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Reducing the Concentrate Ash Content of Coal Flotation by Changing the Operating Parameters

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ABSTRACT

One of the most important industries in the country is the steel industry, which is the most important coke consumer in this industry. One of the important parts of the coke production is the appropriate quality of coal, which the ash content should be low according to the standards. In this research, an attempt was made to increase the recovery of the flotation unit and reduce the ash content of the Alborz-Sharghi coal washing plant. Three stages of flotation tests were designed. The amounts of kerosene as the collector and MIBC as the frother were set and the best result was obtained in the slurry solids concentration of 10 percent and the particle size of -50+500 microns, which decreased the ash content from 14.6% to 5.9% and increased the recovery from 49. 6% to 74.6%. After applying the circulating load, the recovery and ash both decreased and the total recovery reached 69.9% and the ash of the final product reached 18.6%.

KEYWORD

Ash, Coal, Flotation, slurry solids concentration, particle size, circulating load

I. INTRODUCTION

Coal ash is one of the most important factors that often enters the slag phase in the blast furnace, and with the increase in ash content, the volume of slag increases and, as a result, the energy consumption increases. The presence of ash in a large proportion causes a drop in the quality of the produced coke and controls the efficiency of the blast furnace. Also, the total removal of the ash causes a drop in the production level. Because, tailing particles have some amount of coal. However, ash reduction is one of the main efficiencies of coal washing. The ideal coke ash in the blast furnace is less than 9% (Eun, 2012). Flotation, based on the hydrophobic property of coal and hydrophilicity of ash and pyrite, performs the separation operation in a fluid environment with airflow. The size limit of this method is between 74 and 800 microns (Rezaei, 1996). The parameters investigated in the flotation operation in this research include slurry solids concentration and particle size. Fixed parameters include the type of collector and frother and sample preparation time. Also, in this research, the effect of circulating load in the flotation system has been investigated. The experiments were conducted in three stages. In the first and second stages, a detailed investigation of the effect of slurrysolids concentration and particle size was carried out. After obtaining the best conditions in the third stage by defining the flotation system and applying the obtained conditions, the trend of the effect of the circulating load on the ash content of the product was evaluated.

In 2002, Sais et al. compared ionic and non-ionic collectors in coal particle flotation. Some ionic collectors were used as an alternative to conventional non-ionic collectors to obtain clean concentrates from fine coal samples containing 46.1% ash. They used a mixture of kerosene and pine oil as conventional collectors and commercial fatty acids as ionic collectors. The flotation results showed that the conventional collectors could not reduce the concentrate ash by less than 21%, while the ionic collectors were significantly better at reducing ash by 16%, but their efficiency was lower (Sis et al., 2003). In the same year, Akdemir and Sonmez researched on the effect of particle size, impeller speed and pulp density on flotation, coal bubbles and related tailings, which were mainly kaolinite and illite. The experimental work showed that particle size is the most important parameter affecting the recovery and behavior of bubbles. The effect of impeller speed and pulp density on bubbles was fewer. Lower agitation or solid density with higher kerosene concentrations yielded more selective froth products at the same level of recovery and less bubbles (Akdemir and Sönmez, 2003). Peng et al. (2015) worked on the impact of ultra-fine coal

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particles on the flotation of coarse coal particles investigated in this work. Flotation experiments of three coal samples were conducted. The results showed that the recovery of coarse coal particles (N74 μm) decreases when low-ash ultra-fine coal particles are added into coal samples, In contrast, the addition of high-ash ultra-fine coal particles has a very slight impact on it. Measurements of contact angle and wetting heat were conducted to examine the interaction between ultra-fine coal particles and flotation reagents. The results showed that low-ash ultra-fine coal particles have very strong adsorption to both collector and frother. In contrast, high-ash ultra-fine coal particles have strong adsorption to collector but weak adsorption to frother, which indicates that frother may play a more important role in the recovery of coarse coal particles (Peng et al., 2015). Liang et al. (2016) researched on the effect of the polyaluminum chloride (PAC) on reducing the kaolinite entrainment in coal flotation. The settling experiments show that the settling velocity of kaolinite was the highest when pH was around 5.5. With the addition of PAC, the settling velocity of kaolinite increased at low PAC concentration, whereas it reduced at high PAC concentration. The flotation results show that PAC significantly reduced the concentrate ash content (Liang et al., 2016). Li et al. (2019) studied the effect of ultra-fine coal on the flotation behavior of silica in subbituminous coal reverse flotation. In this study, X-ray Photoelectron Spectroscopy (XPS) was used to analyze the elements on the surface of sub-bituminous coal, and reverse flotation was introduced to float sub-bituminous coal. The effect of ultra-fine coal on the flotation behavior of silica in coal reverse flotation was discussed by comparing the flotation performance with two different artificial mixed flotation feedings, with ultra-fine coal (UFC, -45μm) or without ultra-fine coal. The comparison results showed that the existence of UFC reduced the flotation rate and the recovery of silica, as well as the separation efficiency of sub-bituminous coal reverse flotation. Compared to the flotation performance of feeding with UFC, the concentrate ash content of feeding without UFC was lower (9.18%), and the separation efficiency was higher (68.69%). Total Organic Carbon Analyzer was used to test the adsorption quantity of collector by coal and silica to explain the mechanism. Conclusions were obtained that ultra-fine coal particles could adsorb more collectors due to their larger specific surface area, leading to less collector left in the pulp to float silica particles. Selective flocculation reverse flotation method could increase the separation efficiency of coal reverse flotation with appropriate dosage flocculant (Li et al., 2019). Ying et al. (2019) investigated the effect of particle size on coal ash flotation behavior in their research. Three particle size fractions, −125+74, −75+45, and −45 microns, and an unclassified −500 microns particle size fraction of coal ash were used to study the fundamental properties by measuring induction time, contact angle, and heat of wetting. In addition, flotation kinetics experiments of coal ash with different particle size fractions were conducted. The results showed that the particle size significantly affects the flotation kinetics of coal ash and the average particle size sections of -125+74 microns and -75+45 microns had better flotation performance and higher flotation rate than the fine particle size of -45 microns. Six flotation kinetic models were used to fit the experimental data of unburned carbon recovery in coal ash flotation. The data fitting results showed that for each particle size fraction, coal ash flotation can be best described by the first-order classical model (Li et al., 2020). The main difference between this research with others is that it's been trying to keep the executive terms in the plant of East Alboraz coal washing for the minimum changes in the plant instruction. Even the type of chemical using materials was considered constant. The executive terms of the East Alborz coal washing plant optimization were put on the agenda.

II. MATERIALS AND METHODS

Coal prepared from East Alborz plant feed and extracted from the Tazare coal mine was analyzed and the results are described in Table 1.

Table 1. Characteristics of feed coal for the coal washing plant

Parameter	S (%)	X (mm)	Y (m)	V (%)	WP (%)	AC (%)
Amount	0.60	25	12.1	24.9	2.9	36.7

In Table 1, S (%), X(mm) and Y(m), V (%), Wp (%) and Ac (%), respectively refer to Sulfur (%), Plastometer, Volatile substances, Moisture percentage, and the Ash content. Also, the input feed to the flotation unit was subjected to size classification analysis, the result can be seen in Table 2. In the flotation unit of mentioned plant for different coal mines, there were different dosages of used reagents and conditions of slurry solids concentration but always with -500 micron of particle size. Ash content of the final product in flotation unit of East Alborz coal washing plant is around 14.64% with a recovery of 49.61%.

Samples were taken as needed from the entrance of flotation system of the plant. In all experiments, kerosene was used as a collector and MIBC as a frother. The pH of all experiments was considered to be 7.5. The preparation time for flotation tests was that coal was mixed with water for 5 minutes and then added kerosene. After 2 minutes, a frother was added and after 30 seconds of mixing, aeration and foaming were done for 3 minutes. The flotation tests were performed in a Denver mechanical device with an engine speed of 750 rpm.

Table 2. Size classification analysis of flotation unit feed

Size (micron)	Remaining weight (g)	Remaining weight (%)	Ash (%)
500	108.7	48.40	14.5
400	41.3	18.39	26.1
200	28.1	12.51	36.9
105	13.6	6.06	28.7
-105	32.9	14.64	43.9
SUM	224.60	100.00	24.60

A. First Stage of Flotation Tests

Six different types of experiments with two parameters of slurry solids concentration and particle size were designed to see the changes in results because of the possibility of high ash content in fine particles, as follows. According to the studies and research in the operating conditions of the plant, the content of solids is 10, 15 and 20% and the particle size of -500 microns (removal of particles of -600+500) and also the size of -500+100 microns (removal of particles of -100 microns) for the tests were considered. The rest of the laboratory conditions according to the plant conditions are given in Table 3.

B. Third Stage of Flotation Tests (Circulating Load)

The current flotation system of the East Alborz plant includes 7 rows and each row has 3 flotation cells, a rougher, and 2 scavenger cells. The concentrate of the first cells of scavenger stages in the first 6 rows is combined with their rougher stage and directed to the vacuum filter and concentrate depot. The concentrate of the second cells of scavenger stages in the first 6 rows is also directed to the first cell of the 7th row as the cleaner cell, and the concentrates of the 7th row, which also have two scavenger cells, are combined with the concentrate of the cleaner and sent to the vacuum filter. This system causes the ash of the flotation concentrate to rise. Therefore, testing a new flotation system was at the forefront of the work. This system includes the rougher stage, the concentrate of which enter the cleaner stage, and the tailings enters the scavenger stage. Now, in the cleaner part, the concentrate is directed to the filter part and then to the concentrate depot, and the tailing of this stage returns to the feed of the rougher stage as a circulating load. In the scavenger, the concentrate returns to the rougher feed as a circulating load, and its tailings as the final tailing are directed to the tailing dam. A schematic of this circuit and the current flotation system of East Alborz plant are shown in Fig.s 1 and 2.. In order to design the tests related to this system, which includes three parts: rougher, scavenger and cleaner, according to the results obtained from the previous tests, the slurry solids concentration and the particle size have been considered fixed. The experimental conditions of the third stage are shown in Table 5, as well as the type of input feed for each cell in Table 6.

Table 3. Conditions of the first stage flotation tests

Test No.	Parameters			
	Solid (%)	Kerosene (gr/t)	MIBC (gr/t)	Dimensions (μm)
1	10	28	24	-500
2	10	28	24	-500+100
3	15	32	28	-500
4	15	32	28	-500+100
5	20	35	32	-500
6	20	35	32	-500+100

C. Second Stage of Flotation Tests

Fine particles are disruptive to flotation performance. In the previous step, -100 μm particles were removed and relevant experiments were designed, but there is a hypothesis that -50 μm particles can be considered fine particles. In this regard, two tests of ash from the fine particles of the incoming feed were taken, once from the particles of -100 microns and once from the particles of -50 microns, and then three more flotation tests were designed as described in Table 4.

Table 4. Conditions of the second stage flotation tests

Test No.	Parameters			
	Solid (%)	Kerosene (gr/t)	MIBC (gr/t)	Dimensions (μm)
7	10	28	24	-500+50
8	15	32	28	-500+50
9	20	35	32	-500+50

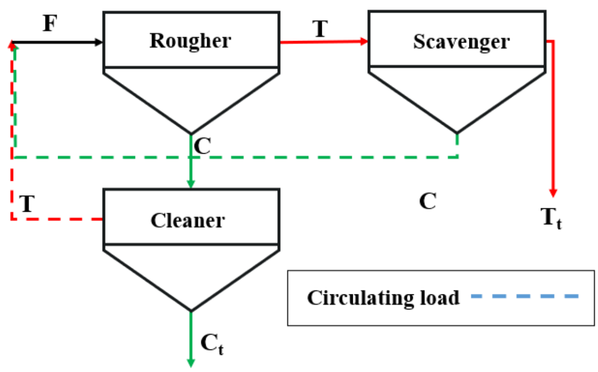

Fig. 1. Flow sheet of the new flotation system

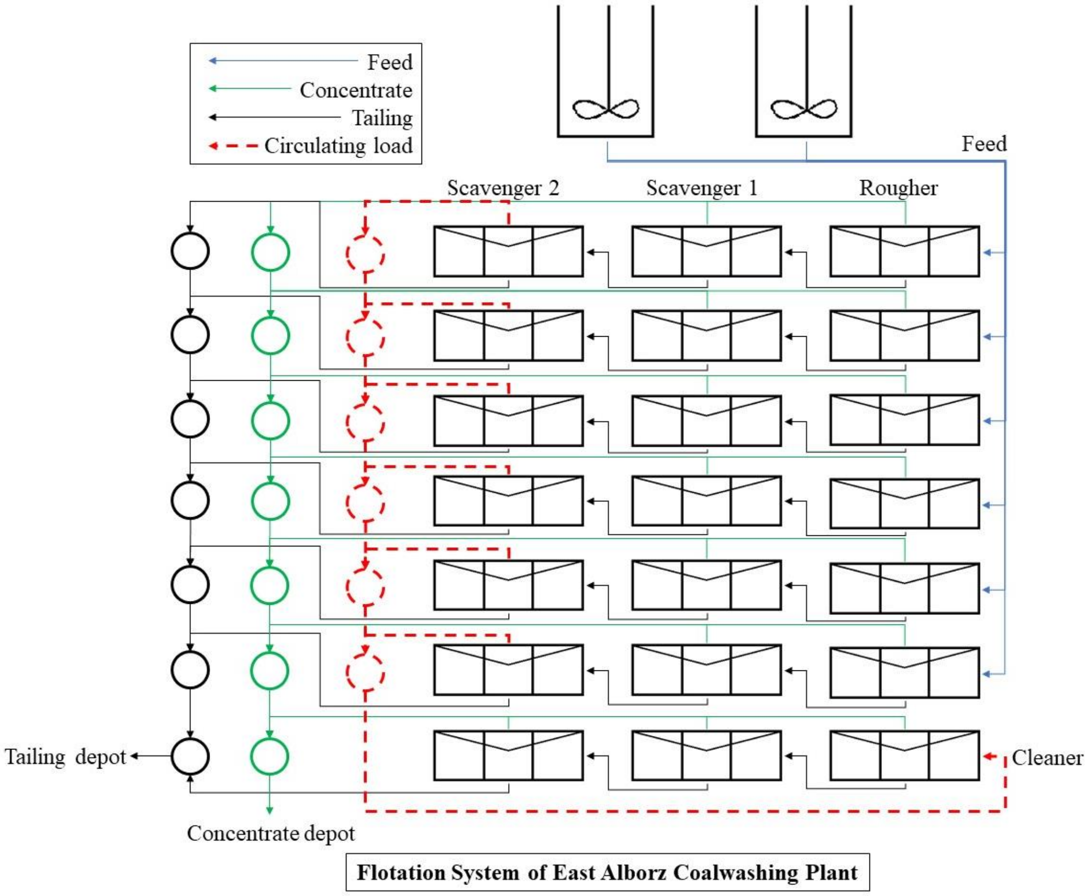

Fig. 2 . Flotation System of East Alborz Coal washing Plant

Table 5. Test conditions related to the new flotation system

Test No.	Cell	Parameters				
		Amount of feed (gr)	Solid (%)	Kerosene (gr/t)	MIBC (gr/t)	Dimensions (μm)
10	Rougher 1	600	10	35	28	-500+50
11	Scavenger 1	160		32	24	
12	Cleaner 1	400		38		
13	Rougher 2	200		32		
14	Scavenger 2	35		28		
15	Cleaner 2	205		32		

Table 6. type of feed to the new system flotation tests

Test No.	Cell	Type of feed (g)
10	Rougher 1	Fresh feed
11	Scavenger 1	Tailings of the rougher 1
12	Cleaner 1	Concentrate of the rougher 1
13	Rougher 2	Fresh feed + concentrate of the scavenger 1 + tailings of the cleaner 1
14	Scavenger 2	Tailings of the rougher 2
15	Cleaner 2	Concentrate of the rougher 2

III. Results and Discussions

All the results of the tests are under two parameters: recovery calculated through weight recovery and ash content measured and reported through ASTM D3174 standard.

A. The results of the first stage of flotation tests

The first stage test was done to know the effect of the selected parameters, the results of which are described in Table 7.

According to the diagram in Fig. 3, in the same slurry solids concentration (test No, 1&2, 3&4, 5&6), the highest amount of recovery belongs to the granulations of -500+100 microns. However, in the same size (test No, 1&3&5 or 2&4&6), the highest amount of recovery is related to 10% solids. From the comparison of recovery values in the six tests of the first stage, the highest recovery rate is 10 percent solid and the particle size is -500+100 microns. Which results in 82.2% of recovery and ash content of 6.77%.

B. The results of the second stage of flotation tests

Ash test results according to ASTM D3174 standard of -100 µm and -50 µm fine particles were 19.65 and 19.50%, respectively. Ash content values are close to each other, so it is more reasonable to remove particles of -50 than -100 µm. The second stage experiments were conducted to know the effect of removing -50 µm particles compared to removing -100 µm particles, the results are presented in Table 8.

By changing the granulation from -500+100 to -500+50 microns, progress was achieved in the parameters of the recovery rate and ash content of the concentrate. In this way, in the condition of the same slurry solids concentration, with this change, the recovery rate increased and the concentrate ash content also decreased. As a result, the best laboratory conditions according to the diagram in Fig. 4, compared to the best conditions in the first-stage tests (test No, 2&4&6), to obtain the maximum recovery and the minimum ash content of the concentrate is under the slurry solids concentration of 10 and the particle size of -500+50 microns. Which results in 83.41% of recovery and ash content of 5.23%.

C. The results of the tests of the third stage of flotation (circulating load)

The purpose of conducting this stage of the experiments is to investigate the feeding method to the flotation cells and the effect of mixing the concentrate of the rougher, scavenger and cleaner cells. The results of these tests are shown in Table 9.

Before applying the circulating load in the final of the first circuit the total recovery reached 74.6% with ash content of 5.93% (test No,10&11&12), after applying the circulating load, the recovery as well as the ash content of the concentrate both had a regression (test No, 13&14&15). The total recovery was 69.9% and the ash percentage of the final product was 18.6%. This shows the effect of mixing materials with high ash to high-quality materials and low ash. The amount of recovery in the cleaner cell was higher than that of the rougher, and the recovery in the scavenger cell was the lowest. The amount of recovery in the tests of the cells decreased proportionally after the circulating load was applied. The ash concentrate content in the cleaner cell should naturally be better than the rougher, as seen in the rougher 1 and cleaner 1 test. However, as soon as the circulating load entered the feed of rougher cell 2, the result was different and the ash concentrate content in this cell increased. The effect of circulating load showed itself negatively, which is visible in the comparison chart of these parameters in the new flotation system tests (Fig. 5).

Table 7. The results of the first stage of flotation tests

Parameters	Test no.					
	1	2	3	4	5	6
Prototype weight (g)	200		300		400	
Concentrate weight (g)	133.90	164.4	156.6	170.30	191.83	228.22
Waste weight (g)	63.20	33.20	139.70	128.40	203.9	170.25
Recovery (%)	66.95	82.20	52.20	56.76	47.96	57.05
Ash content of concentrate (%)	7.36	6.77	10.76	10.12	9.90	7.94
Ash content of tailings (%)	52.51	65.29	31.12	38.11	37.32	51.96

Table 8. The results of the second stage tests with granulation changes

Parameters	Test No.		
	7	8	9
Prototype weight (g)	200	300	400
Concentrate weight (g)	166.82	205.63	281.31
Waste weight (g)	29.38	90.45	113.53
Recovery (%)	83.41	68.54	70.32
Ash content of concentrate (%)	5.23	8.3	7.28
Ash content of tailings (%)	80.71	57.1	53.9

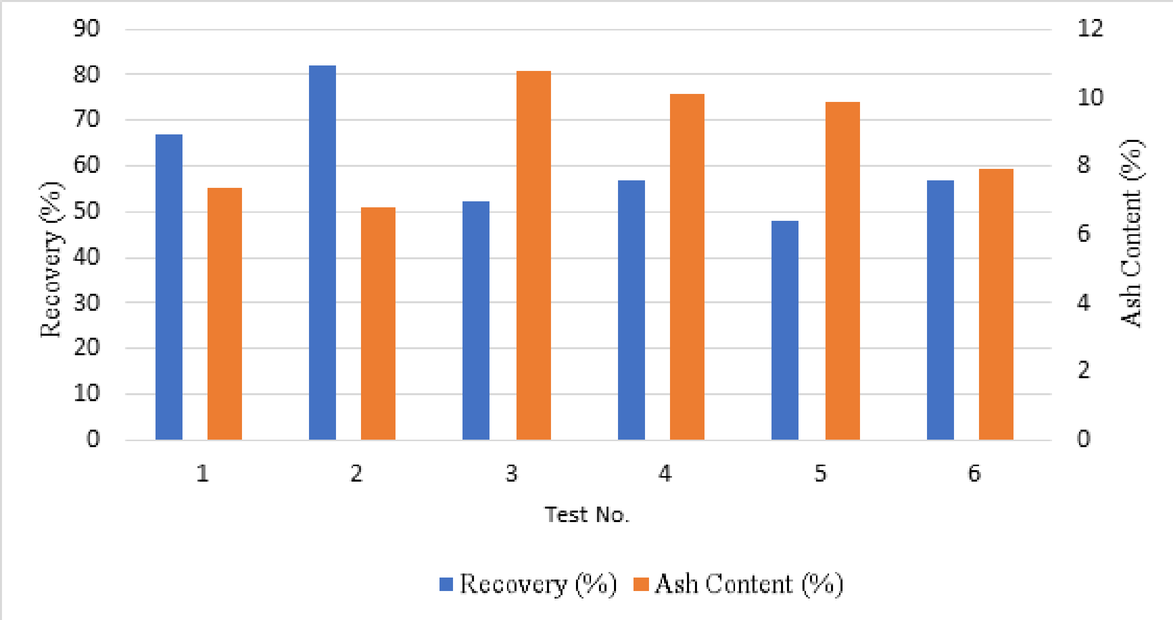

Fig. 3. Comparison graph of the amount of recovery and ash content of concentrate in the first stage tests

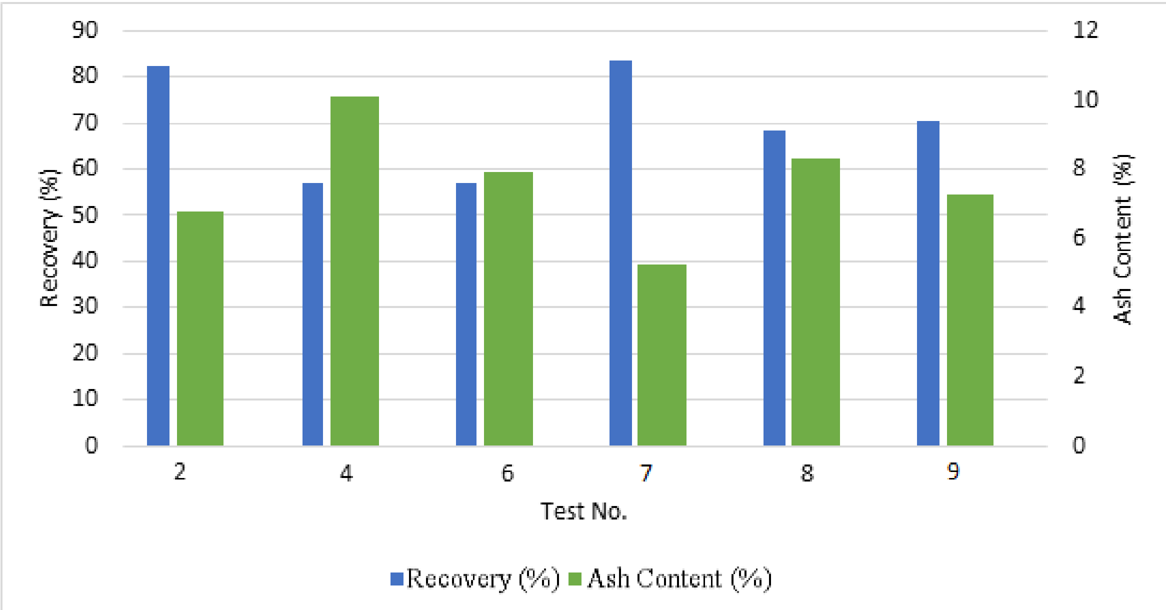

Fig. 4. Comparison graph of the amount of recovery and ash content of concentrate in the second stage and selected first stage experiments

Table 9. Results of new flotation system experiments

Parameters	Test No.					
	10 Rougher 1	11 Scavenger 1	12 Cleaner 1	13 Rougher 2	14 Scavenger 2	15 Cleaner 2
Prototype weight (g)	600	160	400	200	35	205
Concentrate weight (g)	483.88	75.52	383.72	154.73	13.78	190.99
Waste weight (g)	113.74	83.5	12.66	42.20	20.28	12.01
Recovery (%)	80.64	47.2	96.18	77.36	39.37	93.16
Ash content of concentrate (%)	7.03	45.66	5.93	18.60	33.48	19.48
Ash content of tailings (%)	58.19	82.09	72.84	78.01	52.37	72.67

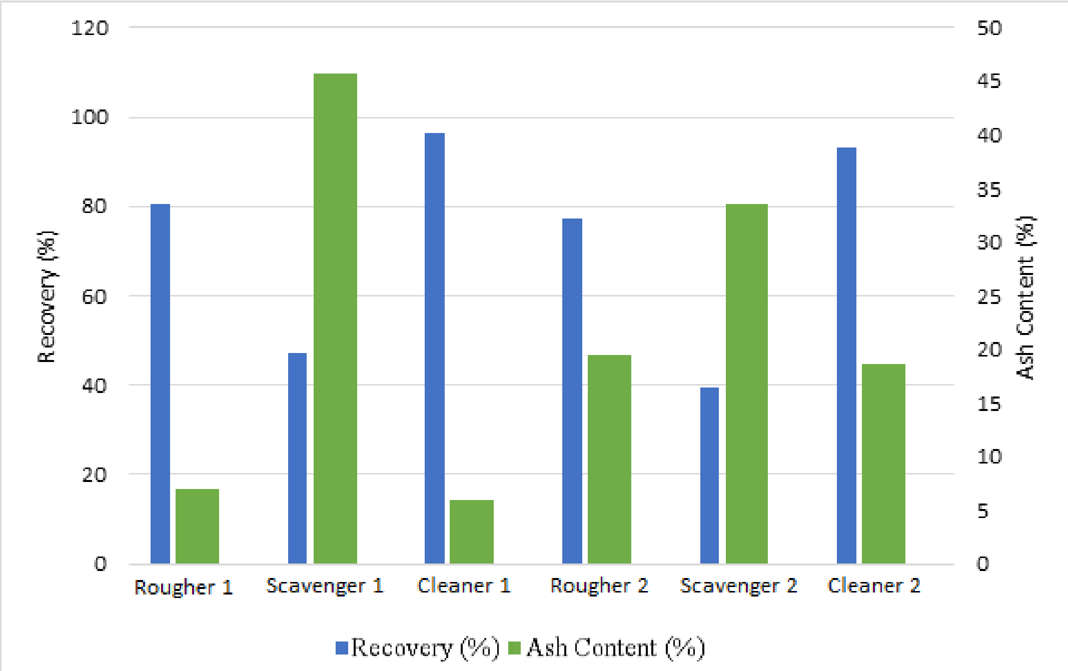

Fig. 5. Comparison chart of recovery rate and ash content of concentrate in new flotation system tests

IV. CONCLUSIONS

✓ The results showed the ash content of the fine particles was high and by removing them from circuit the ash content was improved.

✓ In the first stage tests, the slurry solids concentration of 10 and the particle size of -500+100 microns had the best results, and the plant recovery increased 50 to 82% and the ash concentrates 13 to 6.77%.

✓ In the second stage experiments, the best result was obtained in slurry solids concentration of 10 and particle size of -500+50 microns. The changes in the recovery compared to the previous stage reached from 82 to 83.4% and ash from 6.77 to 5.23%.

✓ In the tests of the third stage, in cleaner part 1, the best result was the total recovery of 74.6% and the ash content of the final product was 5.93% before applying the circulating load. After applying the circulating load, the recovery and ash both decreased and the total recovery reached 69.9% and the ash of the final product reached 18.6%.

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