-RESEARCH PAPER-

International Journal of Mining and Geo-Engineering

IJMGE

IJMGE 58-1 (2024) 21-30

DOI: 10.22059/IJMGE.2023.358810.595064

Development of mineralogy-based approaches to study the loss of copper minerals into tailings of scavenger flotation circuit – Part I

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Article History:

Received: 05 May 2023.

Revised: 28 August 2023.

Accepted: 01 October 2023.

ABSTRACT

Loss of copper minerals to tailings of the rougher and scavenger circuits is one of the challenges in copper concentration plants, which reduces the efficiency of the circuit. The goal of this research is to utilize mineralogy-based techniques to identify the cause of the loss of copper minerals to tailings of the scavenger circuit. Process mineralogy studies have been performed on the scavenger of the flotation circuit at the Sungun copper concentration plant (located in northwestern Iran). First, samples from the feed, final concentrate, and tailing, as well as the concentrate and tailing flows of each of the scavenger circuit cells were collected at different time intervals. Then, chemical composition analysis, laser particle size distribution analysis, and optical microscopy studies were performed on these samples. According to the results, the presence and changes in the abundance of copper oxide minerals, which make up about 45% of copper minerals, are one of the main reasons for the copper loss to tailings. Also, fine-grained particles of copper sulfide minerals (d_{80}~45 µm), and the interlocking of copper sulfide minerals, especially chalcopyrite, with pyrite and gangue minerals (silicate), are among the most important causes of increased copper grade in the scavenger circuit tailings. In addition, the malfunction of the scavenger circuit cells due to the simultaneous presence of sulfide and oxide minerals and their fineness is another cause of the loss to tailings.

Keywords: *Copper oxide minerals, Copper sulfide minerals, Flotation, Tailings, Scavenger circuit, Sungun.*

1. Introduction

Achieving maximum recovery in the rougher and scavenger stages of the flotation circuit is a general strategy in the flotation of copper sulfide ores. After achieving this goal during these stages, regrinding and subsequent flotation in the cleaner and recleaner stages, to separate iron sulfide minerals (including pyrite and arsenopyrite), silicate minerals, talc, etc., will take place to ultimately increase the copper grade of concentrate. Meanwhile, the loss of copper minerals to tailings of the flotation circuit is one of the challenges in copper concentration plants, which affects the efficiency of the circuit. Copper minerals that are lost to tailings of the rougher and scavenger circuits are transferred to the tailings dams (such as the flotation circuits of the Sarcheshmeh and Sungun copper concentration plants) [1-3]. Generally, the most considerable amount of copper loss to tailings (about 90%) with a grade of about 0.1%, occurs in the rougher circuit. It should be noted that the tonnage of rougher circuit tailings is on average 10 times the tonnage of scavenger circuit tailings [4]; while studies indicate that the copper grade is up to about 0.35% in the tailings of the copper flotation circuit [1, 2]. The loss of coarse copper sulfide particles (+74 µm) to tailings and the increase in the number of oxide minerals in the feed are the most important factors in increasing the copper grade in tailings [2]. The presence of copper minerals in the tailings of scavenger cells is related to fine-grained particles (-9 µm) of copper oxide minerals and interlocked particles in sulfide minerals with gangue minerals [4].

Numerous studies have been conducted on copper flotation and the effect of different parameters and operating conditions on its overall efficiency [5 – 10]. According to these researches, particle–bubble collision efficiency and particle–bubble aggregate stability determine the recovery of target particles and they have the most impact on the loss of tailings. About 55% of the copper loss in the scavenger tailings is due to tiny adhesions or inclusions of copper sulfide minerals in non-sulfide minerals or as complex multiphase structures [11, 12]. Based on a study conducted by Markovic et al. (2008), particle size and the degree of liberation of minerals in copper porphyry ores are among the most important factors affecting the recovery and efficiency of copper flotation. Most of the copper minerals were lost in the rougher flotation circuit (in the final cells of the rougher circuit) and were related to the particles of copper minerals interlocked with the gangues [13]. Therefore, to improve process efficiency, researchers have proposed the utilization of column flotation and regrinding mills in the processing line [14, 15]. Celik et al. (2010) employed process mineralogy to improve the performance of flotation metallurgy. In this regard, size-by-size mineralogical analysis for the flows of the rougher, scavenger, and

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cleaner cells has been utilized via an optical image analysis (OIA) system. Based on these studies and the solutions provided by them, increasing the retention time, collector dosage as well as adding a suitable collector for the floatation of copper oxide minerals, have led to a 20% increase in the copper recovery of scavenger cells [16]. Asghari et al. (2019) found that approximately 95% of the total copper loss in the final tailings of the Sarcheshmeh copper concentration plant occurred in the rougher circuit. It was found that an important factor in reducing the recovery and loss of copper to the final tailings is the increase in the ratio of copper oxide to the feed of the plant [2]. In a study conducted by Bakalarz (2019) on the flotation tailings of the Lubin processing plant, the lack of a suitable degree of liberation at the optimal particle size for flotation was considered the reason for the copper loss to the flotation circuit tailings. It should be noted that the optimal degree of liberation for the ore entering this plant is achieved at a particle size of -20 µm [17]. Agheli et al. (2020) studied the mineralogy of the flotation circuit of the Sarcheshmeh copper concentration complex to increase its efficiency and reduce copper grade in tailings [18]. According to these studies, maximum recovery will be achieved via milling the tailings from the rougher and scavenger cells down to -44 µm. According to mineralogical studies, the degree of locking of chalcopyrite with pyrite and non-sulfide gangue minerals is the main cause of copper minerals loss to tailing. Zhang et al. (2021) used quantitative mineral liberation analysis (MLA) integrated with scanning electron microscopy-energy dispersive spectroscopy (SEM-EDS) for identification the reasons of copper loss to tailings. The results showed that copper sulfide minerals are lost due to their interlocking with coarse gangue minerals particles [19].

Based on the above studies and similar research, the loss of copper minerals to the flotation circuit tailings is mainly due to changes in the composition of the feed, and mineralogical properties which include particle size, degree of liberation, and mineral interlocking [20 – 25]. It should be noted that in some cases, the hydrodynamic and mechanical parameters of flotation cells have also been effective in recovery through the loss of copper minerals to tailings [2, 26]. The presence of copper oxide minerals, such as malachite, azurite, and cuprite, along with sulfide minerals (including chalcopyrite, chalcocite, covellite, and bornite) and changes in their ratio in the feed, are among the most important reasons for the copper grade in tailing which takes place in the flotation circuit. This is because copper sulfide collectors (thiols) are not adsorbed on the surface of oxide minerals and the presence of oxide minerals leads to over-consumption of the collector, limitation of selective flotation, and ultimately increased copper grade in the tailings [2]. The interlocking of copper sulfide minerals with oxide ones or the interlocking of each of them with gangue minerals can also be factored in the loss of copper minerals to tailings. By conducting process mineralogy studies on the feed and the outputs of the scavenger cells of the flotation circuit, it is possible to obtain comprehensive information about factors related to the copper loss to tailings. The present study tries to investigate the causes of copper loss to the scavenger circuit tailings of the Sungun plant through a process mineralogy approach. Therefore, the combined effect of feed properties, including the type of minerals (sulfide or oxide), particle size, degree of liberation, and mineral texture were studied. These studies involved OIA, and other techniques such as XRD, particle size analyser, and SEM-EDS. It should be noted that the mentioned mineralogical properties alone are not sufficient to optimize the scavenger circuit. However, the combination and adaptation of the process mineralogical studies to the operating conditions of the circuit will result in a solution for circuit optimization. In this regard, in addition to examining the performance of the entire scavenger circuit, the efficiency of each scavenger cells in the circuit and their role in the loss of copper minerals to the tailings circuit has been investigated.

2. Materials and Methods

2.1. Scavenger circuit (of Sungun plant) and sampling procedure

Sungun copper deposit is the second largest in Iran and the ore extracted from this deposit is processed in phases 1 and 2 of the Sungun copper concentrating plants, which utilize flotation technology. In phase 1 of the aforementioned plant (on which the present study has been carried out), the feed input to the plant, after being ground by the semi-autogenous mill (SAG mill) is transferred to hydrocyclone and then to flotation cells. The rougher stage of the flotation circuit incorporates a bank that consists of 12 RCS130 type cells (with a capacity of 130 m^3 per cell). The solid weight percent of the feed pulp to rougher cells is 34% and the pH of the feed pulp in the cell is 11 (adjusted with lime). Z11 (Sodium isopropyl xanthate ($(CH_3)_2CHOCS_2Na$)) and Flomin7240 (Sodium Di Sec Butyl Dithiophosphate + Sodium Mercaptobenzothiazole) are used as collectors and A70 (Poly propylene glycol) and A65 (Methyl Isobutyl carbonyl) are used as frothers. Primary cleaner flotation cells consist of 2 column-type cells and produce concentrate and tailings with an average copper grade of 18.66 and 1.99%, respectively. Tailings of the cleaner cells with percent solids of 18% are fed to the scavenger circuit for re-cleaning and the production of the final product. The concentrate is transferred to the secondary cleaner-column flotation cells (Fig. 1-A). The scavenger flotation circuit of phase 1 of the Sungun copper concentration plantconsists of 4 RCS50 flotation cells with a capacity of 50 m^3 per cell (Fig. 1-B).

As illustrated in Fig. 1-B, these cells are arranged in series, and the concentrate of each cell is collected by the available launders which together form the scavenger section concentrate. The tailings of each cell are then fed to the following cell, and finally, the tailing of the scavenger circuit discharges from cell No. 4. The retention time of the pulp in the flotation cells of the scavenger circuit is approximately 15 minutes. The tailings from the scavenger cells with an average copper grade of 0.25 – 0.40% are transferred to the tailings thickener along with the tailings flow of the rougher cells. Concentrate of the scavenger circuit with an average copper grade of 7% is fed to the cleaner cells.

The sampling was performed on the feed to the scavenger circuit (cleaner tailing), concentrate and tailings flows of cells 1-4, the final concentrate of the scavenger circuit, as well as the rougher tailing flow of the flotation circuit (all flows of the scavenger circuit are presented in Fig. 1-B). The purpose of sampling from rougher tailings is to compare the grade as well as the characteristics of the loss of copper minerals to the rougher tailings along with scavenger tailings. Sampling was conducted at three distinct time intervals under stable plant conditions, which took place one month apart. The method presented by Gy (1981) was used for sampling from the pulp of different flows of the scavenger circuit [27]. Sampling was performed utilizing a sampling spoon and container available at the concentration plant (Fig. 2). In this method, samples were taken from the outgoing pulp flow from each stage of the process using a spoon with a volume of about 500-1000 ml, depending on the flow rate, and poured into sampling containers. It should be noted that sampling from each of the mentioned flows was carried out in two hours and at intervals of 15 minutes (eight times for each flow). After collecting the samples in each of the sampling intervals, the percent solids of the pulp were determined, and then particle size distribution, chemical composition, and microscopic studies were performed on them.

2.2. Chemical and mineralogical analysis

Throughout three sampling stages, more than 35 samples were taken from 9 flow branches of the scavenger circuit (branch and nodes of the circuit are illustrated in Fig. 3) as well as the tailings flow of the rougher flotation circuit. All samples were weighted (to calculate the percent solids of the pulp), then filtered, dried, and re-weighted to obtain their dry weight. The flow rates of the scavenger circuit flows were obtained via the mass balancing technique for each flow, the results of which are shown in Table 1. To determine the amounts of copper oxide, sulfide as well as iron, chemical composition analysis was conducted by the atomic absorption spectroscopy technique. Particle size distribution analysis was conducted using the SLS: mastersizer 2000/Malvern Panalytical technology, and optical microscopic image analysis was performed on each sample. To study the grade changes and mineralogical properties of copper minerals in two size fractions of coarse and fine-grained

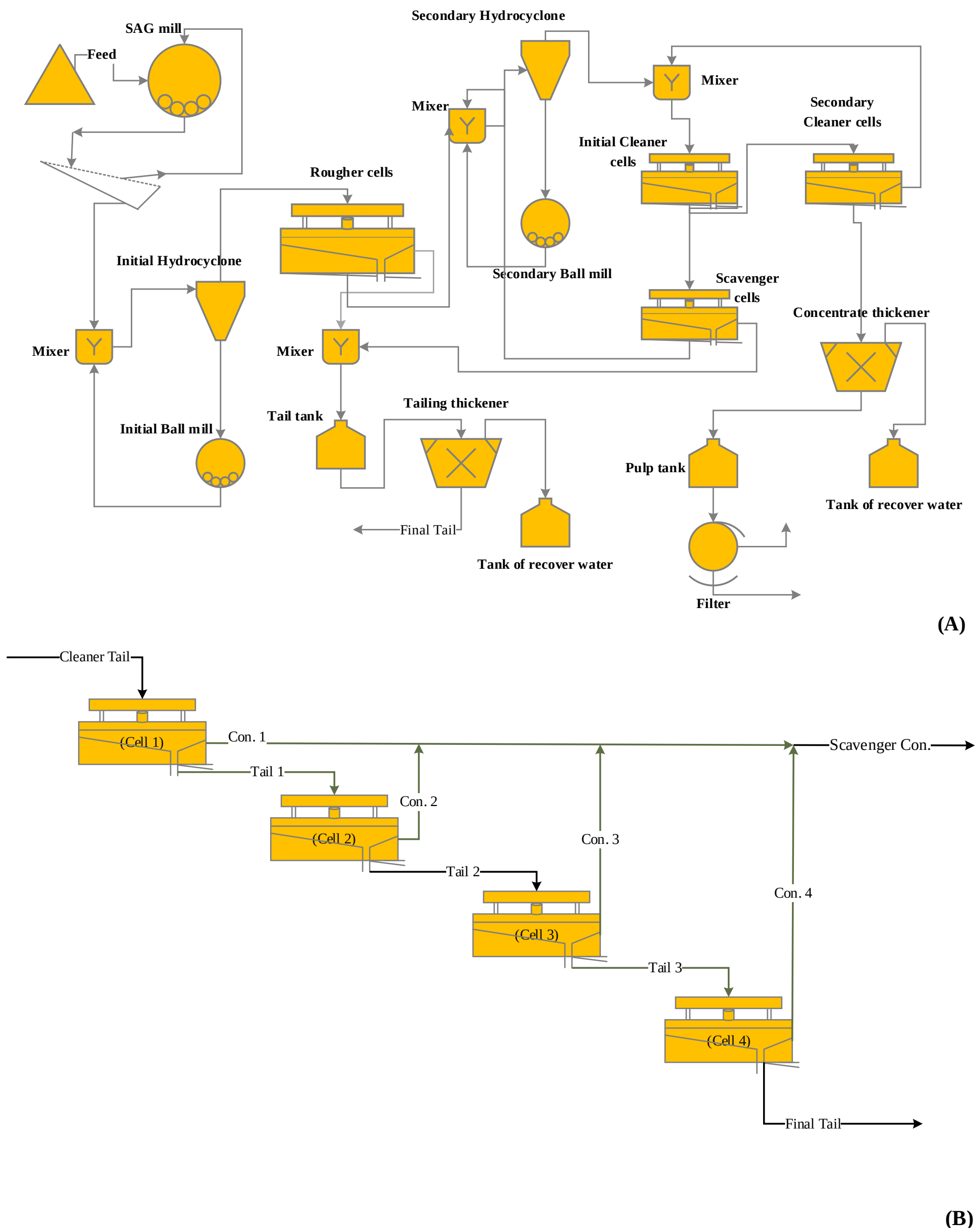

Fig. 1. The schematic flowsheet of A) phases 1 and B) scavenger circuit phase 1 of the Sungun plant.

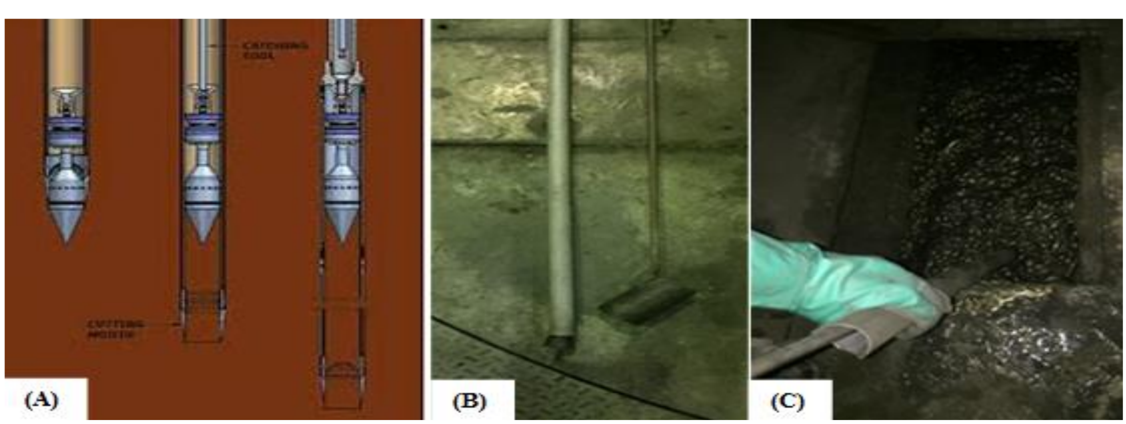

Fig. 2. A) Method, B) instrument and C) sampling in the spoon sampling method.

particles; each of the samples was divided into two fractions of +25 μm and -25 μm utilizing a 500 mesh sieve. Then, chemical composition analysis and microscopic studies were performed on each of them. Thus, by preparing polished sections from each of the aforementioned samples, microscopic studies were performed using the Leitz Model SM-LUX-POL polarizing light microscope. The microscopic studies attempted to determine the minerals that make up each flow, their abundance, the degree of liberation, and how the minerals are interlocked, as well as their size distribution.

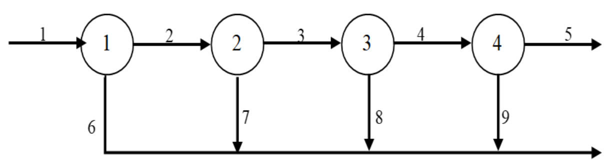

Fig. 3. The Sungun copper scavenger circuit - branches and leaves (branches 2-5: tailings, branches 6-9: concentrate).

Table 1. The tonnage of scavenger circuit flows of the Sungun copper concentration plant.

Flow No.	Description	flow tonnage (tph)
1	Scavenger circuit feed	100.00
2	Scavenger cell No. 1 tailings	87.36
3	Scavenger cell No. 2 tailings	84.04
4	Scavenger cell No. 3 tailings	78.85
5	Final scavenger circuit tailings	76.64
6	Scavenger cell No. 1 concentrate	12.64
7	Scavenger cell No. 2 concentrate	3.32
8	Scavenger cell No. 3 concentrate	5.19
9	Scavenger cell No. 4 concentrate	2.21

3. Results and Discussion

3.1. Performance monitoring of scavenger circuit

Investigation and monitoring of copper grade data generated from the scavenger circuit (phase 1 of the Sungun copper concentration plant) for a period of one month, indicates a copper loss to tailings of this circuit, and fluctuations in the copper amount loses to the scavenger tailings on different days (Fig. 4). According to Fig. 4, the average grade of total copper in the period of one month (data received from the plant) for the scavenger circuit feed and tailings are 3.59 and 0.27%, respectively. The copper grade of the scavenger circuit (except on days 5, 7, and 28) fluctuated in the range of 2 – 8%. The amount of copper in the scavenger circuit tailings was mainly in the range of 0.10 – 0.30%. Given the copper content in the tailings, it is important to improve the efficiency of the scavenger circuit to reduce the copper grade in tailing; because, the loss of copper minerals to tailings of the copper flotation circuit is one of the main reasons associated with the reduction of recovery of the circuit. Although the tonnage of scavenger circuit tailings is lower than that of the rougher circuit tailings (the tonnage of rougher tailings is approximately 10 times that of the scavenger tailings), the copper grade in scavenger tailings is about 2 – 3 times that of the copper in the rougher circuit tailings. In general, due to the average copper grade of the rougher tailings and their flow rate, which are 0.27%, and 60 m^3/h, respectively, there will be a decrease of approximately 4% in the total recovery.

To investigate the effect of oxidation and the type of copper minerals (oxide and sulfide) that have reached the scavenger tailings, chemical analyses have been performed to determine the grade of copper sulfide and oxide in the feed and tailings of the scavenger circuit. Fig. 5 shows the effect of grade changes of copper sulfide and oxide minerals in the feed and tailings of the scavenger circuit. Throughout the study period, the grade of copper sulfide in the feed of the scavenger circuit is approximately 20 times that of copper oxide. In the case of scavenger circuit tailings, on most days of the study period (except on days 8 – 10 and 13), the grade of copper sulfide is higher than that of copper oxide. In general, the ratio of sulfide to copper oxide in scavenger tailings is less than 2. Therefore, it can be inferred that the recovery of copper oxide is much lower than that of copper sulfide. On some of the studied days, such as 16 – 20, the amount of losses of copper sulfide minerals was very significant. By comparing the diagrams in Figs 4 and 5, it can be concluded that the main copper minerals lost to tailings are related to copper sulfide minerals.

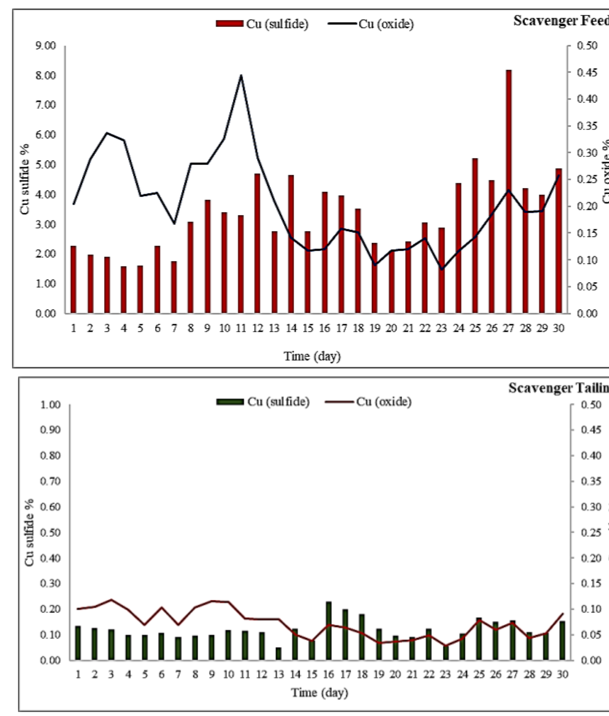

Fig. 5. Copper sulfide and oxide grade changes in the feed and tailings of scavenger circuit of the Sungun phase 1 copper flotation plant.

3.2. Investigation of the efficiency of scavenger circuit

To investigate the changes in copper grade in the tailings of scavenger cells and to determine the role of each cell in the loss of copper minerals, the total copper, copper sulfide, and copper oxide grade of each of the samples (taken from the tailings of scavenger circuit) has been measured. It should be noted that to investigate the effects of changes in feed composition on circuit performance, analyzes were performed for all three different sampling periods. Fig. 6 shows the copper grade changes in the tailings flows of the scavenger circuit cells. According to the results, changes in copper sulfide and oxide grade with a decreasing trend (as an exponential function) can be seen from cells 1 – 4. In all the studied periods, the highest amount of loss of copper minerals to tailings of all cells was related to copper sulfide minerals. The amount of copper oxide in scavenger circuit feed in samples 1, 2, and 3 was 0.12, 0.22, and 0.10%, respectively. The copper oxide grade in the final tailing of the scavenger circuit is 0.03%, 0.06%, and 0.03% for the mentioned feeds, respectively. Therefore, it can be stated that according to the change in the grade of copper oxides in the feed of the scavenger circuit, their grade in the scavenger tailings has changed.

During the sampling periods, the copper oxide grade in the rougher circuit tailings was also measured. Based on the results of the analysis, the amounts of copper oxide during the three study periods were 0.02, 0.04, and 0.02%, respectively; which is almost identical to scavenger circuit tailings. Due to the similar operating conditions of rougher and scavenger flotation cells, from the utilized flotation chemicals standpoint (xanthates for flotation of copper sulfides), almost always certain amounts of oxide minerals (especially free copper oxide minerals) find their way into scavenger circuit tailings. According to Fig. 6, loss of copper oxide minerals occurred in all of the scavenger circuit tailings, but its extent is more pronounced in the primary cells. In the case of copper sulfide minerals, most of the loss to tailings occurred in the primary cells of the scavenger circuit.

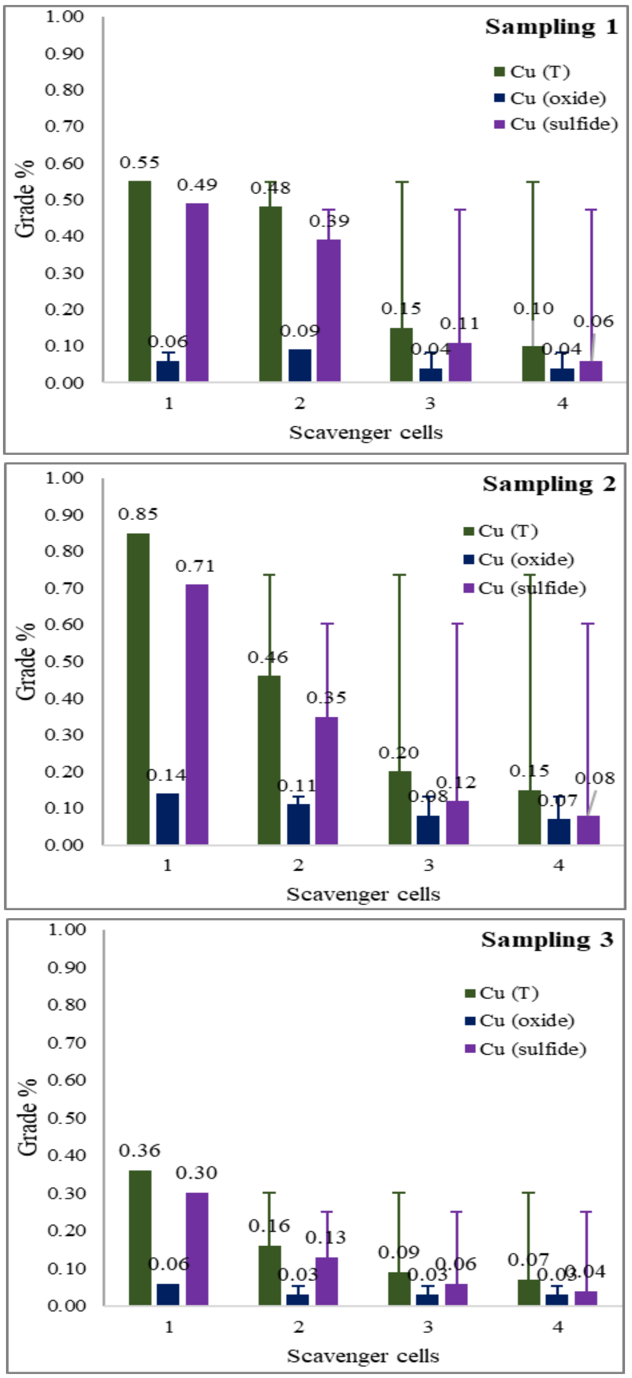

Fig. 6. Copper grade in the tailings of scavenger circuit cells 1-4 of the Sungun phase 1 copper flotation plant.

The grade analysis results of concentrate from scavenger circuit cells 1-4 are presented in Fig. 7, which have been utilized to thoroughly study the scavenger circuit and identify the distribution and grade changes of copper sulfide and oxide minerals in the output of each scavenger circuit cells. In sampling periods 1, 2, and 3, the copper oxide grade in the scavenger circuit feeds were 0.12, 0.22, and 0.10%, respectively. Given the copper sulfide content in the scavenger circuit feed which had values of 1.57, 1.52, and 0.74% for the three sampling periods, it can be inferred that the copper sulfide and oxide grades in the scavenger circuit feed have always been associated with fluctuations. When these fluctuations were less than 0.20% for copper sulfide and less than 0.02% for copper oxide; these changes did not have a significant effect on the grade changes of the concentrates. In general, in the case that the feed grade (Cu total that containing copper sulfide and oxide) of the scavenger circuit is 1.69% (sampling 1 , where Cu oxide = 0.12% and Cu sulfide = 1.57%, so Cu total = 1.69%), the final concentrate grade of the scavenger circuit is reported to be in the range of 6.70 – 8.60% (Cu total). However, with a reduction in the feed grade to less than 1% (sampling 3 , where Cu oxide = 0.10% and Cu sulfide = 0.74%, so Cu total = 0.84%), the total copper grade in concentrate has reached about 5.20%. According to Fig. 7, changes in copper sulfide grade in the scavenger cell concentrates over different periods have had a similar trend. In this regard, the copper sulfide grade has decreased exponentially from cell 1 to 4. Interestingly, regarding the performance of scavenger circuit cells, no specific relationship has been observed between the copper sulfide content of the feed and the associated concentrate. This is also true for copper oxide grades; which indicates the proper functioning of the flotation cells in the scavenger circuit.

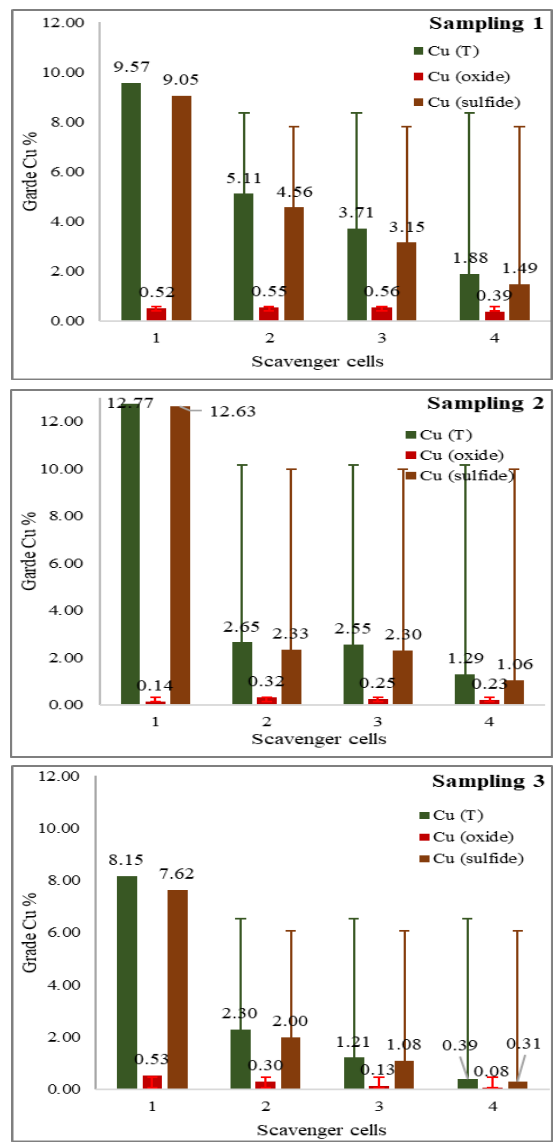

Fig. 7. Copper grade in the concentrate of scavenger circuit cells 1-4 of the Sungun phase 1 copper flotation plant.

The recovery values of total, sulfide, and copper oxide in the scavenger circuit and each of its cells for the three sampling steps are presented in Table 2. Total copper recovery is different in each of the aforementioned cases and varies from about 70.10% to 95.87%. By comparing the feed grade of the scavenger circuit, it is observed that in the samples of the first to third stages, the total copper grade varies from about 0.70% to 2.35% (Table 2). Therefore, it can be stated that the efficiency of the scavenger circuit is largely affected by the composition of the feed. According to Table 2, the composition of the scavenger circuit feed varies in term of abundance of copper sulfide and oxide minerals at different time intervals. Therefore, the main reason for the loss of copper minerals to tailings is the increase in the ratio of copper oxide minerals in the feed of the scavenger circuit. As the grade of oxide minerals increased, the amount of total copper recovery decreased by about 25%; while the recovery rate of copper oxide minerals almost remained constant.

Table 2. The grade and recovery of copper in the scavenger circuit of the Sungun phase 1 copper flotation plant.

Sampling stages	Grade %			Recovery %		
	Cu Ox.	Cu S.	Cu total	Cu Ox.	Cu S.	Cu total
First	0.12	1.57	1.69	75.81	97.87	95.87
Second	0.23	2.22	2.35	79.53	63.73	70.10
Third	0.10	0.64	0.74	75.68	94.53	91.77

3.3. Effect of particle size on loss of copper minerals to the scavenger tailing

Investigating the particle size distribution of the flotation cells in the scavenger circuit's output can be a good guide to finding the reasons for the increase in copper grade in the scavenger tailings. Graphs of feed, concentrate, and final tailings size distribution of the scavenger circuit are shown in Fig. 8. Table 3 also indicates the values of d10, d50, and d90 for these graphs. According to the results, the average dimensions of the particles recovered in the concentrate are larger than those of the particles sent to the tailings. This describes the inability of fine particles to adhere to the air bubbles and their transfer to the tailings i.e., larger particles are more likely to be recovered in the concentrate.

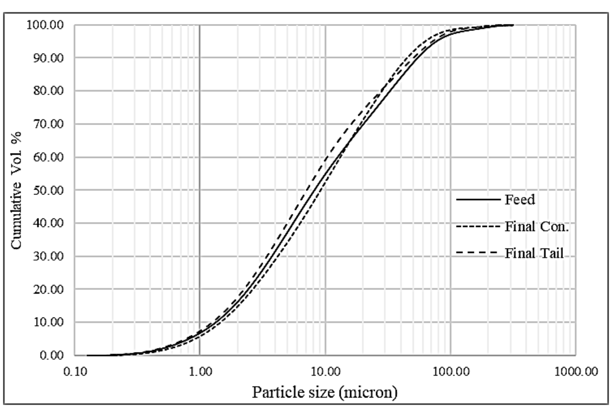

Fig. 8. Particle size distribution of feed, concentrate and final tailings of the scavenger circuit.

The particle size distribution analysis has been performed on the concentrate and tailings flows of cells 1 – 4 of the scavenger circuit to investigate the particle size changes in the output flows of the aforementioned cells. The graphs presented in Fig. 9 and Table 2 show the PSD analysis results of these flows. According to the graphs, in the case of concentrates, coarser particles are removed from cell No. 1, and in the case of cells 2 – 4, the particle size was smaller than the feed entering the circuit. With the movement of the pulp from cells 2 – 4, the particle size of the concentrate gradually decreased. Particle size changes in scavenger cell tailings are not significant. According to the results, most of the fine particles were removed through the tailings of cell No. 1. In cells 2 – 4, the particle size of the tailings particles is larger than that of the circuit feed. Meanwhile, cell No. 3 tailings with d_{90} of 80 µm have a larger particle size distribution.

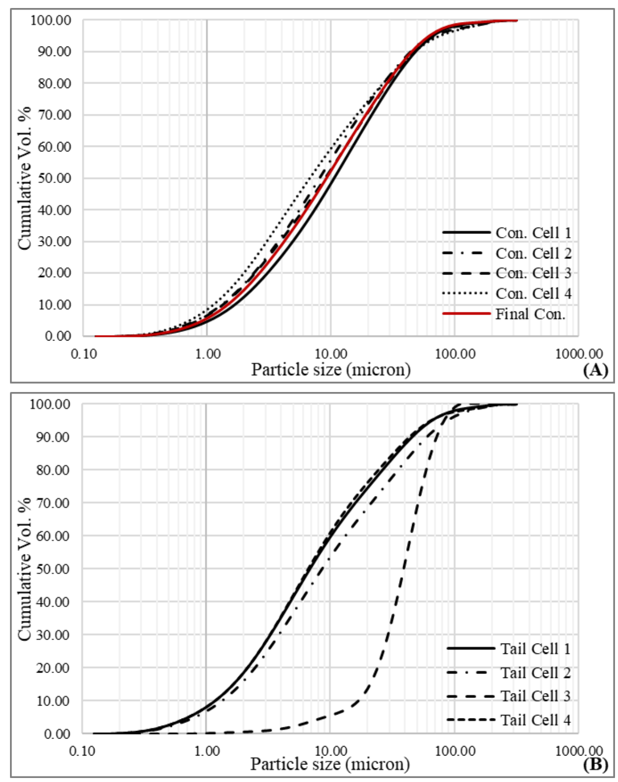

Fig. 9. The particle distribution diagrams of A) concentrate and B) tailings of cells 1 – 4 of scavenger circuit.

Table 3. The results of particle size analysis of the scavenger stage of copper flotation circuit flows.

Flow		d_{10} (µm)	d_{50} (µm)	d_{90} (µm)
Scavenger feed		1.49	9.15	60.90
Final scavenger concentrate		1.62	10.26	50.30
Final scavenger tailing		1.40	7.96	56.25
Concentrate	Cell 1	1.85	11.86	53.94
	Cell 2	1.45	9.05	49.30
	Cell 3	1.48	10.03	52.40
	Cell 4	1.25	7.53	53.02
Tailing	Cell 1	1.32	7.68	51.01
	Cell 2	1.50	9.63	67.04
	Cell 3	18.88	43.83	80.84
	Cell 4	1.40	7.96	56.25

3.4. Mineralogical studies

A) Feed and concentrate of the scavenger circuit: Based on the monitoring of copper grade fluctuations in the scavenger circuit, the copper grade changes in the tailings have a high correlation with the grade changes in the feed (Fig. 4). On the other hand, due to the small particles in the scavenger circuit flows, especially in the final concentrate of the circuit (with a d_{50} of 8.72 μm), the copper particles that are interlocked with fine-grained silicate minerals are transferred directly to the secondary hydrocyclone overflow and enter the cleaner circuit. Due to the mechanism of the cleaner cells and the interlocking of copper minerals, these minerals are trapped in the cleaner phase and enter the cleaner tailings. Finally, re-enter the scavenger circuit; and this cycle continues. In this regard, to investigate the causes of the passage of copper-bearing minerals to tailings, optical microscopic studies have been performed on the feed and concentrate of the scavenger circuit of the Sungun copper concentration plant. Examination of microscopic sections of the scavenger circuit feed indicates that copper minerals are often of the sulfide type which includes chalcopyrite, chalcocite, covellite, and bornite, with abundance of 6 – 8% by volume, and oxide minerals of less than 5% by volume. The changes in copper sulfide and oxide grade shown in Fig. 5 also confirm this. Chalcopyrite with a degree of liberation of more than 90%, makes up 95% of the volume of copper sulfide minerals. About 15 – 20% of the volume of copper sulfide minerals are particles with a size of -25 μm that is in the form of free particles without any interlocking (Fig. 10). Due to their small size and lack of proper adherence to air bubbles, these particles are more likely to reach the tailings of the scavenger circuit. The interlocking of copper sulfides in the circuit feed is mainly with each other and rarely with silicate and pyrite minerals.

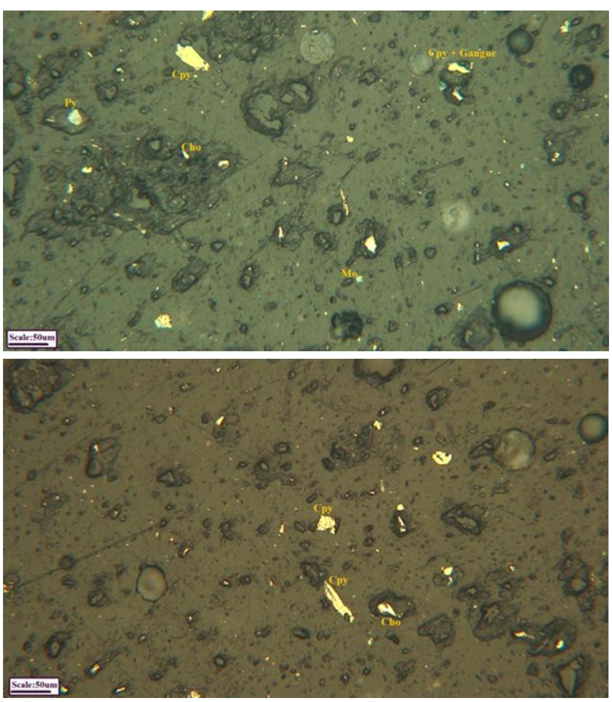

Fig. 10. Images of abundance (upper image) and distribution (lower image) of copper sulfide minerals in the scavenger circuit feed (Cpy: chalcopyrite, Cho: chalcocite, Py: pyrite, Mo: molybdenite) - PPL

In the scavenger circuit concentrate, copper sulfide minerals including chalcopyrite, chalcocite, bornite, covellite, and to a lesser extent tennantite and enargite, account for 20 – 25% of the volume of particles. Copper sulfide mineral particles in the size range of -25 μm are often free; approximately 90% of the sulfide mineral particles in the scavenger circuit concentrate are +25 μm in size, and only 10% of them are -25 μm in size. Therefore, it can be stated that most of the fine-grained particles of copper sulfide minerals (-25 μm) have been transferred to the tailings circuit. Studies indicate that the abundance of copper oxide minerals in the concentrate of the scavenger circuit is less than 2%. Therefore, it can be inferred that the inability of the scavenger circuit to recover particles of copper oxide minerals is another reason for the increase in copper grade in the tailings (Fig. 11).

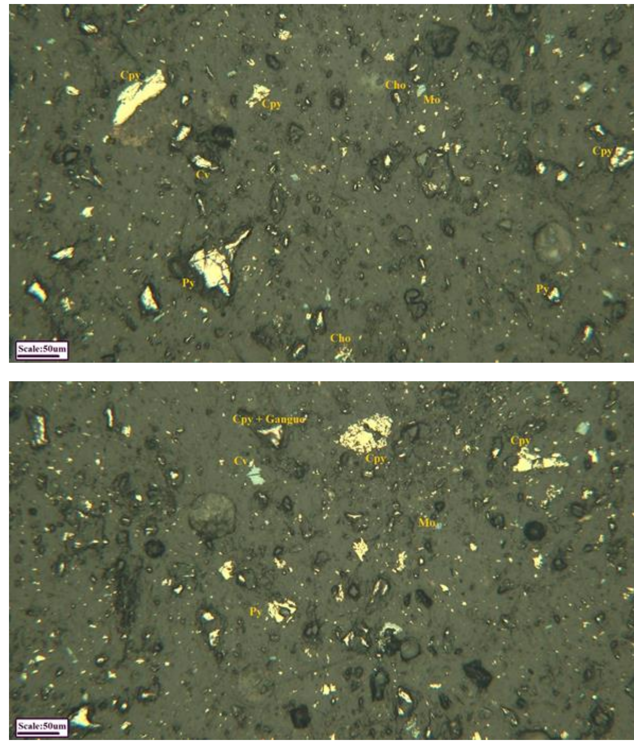

Fig. 11. Images of the abundance (upper image) and distribution (lower image) of copper sulfide minerals in the concentrate of the scavenger circuit (Cpy: chalcopyrite, Cho: chalcocite, Cv: covellite, Py: pyrite, Mo: molybdenite) – PPL.

B) Tailings of the scavenger circuit: Both microscopic studies and chemical analyzes have been performed on the tailings of the scavenger circuit in two fractions of +25 and -25 μm. Fig. 12 shows the distribution of minerals in the tailings of the scavenger circuit in the aforementioned fractions. Pyrite is the main sulfide mineral in the final tailings of the scavenger circuit. In addition to pyrite, other sulfide minerals, including copper sulfides, are visible in the tailings. It should be noted that copper oxide minerals, such as malachite are also rarely found constituting less than 0.01% by volume. Copper sulfides include chalcopyrite, chalcocite, bornite, covellite, and rarely elemental copper which constitutes 0.30 – 0.40% by volume of scavenger tailings. The mineral chalcopyrite accounts for 95% of the copper sulfides that pass into the tailings of the scavenger circuit. These minerals are mostly interlocked, often with non-metallic gangue minerals and to a lesser extent with pyrite. The degree of liberation of total copper sulfide-bearing minerals, with the predominance of chalcopyrite, was determined to be about 45 – 50%. Therefore, it can be said that in the +25 μm size fraction, the interlocking between copper sulfide minerals, especially chalcopyrite, with pyrite and other gangue particles, is the reason for the depression of these minerals (especially chalcopyrite) and prevents their flotation. It should be noted that about 90% of chalcopyrite particles are interlocked with non-metallic (silicate) particles are considered to be locked minerals, and only about 10% of them are interlocked with pyrite. Based on this, it can be inferred that regrinding can be an effective way to increase the degree of liberation of copper sulfides and thus prevent them from entering the tailings.

Pyrite makes up 1.5 – 2.0% of the volume of mineral particles in the scavenger circuit tailings. The pyrite found in the scavenger circuit tailings has an appropriate degree of liberation (90 – 95%). Thus, it can be stated that the free pyrite particles remaining in the pulp, which are formed via or through grinding the concentrate of the rougher circuit, are captured in the scavenger stage and removed from the circuit i.e., given the Eh value of the scavenger circuit cells, which are in the range of -70 to -65 mV (the depression of the pyrite minerals occurs at potentials less than +300 mv). Consequently, floated pyrite minerals in the rougher circuit are trapped under the negative potentials of the scavenger circuit and transferred to the tailings.

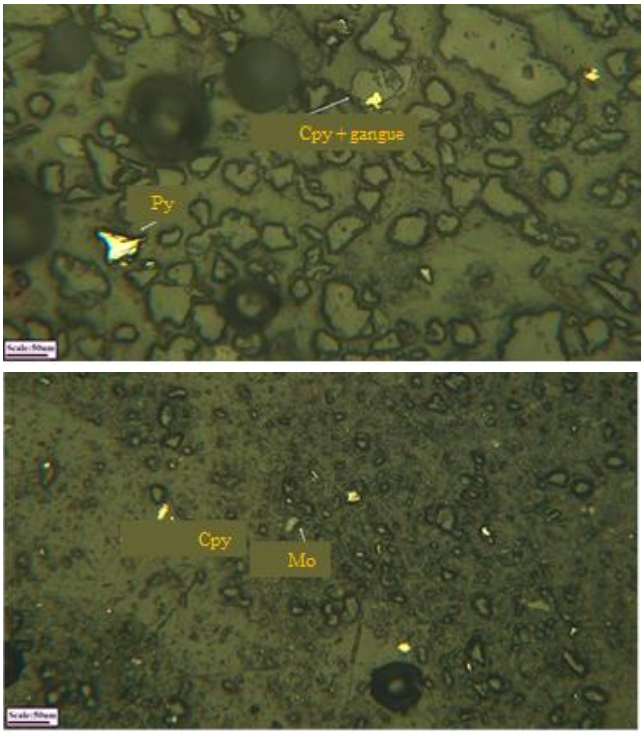

Fig. 12. Distribution of copper minerals in the final tailing of the scavenger circuit - upper image shows +25 µm size fraction and lower image shows -25 µm (Cpy: chalcopyrite, Py: pyrite, Mo: molybdenite) - PPL

C) Tailings of cells – the scavenger circuit: Copper grade changes (total, sulfide, and oxide) in the scavenger circuit tailings flows for particles coarser than 25 µm, and particles smaller than 25 µm are presented in Fig. 13. According to the diagrams in Fig. 13, for particles with a size of +25 µm, the highest grade in the tailings of cell 2 was 1.98%. A grade of 1.95% was observed for particles with a size of -25 µm in the tailings of cell No. 3 of the scavenger circuit i.e., the copper grade in tailing is caused by coarse-grained particles in cell No. 2, and fine-grained particles in cell No. 3. According to Fig. 13, the largest amount of copper grade in tailing is stemmed from the passage of copper sulfide minerals into the tailings flow. In the case of copper sulfide minerals, the highest amount of copper loss to tailings occurred in cell No. 3 of the scavenger circuit; the copper content of particles coarser than 25 µm in the tailings of this cell is about 2%. Copper sulfide minerals with a particle size of less than 25 µm, on the other hand, had a greater amount of copper loss to tailings of scavenger cell No. 2. Cell No. 2 of the scavenger circuit has the highest amount of copper oxide grade in tailing. In the case of both oxide and copper sulfide in the tailings of cell 2, the highest grade of copper is associated with particles smaller than 25 µm. In general, according to Fig. 13, cells No. 2 and 3 of the scavenger circuit have the greatest effect on the loss of copper to tailings.

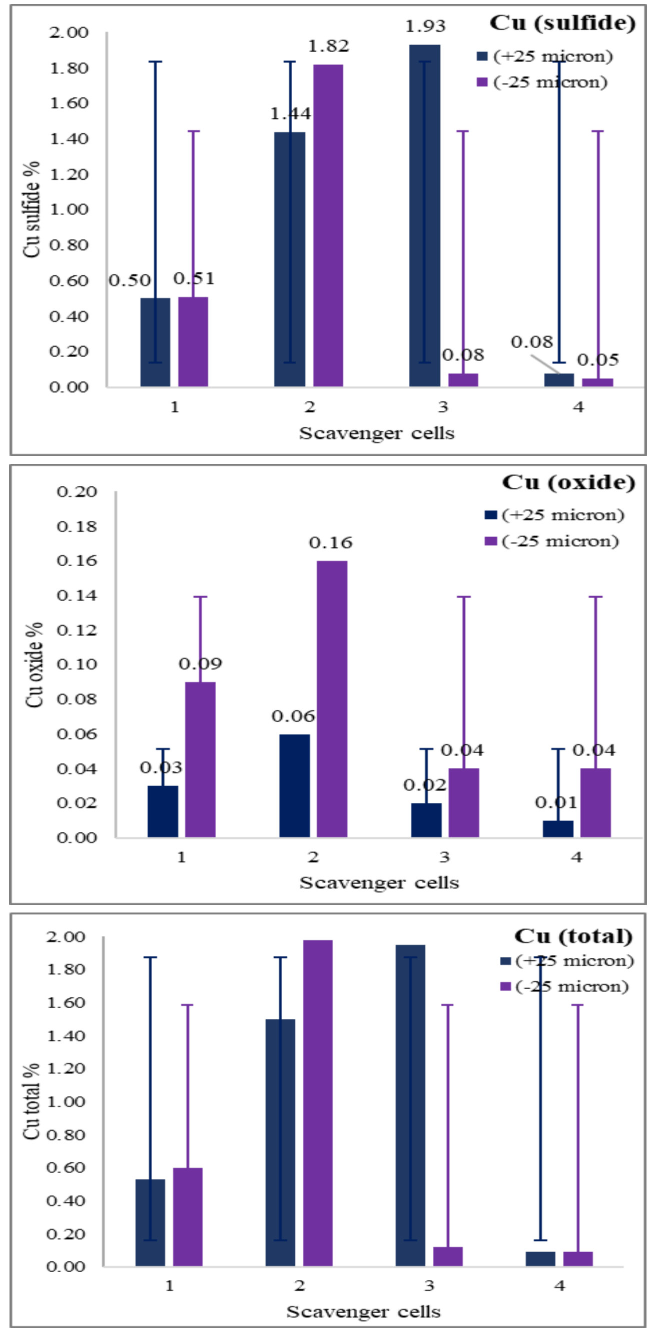

Fig. 13. Copper grade in size fractions which are coarser and smaller than 25 µm in the tailings of cells 1-4 of the scavenger circuit.

4. Conclusion

Loss of copper-bearing mineral to tailings of the scavenger circuit is one of the challenges and problems in the flotations of copper sulfide ores. The copper grade exceeding 0.20% in the scavenger flotation circuit of the Sungun copper concentration plant's tailings has highlighted the need to develop a solution to solve this problem more than ever before. The application of mineralogy-based approaches to solve this issue indicates that the operating conditions of the scavenger circuit and flotation cells are one of the main causes of the loss of copper minerals to scavenger tailings and consequently, the high grade of copper in the tailings. The low efficiency of hydrocyclones in the circuit and the resulting generation of fine particle due to excessive milling are one of the main reasons for the loss of copper minerals to the scavenger circuit tailings. About 30% of the copper loss to tailings is due to the small size of the particles and the inefficiency of the scavenger cells in their recovery.

On the other hand, the presence of copper oxide minerals such as malachite in the tailings of the scavenger circuit can be attributed to the inability of copper oxides to be floated via the chemicals (collectors) utilized for the flotation of copper sulfides in the scavenger circuit. Also, pyrite minerals due to being depressed at negative potentials of the scavenger circuit (pyrite is depressed at potentials less than +300 mV), and chalcopyrite minerals because of the interlocking with silicates are the most dominant sulfide minerals that are lost to tailings of the scavenger circuit. In coarser size fractions, the interlocking of copper sulfide minerals with non-metallic gangue minerals and pyrite is one of the most important reasons for these minerals to enter the scavenger circuit tailings. Copper minerals losses in fine-grained size fractions due to the small weight and size of the particles, reducing the possibility of colliding and adhering to air bubbles during flotation, and ultimately leading to their lack of flotation. The entrance of finer-grained particles to the scavenger concentrate and coarse-grained particles to the scavenger tailings, an increase in the variety of minerals (interlocking) in a coarse-grained particle, and interlocking of copper minerals with gangue can all be attributed to the loss of copper to the scavenger circuit tailings.

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