frother decreases the size of the bubble in the slurry, thus increasing the surface area of the air fed into the column flotation machine [12, 13].

Table 6. Analysis of variance for coal ash content in the flotation

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	411.13	10	41.1135	34.10	0.0002
A-A: Kerosene dosage	1.43	1	1.434409	1.19	0.3172
B-B: MIBC dosage	84.52	1	84.51643	70.10	0.0002
C-C:Air Rate	152.99	1	152.9917	126.89	< 0.0001
D-D: wash Water Rate	29.61	1	29.60631	24.55	0.0026
E-E:Feed Rate	47.79	1	47.79	39.64	0.0007
AD	19.40	1	19.40	16.09	0.0070
AE	7.76	1	7.76	6.44	0.0442
BC	17.16	1	17.16	14.23	0.0093
BE	36.02	1	36.02	29.88	0.0016
DE	14.45	1	14.45	11.99	0.0134
Residual	7.23	6	1.21		
Lack of Fit	7.21	5	1.44	59.45	0.0981

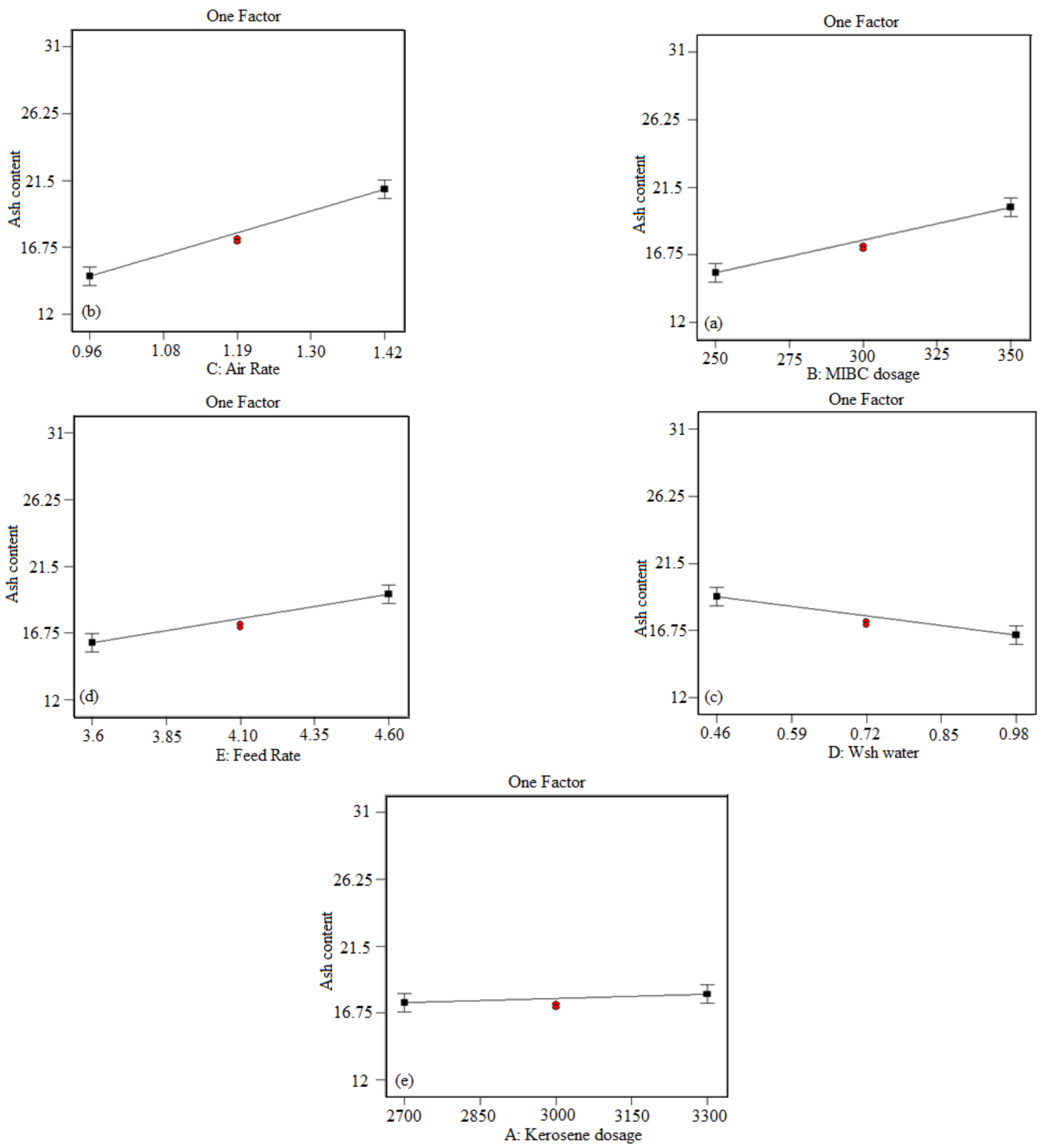

Figure4. The effect of (a) frother concentration (b) air rate (c) wash water rate (d) feed rate (e) collector dosage on the ash content

Therefore it increases the chance of more hydrophilic mineral particles to be floated to the cell surface and generally lead to lower grade. Air rate has an important effect on the ash content and the flotation mechanism. It was found that coal ash content increased in this air rate range (0.98-

1.42cm/s), (Figure 4(b)). Generally increasing air rate causes an increase in the gas holdup in the collection zone, thus increasing ash content [14, 15, 16, 17].

Changing wash water rate from its lower level to higher level causes a considerable improvement in grade of concentrate in Figure 4 (c).

The ash content of coal decreases with increasing wash water rate in the investigated range. Similarly, wash water rate had a significant effect on the coal ash content. The wash water rinses particles at the end of bubbles which are almost impurities from the froth and back into the collection zone and prevent them from passing to concentrate; thereby ash content in the coal concentrate will decrease. Also high water rates may have a negative impact on concentrate grade by increasing axial froth mixing and reducing the wash water effectiveness [18]. The effect of feeding rate was evaluated in the investigated range. Figure 4 (d) shows that high feeding rate caused the increase in ash content. With the decrease in feed rate, time spent by coal particles in column (retention time) increased and thus led to an increase in the ash content [19, 20]. The effect of collector dosage was examined in the investigated range. The results are shown in Figure 4 (e). Increasing of the collector dosage did not make a change in the coal ash content.

4. Optimum conditions

Finally, using these findings about influential parameters on the process, optimum working conditions could be predicted. Design Experts software made it possible to use the fitted model to estimate parameter levels that would maximize the recovery of coal while simultaneously keeping the ash content of coal to a minimum. Figure 5 illustrates the results of optimization: at the optimized conditions coal recovery is 28.51% and coal ash content is12.11% the levels of the parameters are; kerosene, 2909 g/t; superficial air velocity, 0.96 cm/s; feeding rate, 3.6 l/min; superficial wash water velocity, 0.98 l/min; frother dosage, 350 g/t.

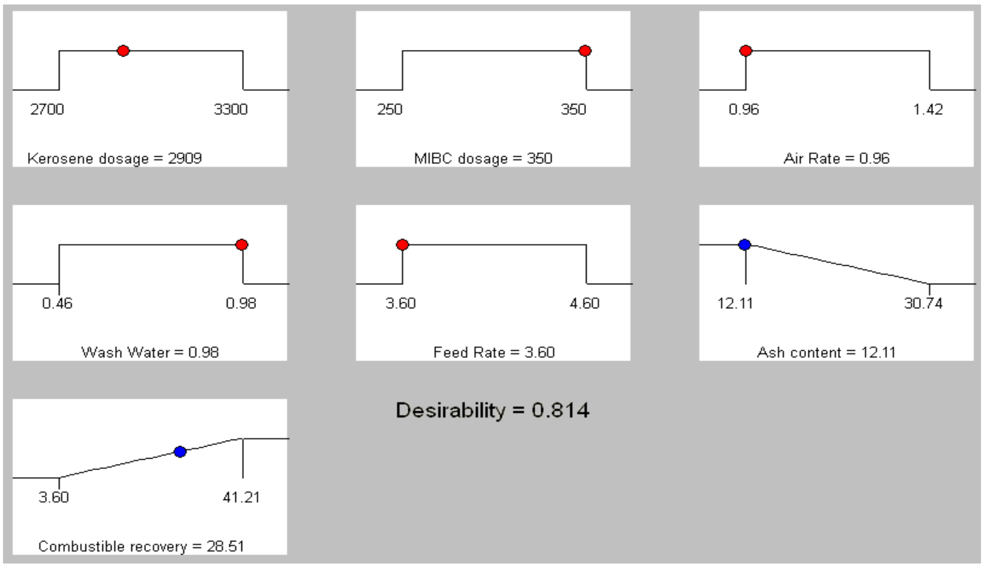

Figure5. ramps

5. Conclusions

The conclusions obtained from this study are as follows:

1- Mixture design, as a statistical method, was used to Clean the coal tailing (<0.6 mm) of Alborz Markazi coal washing plant having 56% ash in both a conventional flotation cell and a laboratory column flotation

2- The effect of the reagent type/dosage on the separation efficiency was investigated by conventional flotation to determine the approximate amount of reagent type/dosage for experiments with column flotation. It was shown that optimum conditions are collector type: kerosene, collector dosage: 3000 g/t, MIBC dosage: 300 g/t.

3- As a result, optimum conditions were found to be, kerosene, 2909 g/t; superficial air velocity, 0.96 cm/s; feeding rate, 3.6 l/min; superficial wash water velocity, 0.98 l/min; frother dosage, 350 g/t. under these conditions, ash content and recovery for concentrate was 12.11%, 28.51% respectively.

4- The results indicated that main factors; superficial air velocity superficial, frother dosage, feeding rate and wash water velocity and interactions (kerosene Dosage x Wash water Rate, kerosene Dosage x Feeding Rate, MIBC Dosage x Air Rate, MIBC Dosage x Feeding Rate) statistically were effective within 95% confidence interval on ash content of coal.

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