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The Flotation System Optimization in Alborz-Sharghi Coal Washing Plant; A Laboratory Study

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Abstract
This paper tries to determine an optimum condition for the flotation operation of the Alborz-Sharghi coal washing plant. For this purpose, a series of comprehensive experiments have been conducted on representative samples from feed of the flotation system of the plant. Four operational variables such as the collector dosage (Fuel oil), the frother dosages (MIBC), the pulp density percent and the impeller speed were taken into account. After obtaining representative samples, 81 required experiments were designed using the orthogonal array (34) of Taguchi method. Three levels of the variables amount including low, base and high were considered for the experiments. The most obvious finding to emerge from this study was that the optimum flotation recovery (61.09 %) is obtained in the base level (L-2) of the collector dosage, the lowest level (L-1) of MIBC and the highest levels (L-3) of the pulp density and the impeller speed. The sensitivity analysis of the variables also indicated that the increase in the collector dosage causes to increase in the total recovery of the flotation and the coal quality. Besides, the largest effect on total recovery was clearly related to the pulp density levels. The increase in values of the pulp density causes to decrease in the recovery values.

Keywords: *Flotation system, Operational variables, Optimum recovery, Alborz-Sharghi coal washing plant.*

1. Introduction

The Alborz-Sharghi coal washing plant, which is located in the Semnan Province, in north-east of Iran, with an annual production of 300,000 tonnes of washed coal is one of the largest coal producers in the Middle-East [1,2]. The extracted coal from state mining including the Tazareh, Razi, Tabas mines and some of the private mines which are located in the region are currently washed in the Alborz Sharghi coal washing plant to raise the coal grade. The net recovery by the plant is less than 50%. The flowsheet of the processing circuit of the plant setup is shown in Figure 1.

The coal extracted from different mines having at least 25% ash content and 12% moisture falls into a bunker by loaders. The particles +12 mm separates by a screen and the others insert to feeder. The ordinary coal processing methods in the plant include jig machine and flotation process. Raw coals are classified to particle size distribution including +1 mm and -1 mm. The feed of the jig machine consists of the particle size including +1 mm and overflow discharge of hydro-cyclone. The tailings of each jig are conducted to a tailings bunker by elevators. It should be noted that the concentrate of jig consists of three particle size distribution (+10 mm, +1-10 mm and -1 mm). The particle size distribution including +10 mm directly falls to the conveyor of output concentrate of the plant. Besides, the particle size distribution -1 mm with the raw coals including particle size -1 mm which are resulted from initial screen conduct to a classifier. There are three different particle size distributions in the classifier: a) the particle size including +1 mm which is fed of hydro-cyclone; b) the particle size including -1 mm which is fed of flotation cells and c) water which is rebounded to the plant. The feed of flotation cells conduct to two conditioners where some frothers (Pine oil) and collectors (Fuel oil) are added to them. However, the MIBC is recently used instead of gasoline in the flotation circuit. The flotation circuit consists of 7 rows including 3 cells which are involved four scavenger cells and three rafer cells. The concentrate of flotation conducted to a conveyor of coals which are washed. Moreover, the tailings of flotation enter the tailings dam. It should be considered that two spirals have been recently added to the plant. The overflow discharge of hydro-cyclone is considered as feed of the spirals which are middling of the spirals. Indeed, the feed of jig consists of the middling of the spirals and the particle size distribution including +1 mm instead of discharge of hydro-cyclone.

For many years, there has been an increasing amount of literature on the improvement of operating variables including pulp density, impeller speed, and type and dosage of collector and frother in coal flotation operations [3-25]. Vanangamudi *et al*. [3] suggested an efficiency index of a coal flotation operation by studying four levels of collector and frother dosage. They found out that maximizing the efficiency index did not correspond to maximum yield alone. Naik *et al*. [13] investigated three reagents for coal flotation including sodium meta-silicate, collector (Kerosene) and frother (MIBC) on recovery of the operation. They concluded that the sodium meta-silicate has positive effect on recovery whereas the Kerosene and MIBC have positive effect on recovery and negative effect on grade. Kor *et al*. [19] investigated the particle size effect on coal flotation kinetics applying different regression analyses. Their results revealed that the quadric regression shows better correlation than the other regressions for different particle size fraction. Bahri *et al*. [21] studied the effects of reagent type/dosage on Alborz- Markazi coal tailings with a conventional and column flotation. The effects of the air rate, the feeding rate, the washing water rate, the frother concentration, and the collector dosage were evaluated using column flotation.

It is becoming increasingly difficult to ignore the importance of the economy of a coal washing plant like the case of the present study. So far, however, there have been no comprehensive researches which compare differences of the amounts of the operational variables in total recovery of the floatation system of the case of this paper. This research will consider the investigation of the optimal recovery of flotation operation in Alborz-Sharghi coal washing plant. For this purpose, the effects of the most important operational variables including pulp density, impeller speed, and amount of collector/ frother are studied on recovery of the flotation system.

2. Experimental work

One hundred coal samples, 2 kg each, were taken from the feed of the flotation circuit of the Alborz-Sharghi coal washing plant. Then, the representative samples were transported to the laboratory of mineral processing for further investigations, where the tests are performed using two laboratory scale flotation cells. The results of primary analysis of the samples are presented in Table 1.

The effects of pulp density (%) (the solid content percent of the pulp), impeller speed (rpm), collector (fuel oil in g/L) and frother

(Methyl Isobutyl Carbonyl- MIBC- in g/L) on the flotation operation were considered. The studied variables and their levels are presented in Table 2. All the experiments were conducted under identical conditions except the variation of the desired variable. In this study, we utilized standard of perpendicular arrays of Taguchi [26].

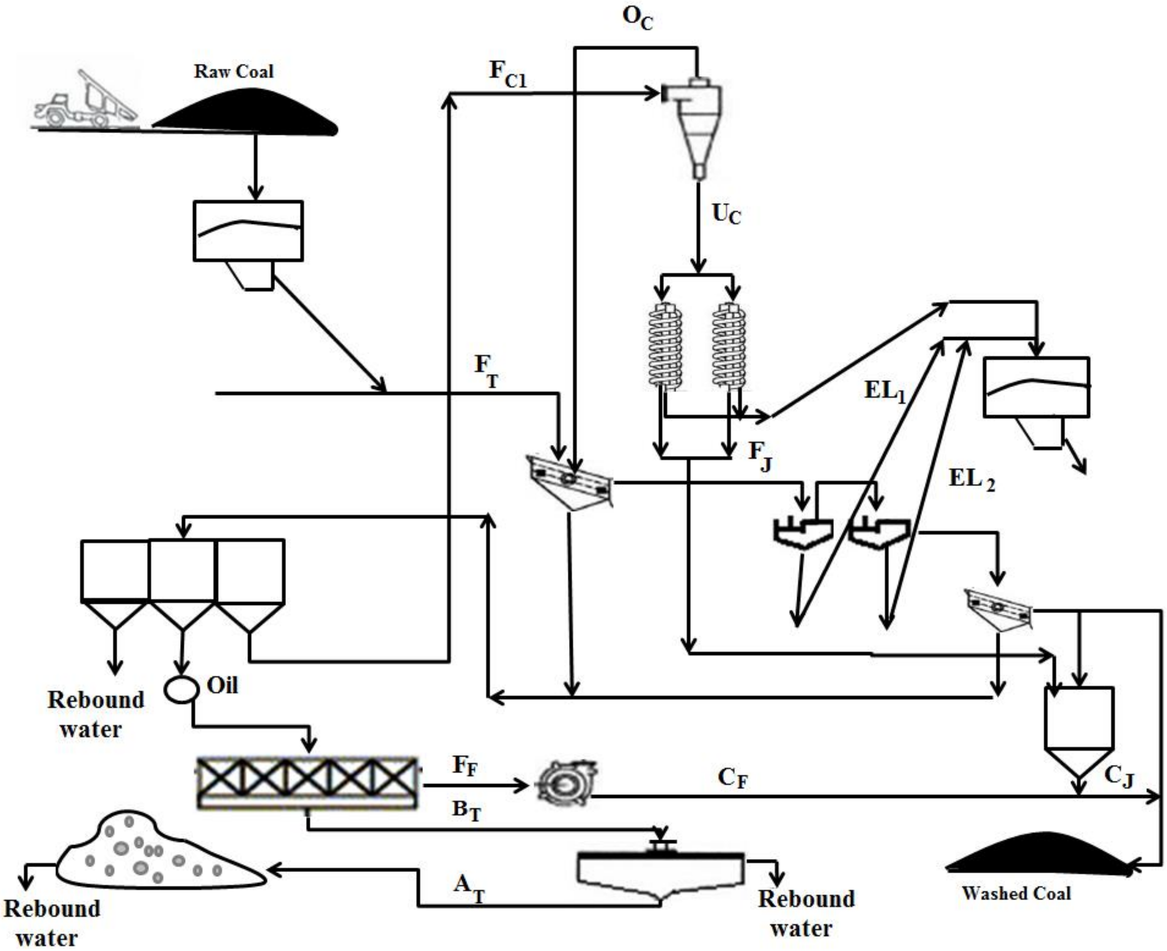


Fig. 1. Processing circuit of the Alborz-Sharghi coal washing plant

Table 1. Results of analysis of the coal samples (in percentage)

Variable	Number of samples	Min.	Max.	Mean	Standard deviation	With 95 % confidence level
Ash	100	19.39	63.11	44.73	10.17	(40.77; 47.52)
Volatile matter	100	21.58	36.62	30.95	05.50	(29.54; 32.83)
Plasticity	100	7.00	22.00	16.00	04.56	(14.25; 15.66)

Table 2. Taguchi method applying 3^4 orthogonal array for the coal flotation

Variable	Low Level (L-1)	Base Level (L-2)	High Level (L-3)
Pulp density (%)	5	10	15
Impeller speed (rpm)	1000	1250	1500
Collector (fuel oil in g/L)	1000	1500	2000
Frother (MIBC in g/L)	50	100	200

The experiments were conducted based on the orthogonal arrays of Taguchi which have been firstly presented in 1987 [26]. Eighty one sets (L_{81}) of trials were found to be required according to the Equation (1):

$$N = 3 * n \quad (1)$$

where N is number of trials and n is number of variables.

The lower, the base and the higher levels were designated as “L-1”, “L-2” and “L-3”, respectively. The matrix of four variables and their levels are presented in Table 3.

Table 3. Orthogonal array (3^4) of Taguchi matrix for experiments of the coal flotation

Number of experiment	Fuel oil	MIBC	Pulp density	Impeller speed
1	L-1	L-1	L-1	L-1
2	L-1	L-1	L-1	L-2
3	L-1	L-1	L-1	L-3
4	L-1	L-1	L-2	L-1
5	L-1	L-1	L-2	L-2
6	L-1	L-1	L-2	L-3
7	L-1	L-1	L-3	L-1
8	L-1	L-1	L-3	L-2
9	L-1	L-1	L-3	L-3
10	L-1	L-2	L-1	L-1
11	L-1	L-2	L-1	L-2
…	…	…	…	…
…	…	…	…	…
…	…	…	…	…
…	…	…	…	..
…	…	…	…	…
…	…	…	…	…
70	L-3	L-2	L-3	L-1
71	L-3	L-2	L-3	L-2
72	L-3	L-2	L-3	L-3
73	L-3	L-3	L-1	L-1
74	L-3	L-3	L-1	L-2
75	L-3	L-3	L-1	L-3
76	L-3	L-3	L-2	L-1
77	L-3	L-3	L-2	L-2
78	L-3	L-3	L-2	L-3
79	L-3	L-3	L-3	L-1
80	L-3	L-3	L-3	L-2
81	L-3	L-3	L-3	L-3

3. Results and Discussion

To find out the optimum recovery of the flotation operation, the samples which were taken from feed of the system were investigated at the laboratory according to Tables 2 and 3. The experiments were carried out in two one-liter Denver laboratory-scale flotation machines, as well as a high temperature oven to measure the coal content of the samples. Then, the experiments of determination of coal ash were conducted before and after flotation tests on feed, concentrate and tailings of each experiment (Table 4). Besides, the measured recoveries of the experiments are presented in Table 5. The recovery values for both the concentrate and the tailings were calculated and the total recovery were achieved. The results revealed that the optimum value of the flotation recovery (61.09%) is seen in the base level (L-2) of the collector dosage, the lower level (L-1) of MIBC and the higher levels (L-3) of the pulp density and the impeller speed.

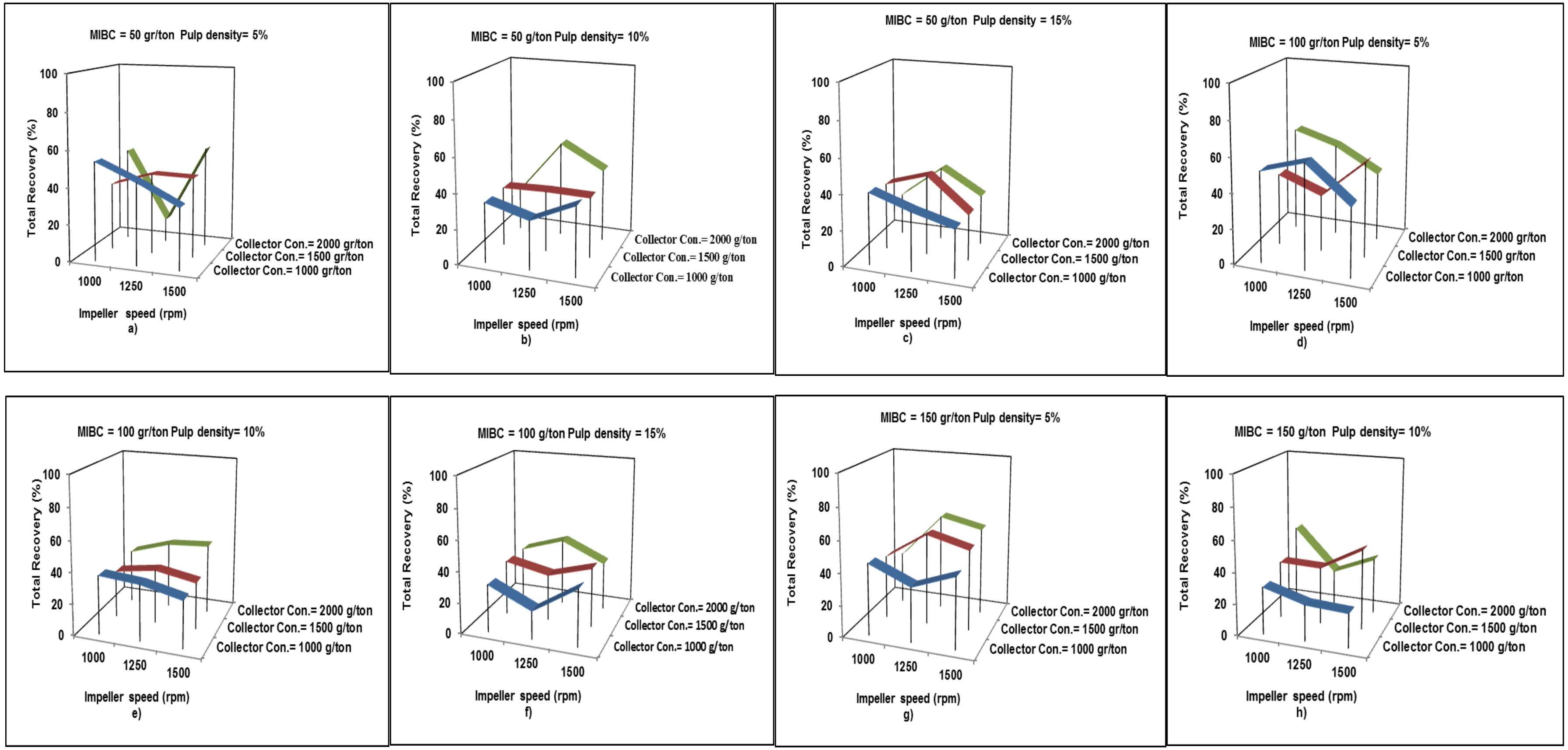
Sensitivity analysis of the effect of the variables on total recovery is comprehensively shown in Figures 2 to 6.

Table 4. Analysis of the feed, concentrate and tailings of the flotation experiments

Number of experiment	Feed ash (%)	Concentrate ash (%)	Tailings ash (%)
1	31.91	17.54	78.49
2	30.38	19.71	83.40
3	32.65	24.75	85.59
4	35.39	26.92	81.87
5	33.48	27.12	82.84
6	36.10	26.00	81.16
7	35.00	24.71	73.75
8	30.95	23.55	79.27
9	35.68	29.38	82.01
10	31.44	71.94	82.37
11	33.85	16.66	83.55
…	…	…	…
…	…	…	…
…	…	…	…
…	…	…	…
…	…	…	…
…	…	…	…
70	30.22	22.26	84.73
71	34.27	22.83	77.80
72	34.79	27.16	85.67
73	29.53	22.22	83.98
74	34.46	16.43	85.94
75	33.22	17.99	85.93
76	33.24	19.34	84.40
77	31.70	26.22	85.71
78	32.07	23.49	86.50
79	32.29	21.31	84.34
80	34.37	23.79	85.50
81	29.37	24.66	77.78

Table 5. The recovery of the flotation experiments

Number of experiment	Concentrate recovery (%)	Tailings recovery (%)	Total recovery (%)
1	92.55	58.00	53.67
2	96.01	46.00	44.15
3	97.22	34.04	33.09
4	95.67	35.66	34.12
5	97.06	28.24	27.41
6	94.60	41.17	38.94
7	91.53	44.21	40.47
8	96.01	34.01	32.66
9	96.65	27.51	26.59
10	94.61	54.89	51.94
11	93.61	63.43	59.38
…	…	…	…
…	…	…	…
…	…	…	…
…	…	…	…
…	…	…	…
…	…	…	…
70	97.21	35.73	34.73
71	92.97	47.25	43.93
72	97.13	32.11	31.19
73	97.31	33.66	32.75
74	94.44	64.69	61.09
75	95.28	57.99	55.25
76	95.01	54.25	51.54
77	98.08	24.91	24.43
78	97.30	36.73	35.73
79	95.97	45.50	43.67
80	96.21	42.65	41.03
81	97.21	23.48	22.83



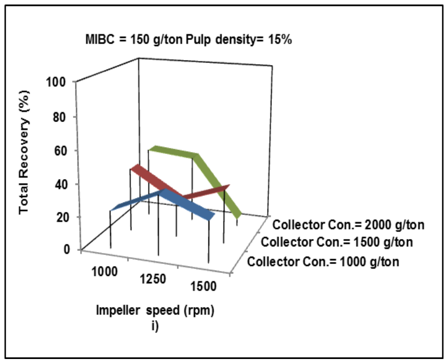


Fig. 2. The effect of impeller speed on the total recovery in different levels of the collector*

* The amount of collector in 1000, 1500 and 2000 (g/lit) is designated as " ", " " and " ", respectively; a) MIBC= 50 (g/ton), The pulp density= 5%; b) MIBC= 50 (g/ton), The pulp density= 10%; c) MIBC= 50 (g/ton), The pulp density= 15%; d) MIBC= 100 (g/ton), The pulp density= 5%; e) MIBC= 100 (g/ton), The pulp density= 10%; f) MIBC= 100 (g/ton), The pulp density= 15%; g) MIBC= 150 (g/ton), The pulp density= 5%; h) MIBC= 150 (g/ton), The pulp density= 10%; i) MIBC= 150 (g/ton), The pulp density= 15%

As it is evident from Figure 2, the effect of the impeller speed on total recovery is related to different parameters. The total recovery will increase in the higher quantities of MIBC and fuel oil while the pulp density varies from minimum to mean values.

According to Figure 3, the increase in the pulp density percent causes to decrease in the total recovery value occurring at the low rates of the impeller speed and low quantity of fuel oil. This trend can be changed in the higher collector dosages. Eventually, the increase of the pulp density has an undesirable effect on the trend of the total recovery.

As it is interpreted from Figure 4, the recovery will have a gradual ascending trend in low rates of the impeller speed and in higher collector amounts. However, the increasing values of the recovery may occur in the higher speed of the impeller and the lower values of the pulp density. It seems that in the higher quantity of the pulp density, the higher dosage in MIBC results in a descending trend in the recovery values except while the collector dosage is at its maximum level.

Figure 5 shows the effect of the impeller speed on the total recovery in different levels of MIBC. According to the plots in this figure, the recovery generally has a low value in higher values of the pulp density. Besides, the increase in rates of the impeller causes to reduce the recovery when both the collector and the frother have high quantities. Generally, high rates of the impeller have a negative effect on the recovery.

The effect of the solid percent on the recovery in different levels of MIBC is depicted in Figure 6. The higher the value of the solid percent, the recovery will reduce. However, the rate of changes in the recovery can be slightly reduces at higher dosages of the collector and the frother.

The results revealed that the higher values of the fuel oil and MIBC cause to decrease the recovery. Besides, variation in the collector dosage shows a more important influence on the total recovery compared to the frother changes.

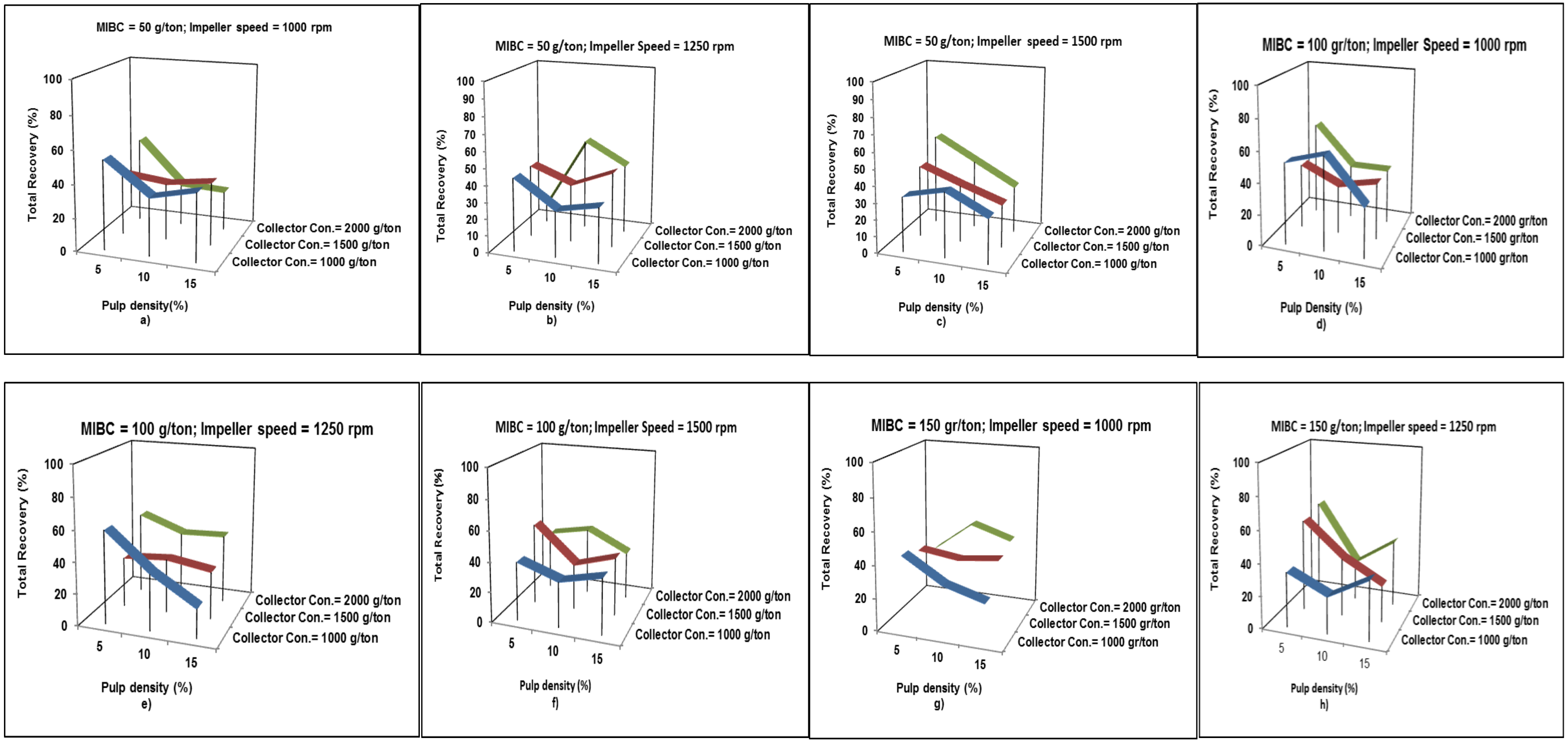
Average values of coal assay in different levels of the variables are presented in Table 6 The effects of the variable levels on variation of average values of the total recovery are also demonstrated in Figure 7.

As it is seen in Figure 7 and Table 7, an increase in the collector dosage results in increase in the total recovery of the flotation and the coal assay. Also, another important finding is that growth in levels of MIBC dosage causes little effect on the total recovery. However, it falls in the highest level of MIBC. The bigger effect on total recovery is clearly related to the pulp density level. Increase in values of the pulp density causes to decrease in the recovery value. It means that for reducing the ash content, the lower levels of the pulp density should be used. Another interesting finding is that the higher rate of the impeller has a little increasing effect on the total recovery of the flotation.

The following factors in the experiments were compared for optimization of the flotation operation (Table 7):

- Ash values in concentrate;
- Ash values in tailings;
- The concentrate recovery;
- Total recovery of the flotation.

According to Table 7, the lowest amount of ash in concentrate (8.02%) occurs in the highest level (L-3) of the collector, the lowest level (L-1) of the frother and the base levels (L-2) of the pulp density and impeller speed. The best condition of the concentrate recovery happens in the base level (L-2) of the collector, in the lowest levels (L-1) of the frother and the pulp density and in the highest level (L-3) of impeller speed. However, the higher ash contents in the concentrate (24.27%) and tailings (85.35%) are the worst in this condition. Finally, the most interesting finding is that the best total recovery (61.09%) occurs in the base level (L-2) of the collector dosage, the lowest level (L-1) of MIBC and the highest levels (L-3) of the pulp density and the impeller speed.



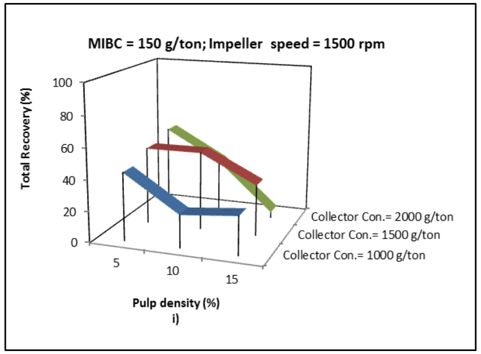
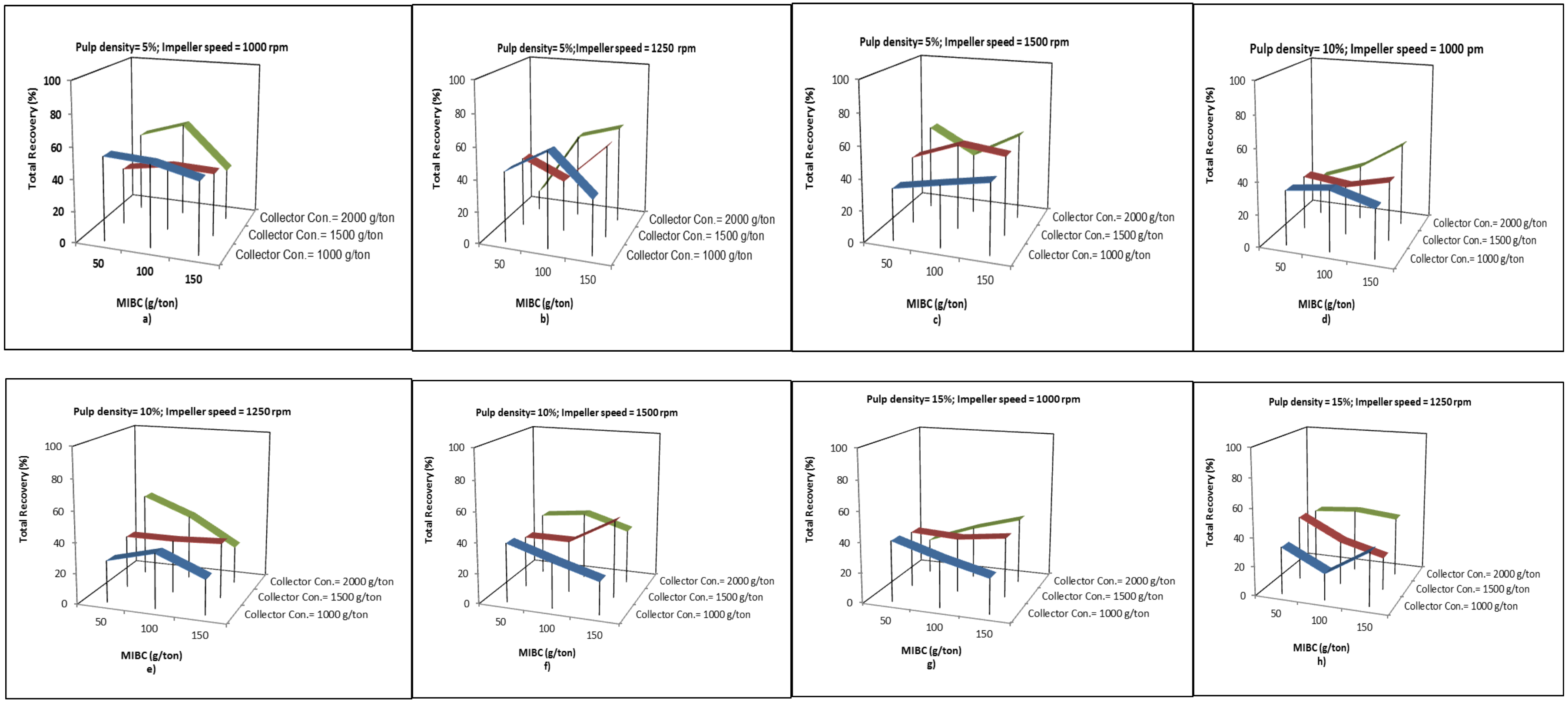


Fig. 3. The effect of pulp density on the total recovery in different levels of the collector*

* The amount of collector in 1000, 1500 and 2000 (g/lit) is designated as " ", " " and " ", respectively. a) MIBC= 50 (g/ton), Impeller speed= 1000 (rpm); b) MIBC= 50 (g/ton), Impeller speed= 1250 (rpm); c) MIBC= 50 (g/ton), Impeller speed= 1500 (rpm); d) MIBC= 100 (g/ton), Impeller speed= 1000 (rpm); e) MIBC= 100 (g/ton), Impeller speed= 1250 (rpm); f) MIBC= 100 (g/ton), Impeller speed= 1500 (rpm); g) MIBC= 150 (g/ton), Impeller speed= 1000 (rpm); h) MIBC= 150 (g/ton), Impeller speed= 1250 (rpm); i) MIBC= 150 (g/ton), Impeller speed= 1500 (rpm)



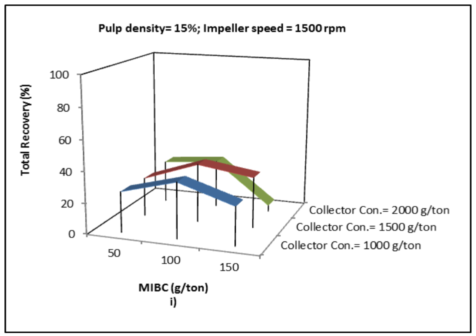
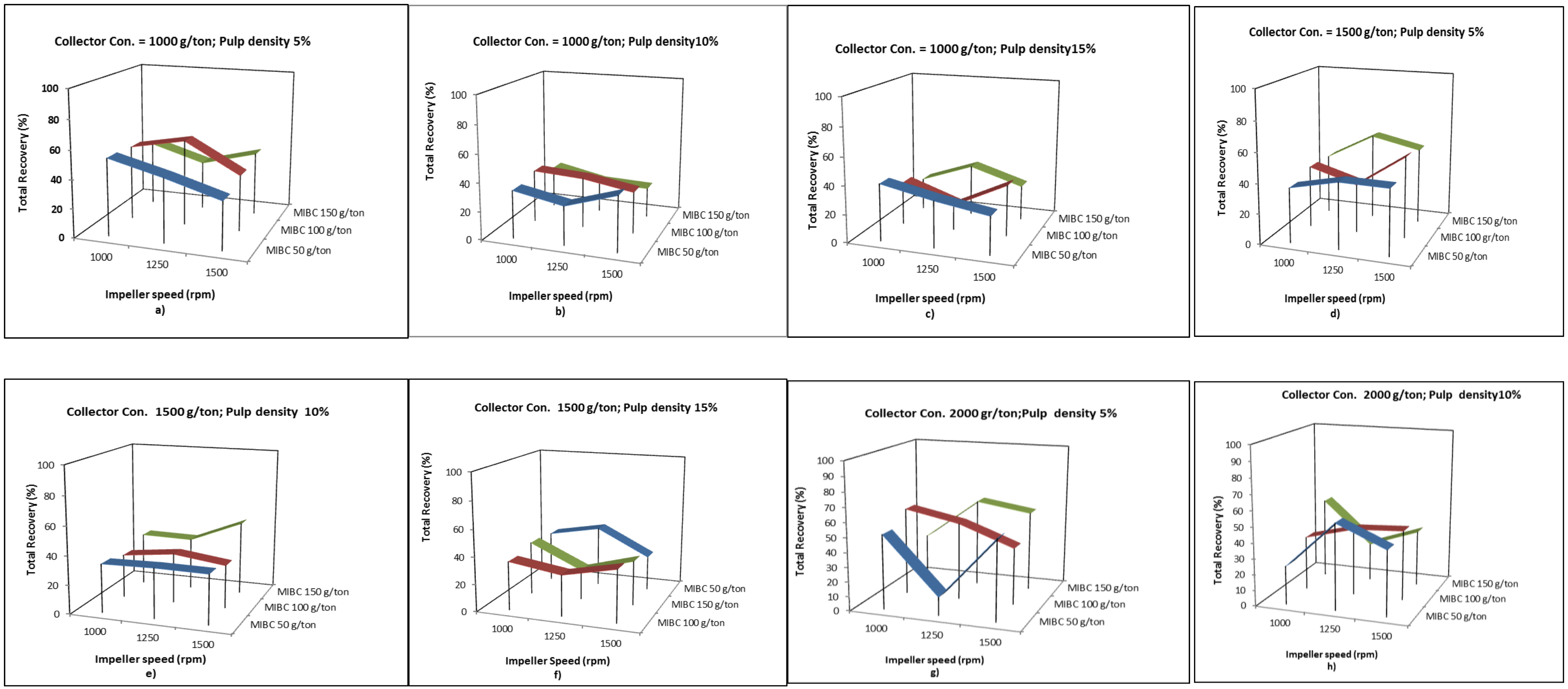


Fig. 4. The effect of MIBC on the total recovery in different levels of the collector*

* The amount of collector in 1000, 1500 and 2000 (g/lit) is designated as " ", " " and " ", respectively. a) The pulp density=5%, Impeller speed= 1000 (rpm); b) the pulp density=5%, Impeller speed= 1250 (rpm); c) the pulp density=5%, Impeller speed= 1500 (rpm); d) the pulp density=10%, Impeller speed= 1000 (rpm); e) the pulp density=10%, Impeller speed= 1250 (rpm); f) the pulp density=10%, Impeller speed= 1500 (rpm); g) the pulp density=15%, Impeller speed= 1000 (rpm); h) the pulp density=15%, Impeller speed= 1250 (rpm); i) the pulp density=15%, Impeller speed= 1500 (rpm)



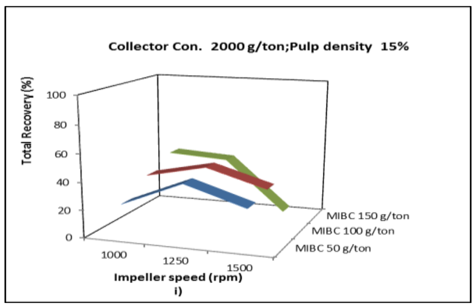


Fig. 5. The effect of impeller speed on the total recovery in different levels of MIBC*

The amount of MIBC in 50, 100 and 200 (g/lit) is designated as " ", " " and " ", respectively. a) Collector con. = 1000 (g/ton), pulp density= 5%; b) Collector con. = 1000 (g/ton), pulp density= 10%; c) Collector con. = 1000 (g/ton), pulp density= 15%; d) Collector con. = 1500 (g/ton), pulp density= 5%; e) Collector con. = 1500 (g/ton), pulp density= 10%; f) Collector con. = 1500 (g/ton), pulp density= 15%; g) Collector con. = 2000 (g/ton), pulp density= 5%; h) Collector con. = 2000 (g/ton), pulp density= 10%; i) Collector con. = 2000 (g/ton), pulp density= 15%

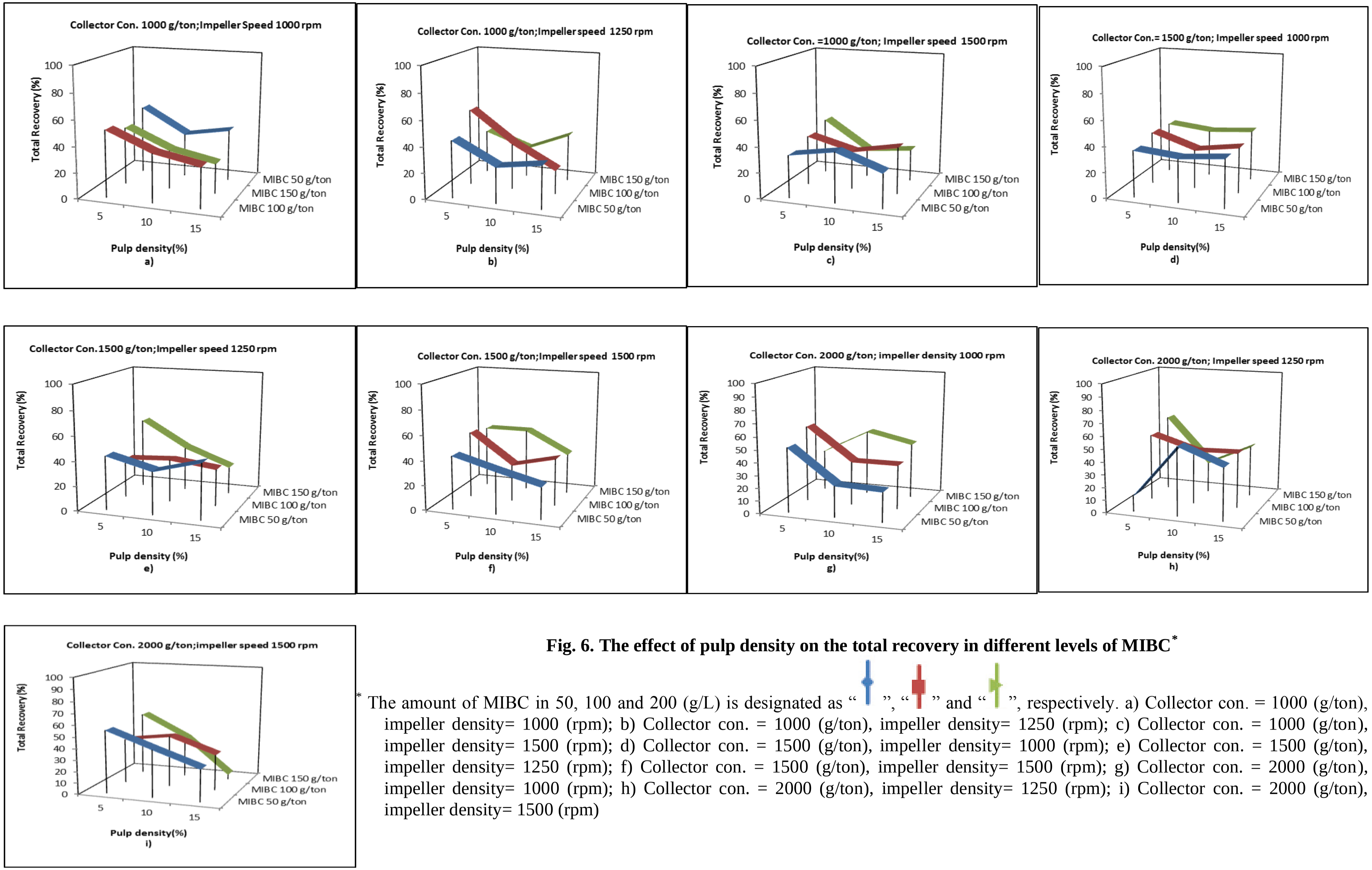


Fig. 6. The effect of pulp density on the total recovery in different levels of MIBC*

* The amount of MIBC in 50, 100 and 200 (g/L) is designated as " ", " " and " ", respectively. a) Collector con. = 1000 (g/ton), impeller density= 1000 (rpm); b) Collector con. = 1000 (g/ton), impeller density= 1250 (rpm); c) Collector con. = 1000 (g/ton), impeller density= 1500 (rpm); d) Collector con. = 1500 (g/ton), impeller density= 1000 (rpm); e) Collector con. = 1500 (g/ton), impeller density= 1250 (rpm); f) Collector con. = 1500 (g/ton), impeller density= 1500 (rpm); g) Collector con. = 2000 (g/ton), impeller density= 1000 (rpm); h) Collector con. = 2000 (g/ton), impeller density= 1250 (rpm); i) Collector con. = 2000 (g/ton), impeller density= 1500 (rpm)

Table 6. Average values of the coal assay in different levels of the variables

Variable	Level	Average value of coal assay in concentrate (%)	Average value of coal assay in tailings (%)	Average value of total recovery of the flotation (%)
Fuel oil	L-1	78.88	15.63	35.19
	L-2	83.44	18.29	37.99
	L-3	78.53	21.72	39.46
MIBC	L-1	79.92	18.75	36.92
	L-2	79.62	17.99	38.82
	L-3	81.31	18.89	36.91
Pulp density	L-1	82.39	17.21	45.33
	L-2	79.55	17.51	35.38
	L-3	78.91	20.92	32.10
Impeller speed	L-1	80.72	18.84	38.33
	L-2	80.06	18.05	37.77
	L-3	80.07	18.74	36.55

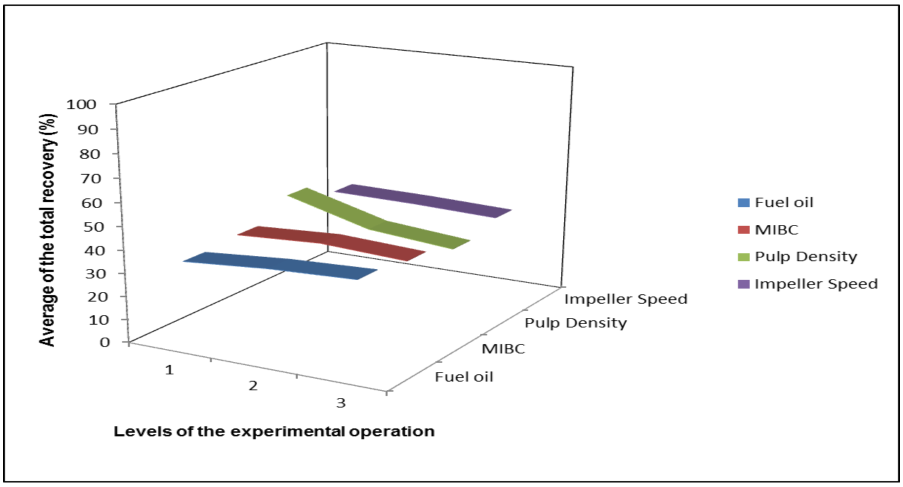


Fig. 7. Variations of the total recovery average in different levels of the operational variables

Table 7. Optimum conditions for the best flotation performance

Optimum condition	Fuel oil	MIBC	Pulp density	Impeller speed	Ash in concentrate (%)	Ash in tailings (%)	Recovery of concentrate (%)	Total recovery (%)
Minimum of ash in concentrate	L-3	L-1	L-2	L-2	8.02	78.74	97.12	54.16
Maximum of ash in tailings	L-3	L-2	L-2	L-3	20.92	87.38	96.85	44.55
Maximum recovery of concentrate	L-2	L-1	L-1	L-3	24.27	85.35	99.22	12.48
Maximum of total recovery	L-2	L-1	L-3	L-3	16.43	85.94	94.44	61.09

4. Conclusions

In this paper, the most important and influencing operating variables of coal flotation procedure in Alborz-Sharghi coal washing plant in northeast of Iran were investigated. The operating variables considered in this research include pulp density, impeller speed, and amount of collector (fuel oil) and frother (MIBC) in three levels (low, base and high). For this purpose, representative samples were firstly taken from feed of the flotation system. Then, the design of required experiments was conducted applying Taguchi method by using an orthogonal array. The results revealed that the optimum recovery of the flotation system (61.09%) will be achieved when the pulp density, impeller density, and amount of collector and frother are equal to 15 %, 1500 rpm, 1500 g/L and 50 g/L, respectively. The sensitivity analysis indicated that the higher values of the fuel oil and MIBC cause to decrease the recovery of the flotation operation. Besides, the variations in the collector dosage have more effect on the total recovery of flotation compared to the frother changes.

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