-RESEARCH PAPER-

International Journal of Mining and Geo-Engineering

IJMGE 58-1 (2024) 31-37 DOI: 10.22059/IJMGE.2023.358812.595065

Copper recovery improvement by reducing the loss of copper minerals into the tailings of scavenger flotation circuit – Part II

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Article History:

Received: 05 May 2023.

Revised: 29 August 2023.

Accepted: 01 October 2023.

ABSTRACT

Loss of copper minerals in the tailings of the rougher and scavenger circuits poses a significant challenge in copper processing plants, diminishing the circuit's efficiency. Part I of this paper identified the causes of copper mineral loss in the scavenger circuit tailings of the Sungun copper concentration plant, situated in northwestern Iran. Changes in feed composition, particularly the ratio of copper oxide to sulfide minerals, along with alterations in the mineralogical properties of the input feed to the scavenger circuit, emerged as pivotal factors contributing to the loss of copper minerals into the tailings. In line with these findings, the objective of the present paper (part II) is to optimize the scavenger circuit by proposing a solution to mitigate the loss of copper minerals to the tailings. Samples were collected from the feed, concentrate, and final tailings, as well as from each cell of the scavenger circuit, followed by comminution and flotation tests on each sample. The results indicate that redirecting the scavenger circuit tailings to the input of the rougher cells, owing to their higher copper grade compared to the tailings of the rougher circuit, can enhance the circuit's recovery by more than 4%. Additionally, employing a combination of sulfide and oxide collectors, along with sulfidation to float the copper oxide minerals in the scavenger circuit, resulted in an overall recovery increase exceeding 11%. Furthermore, adjusting the size of the air bubbles to capture fine copper mineral particles from the scavenger circuit cells proved to be an effective strategy for boosting recovery. Moreover, modifying the grinding circuit to liberate the minerals present in the scavenger circuit feed, predominantly the concentrate of the scavenger circuit itself, led to a recovery increase of approximately 5%. Considering the mineralogical characteristics of the scavenger circuit feed, derived from the tailings of the cleaner cells, implementing changes in the operating conditions of the cleaner circuit—such as employing hybrid bubbles (Nano and coarse bubbles) and utilizing sulfide and oxide collectors—significantly impacted the recovery of fine copper mineral particles and copper oxide minerals to the cleaner concentrate, thereby enhancing the scavenger circuit's performance.

Keywords: *Copper minerals, Tailings, Flotation, Grinding, Recovery, Scavenger circuit, Sungun.*

1. Introduction

Loss of copper minerals into the tailings of the rougher and scavenger stages of the flotation circuit is a significant challenge in copper processing plants, leading to a decrease in circuit efficiency. The presence of copper tailings exceeding 0.2% grade in the scavenger circuit of the Sungun copper concentration plant (located in northwestern Iran) necessitates the development of a solution to address this issue. In Part I of this paper, the causes of copper mineral loss into the scavenger circuit tailings were investigated through process mineralogical studies and examination of the operational parameters of the scavenger circuit cells (such as cell count and chemical usage). The utilization of mineralogy-based approaches revealed that the operational conditions of the scavenger circuit and flotation cells significantly contribute to the transfer of copper minerals into the scavenger tailings. Furthermore, the inefficiency of circuit hydrocyclones and the excessive generation of fine particles due to over-milling emerged as other prominent factors contributing to this phenomenon. Overall, approximately one-third of copper mineral particles are transferred to tailings due to their fine nature and the inefficiency of scavenger cells [1].

The presence of copper oxide minerals, such as malachite, in the tailings of the scavenger circuit at the Sungun copper concentration plant can be attributed to the challenge of floating copper oxides with the chemicals (collectors) utilized in the scavenger circuit. Since copper sulfide-related collectors (thiols) fail to adsorb on the surface of oxide minerals, the presence of oxide minerals results in excessive collector consumption, limited floatability, and ultimately an increase in copper grade in the tailings. Conversely, pyrite and chalcopyrite are the predominant sulfide minerals found in the scavenger circuit tailings of the Sungun copper concentration plant. Pyrite is depressed in the negative potentials of the scavenger circuit (depressed in potentials less than +300 mV) [2], while chalcopyrite is hindered by interlocking with

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silicates, leading to their transfer to the scavenger circuit tailings. Within the size range of +25 μm, the interlocking of copper sulfide minerals (particularly chalcopyrite) with non-metallic gangue minerals and pyrite constitutes one of the primary reasons for these minerals' presence in the scavenger circuit tailings. Escape of copper sulfide minerals occurs in the size range of -25 μm due to the small weight and size of the particles, thereby reducing the likelihood of collision with air bubbles during flotation and, consequently, preventing flotation [3]. To address the issue of copper mineral loss into the scavenger stage tailings of the flotation circuit and consequently improve flotation efficiency, several studies have been conducted. Researchers have proposed methods to enhance process efficiency, such as regrinding the scavenger circuit tailings to liberate interlocked minerals and employing column flotation to float fine particles [4 – 6]. Furthermore, reintroducing the scavenger circuit concentrate into the flotation circuit and regrinding it offers a promising solution to release interlocked particles, preventing their deposition into the tailings [7]. This approach not only aids in liberating interlocked copper minerals but also promotes the creation of new (non-oxidized) surfaces, thereby enhancing floatability and resulting in increased recovery.

Another strategy to recover interlocked copper minerals in the scavenger circuit and prevent their transfer to the tailings involves increasing collector consumption and retention time. By elevating the collector dosage, copper recovery can be enhanced through heightened hydrophobicity of coarse particles over an extended retention period [10]. Furthermore, modifying the type and composition of chemicals in the scavenger circuit serves as another effective parameter to address this challenge. Given the presence of copper oxide minerals in the feed composition, the addition of chemicals such as NaHS (for sulfidation of copper oxides) to the scavenger circuit has the potential to bolster circuit efficiency [11]. Additionally, employing a combination of sulfide and oxide collectors can facilitate the flotation of both copper sulfide and oxide minerals in the scavenger circuit. Espinoza-Ortega et al. (2003) investigated the effect of scavenger concentrate regrinding in the grade and recovery of silver sulfide flotation concentrate (Fresnillo processing plant located in Mexico).

The increased liberation degree of argentite minerals (Ag2S) and the generation of non-oxidized surfaces, consequently enhancing floatability, stand out as the primary factors driving increased recovery [7]. Ekmekçi et al. (2005) assessed the performance of the copper-zinc flotation circuit at the CBI processing plant in Turkey and determined that grinding the flotation circuit feed to less than 50 μm yielded optimal results in terms of copper recovery and prevention of copper mineral loss into tailings [8]. Mohammadi et al. (2018) explored the feasibility of reprocessing the scavenger circuit tailings of the Miduk copper concentration plant, located in southeastern Iran, which exhibited a copper grade of approximately 0.3%. They suggested that transferring the scavenger circuit to a hydrocyclone with a cut size of 60 μm and subsequently grinding its underflow could prevent the loss of copper minerals into tailings [12]. Asghari et al. (2019) identified an increase in the ratio of copper oxide minerals in the feed as the primary cause of copper mineral loss into the tailings of the flotation circuit at the Sarcheshmeh copper concentration plant, situated in southeastern Iran. To address this issue, they proposed the addition of 800 g/ton of hydrogen sodium sulfide (NaHS), resulting in an increase in the circuit's final recovery from 79.3% to 83.8%.

Grinding particles sized +74 μm improved the overall recovery of the circuit from 79.3% to 82.2% [11]. Based on the above, the application of process mineralogy proves to be an effective strategy in enhancing the efficiency of flotation circuits, especially when dealing with sulfide ores characterized by complex mineralogical interferences. In the first part of the present study, consisting of two separate papers (Part I and Part II), the identification of the causes of copper mineral loss into the scavenger circuit tailings of the Sungun copper concentration plant was conducted through process mineralogy studies and examination of the operating conditions of scavenger circuit cells (such as cell count and chemical usage).

In Part II, various comminution and flotation tests were performed on the feed, concentrate, and tailings of the scavenger circuit to propose an optimal solution to address the challenge of copper recovery resulting from the loss of copper minerals to scavenger tailings. It is noteworthy that the pulp of the scavenger circuit at the Sungun copper concentration plant, with a flow rate of 60 m3/h, a percent solids of 20%, and an average copper grade of 0.20%, along with the tailings from the rougher circuit, is directed to the tailings dam of the plant. The tonnage of tailings from the plant's rougher and scavenger circuits amounts to 775 and 60 tons per hour, respectively. Consequently, during flotation tests, the impact of changes in the composition and quantity of chemicals utilized will be examined as a means to enhance circuit recovery. Additionally, the influence of regrinding and particle size reduction on the scavenger circuit's efficiency will be explored.

2. Materials and Methods

2.1. Copper processing circuit (phase 1 of Sungun copper concentration plant)

In the Sungun copper concentration plant, depicted in the schematic flowsheet illustrated in Fig. 1, the concentration of copper-molybdenum is conducted through a flotation process in phases 1 and 2 of the plant, operating in parallel. Within the phase 1 circuit of this plant, the focus of the present study, the tailings of the cleaner cells, boasting an average copper grade of 1.99%, are directed to the scavenger circuit for further beneficiation. The scavenger circuit of Phase 1 at the Sungun copper concentration plant comprises 4 flotation cells of the RCS50 type, each with a capacity of 50 m3. As depicted in Fig. 1, these cells are arranged in series, with the concentrates from each cell collected by the available launders to form the concentrator of the scavenger circuit. The tailings from each cell serve as the feed for the subsequent cell, culminating in the exit of the scavenger circuit tailings from Cell No. 4 after traversing through all four cells. The tailings from the scavenger cells, with an average copper grade ranging from 0.25% to 0.4%, alongside the tailings from the rougher cells, are directed to the tailings thickener. Meanwhile, the concentrate from the scavenger circuit, boasting an average copper grade of 7%, is conveyed to the input of the cleaner cells. Table 1 provides the technical specifications of phase 1 of the Sungun copper concentration plant scavenger circuit.

2.2. Sampling procedure and sample characterization

To optimize the scavenger circuit of phase 1 at the Sungun copper concentration plant, samples were collected from the feed (cleaner tailing), final concentrate, final tailing of the circuit-breaker circuit, and the tailings of cell No. 2 of the scavenger circuit. The sampling points are highlighted in blue in Fig. 1. Sampling was conducted at three distinct time intervals under stable plant conditions, with each interval occurring one month apart. Utilizing a sampling spoon and container available at the concentration plant, sampling was performed employing a method commonly referred to as manual spoon sampling. During this process, samples were extracted from the outgoing pulp flow at each stage of the process using a spoon with a volume ranging from approximately 500 to 1000 ml, depending on the flow rate, and deposited into sampling containers. It is important to note that sampling from each of the mentioned flows was conducted over a period of two hours, with intervals of 15 minutes (eight times for each flow).

All samples underwent chemical composition analysis using atomic absorption spectroscopy (AAS) to determine the concentrations of total copper, as well as copper in the oxide and sulfide phases. Additionally, particle size analysis was conducted using SLS: Mastersizer 2000/Malvern Panalytical technology. The average copper grade values, encompassing total copper, sulfide, and oxide content, for the three sampling steps are summarized in Table 2. Furthermore, Fig. 2 presents distribution diagrams illustrating the particle sizes in the feed, concentrate, final tailings, and tailings of cell No. 2 of the scavenger circuit at the Sungun copper concentration plant. As depicted in Fig. 2, the average particle size of the particles recovered in the concentrate of the scavenger circuit is coarser compared to those directed to the tailings. This discrepancy in particle size is a contributing factor to the

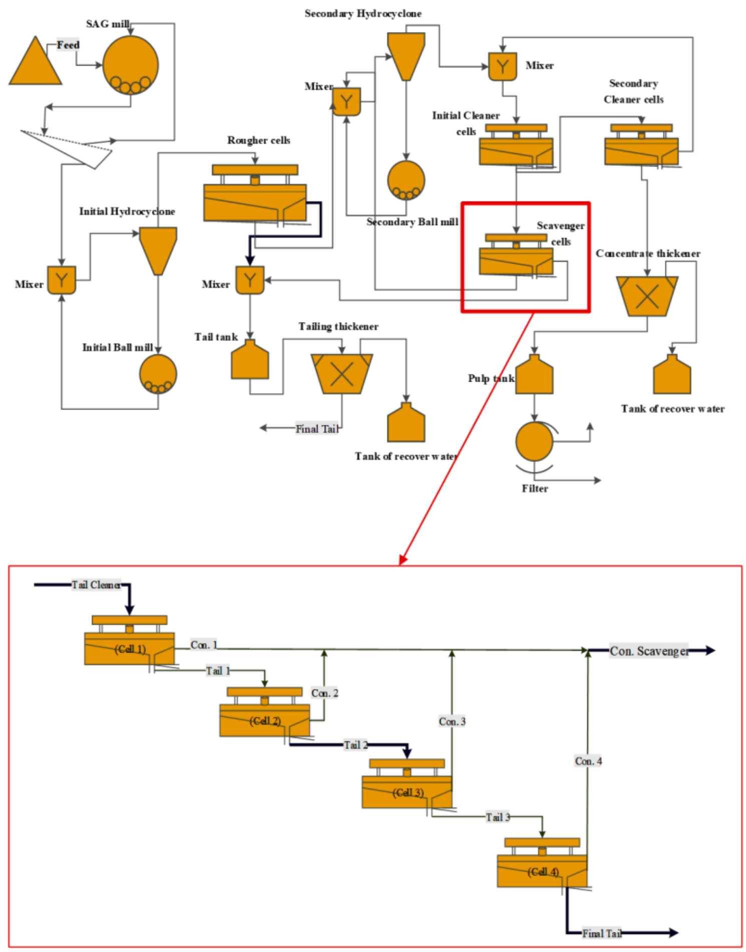

Fig. 1. Schematic illustration of scavenger flotation circuit of phase 1 of the Sungun copper concentration plant.

Table 1. Technical specifications of scavenger cells of phase 1 of the Sungun copper concentration plant.

Item	Amount/type	Item	Amount/type
Number of cells	4	Type	RCS50
Tank volume	50 m^3	Air volume of each cell	15 m^3/min
Retention time	15 min	d_{80} of feed	40 µm
Pulp percent of feed	18%	Flow rate of feed pulp	60 ton/h
Pulp percent of concentrate	16.7%	Flow rate of concentrate pulp	137 m^3/min
Cu grade of feed	1.99%	Flow rate of tailing pulp	462 m^3/min
Cu grade of concentrate	7%	Cu grade of tailing	0.34%

inability of fine particles to adhere to air bubbles and their subsequent transfer to the tailings; coarser particles exhibit greater likelihood of recovery to the concentrate.

Table 2. Average copper grade values during the three stages of the scavenger circuit flows.

Streams	*Cu. Total %*	*Cu. Oxide %*	*Cu. Sulfide %*
Scavenger feed	0.95	0.15	0.70
Scavenger concentrate (final)	6.89	0.60	6.29
Scavenger tailing (final)	0.10	0.04	0.06
Scavenger cell No. 2 tailing	0.36	0.07	0.29

Flotation and grinding tests

Given the loss of copper minerals into the tailings of the flotation circuit due to the presence and fluctuations in the abundance of copper oxide minerals, fine particles of copper sulfide minerals, interlocking of copper sulfide minerals with pyrite, as well as malfunction of scavenger circuit cells due to the simultaneous presence of copper sulfide and oxide minerals, and their fineness, flotation tests were conducted as follows. The purpose of these tests was to optimize and explore the potential for increasing the grade and recovery of copper in the scavenger circuit by accomplishing the following objectives:

- Conducting flotation tests to recover liberated fine copper particles.
- Performing comminution and flotation tests to liberate and recover interlocked copper particles.
- Carrying out flotation tests to recover copper oxide minerals.

In this regard, comminution and flotation tests were performed on samples of the feed, concentrate, final tailings, and tailing of cell No. 2 of the scavenger circuit. These tests aimed to investigate the effects of changes in the composition and quantity of chemicals used in flotation, as well as reprocessing, as strategies to enhance circuit recovery. Table 3 outlines the details of the flotation tests and their respective operating conditions. For each flotation test, a pulp with a solid percent of 20% was prepared. The initial pulp preparation time was set at 2 minutes, followed by an additional mixing period of 1 minute and 30 seconds after the chemicals were added. Additionally, the pH of the pulp and the rotation speed of the rotor were maintained at 12.5 and 1250 rpm, respectively, for each flotation test.

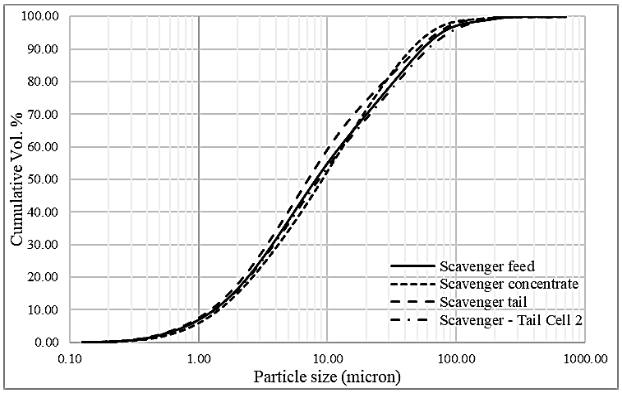

Fig. 2. Particle size distribution diagrams of feed, concentrate, and tailings of the scavenger circuit of the Sungun copper concentrating plant.

3. Results and Discussion

3.1. Optimization with re-flotation of scavenger tailing

Due to the higher copper grade observed in the scavenger circuit tailings at the Sungun copper concentration plant compared to the rougher circuit tailings, flotation tests were tailored based on the scavenger circuit tailings to explore the feasibility of returning them to the rougher cells. The average copper grades of the rougher and scavenger cell tailings are 0.06% and 0.27%, respectively. In the initial flotation test conducted on the scavenger circuit tailings, the test conditions were aligned with the flotation parameters employed for the rougher circuit of the Sungun copper concentration plant (see Table 3 - test No. 1). The results are summarized in Table 4, indicating grade and recovery values of 0.47% and 55.31%, respectively. Consequently, by reintroducing the scavenger circuit tailings to the input of the rougher cells, the recovery of the entire phase 1 circuit could potentially increase by 4.2%, thus mitigating copper losses.

To assess the impact of chemicals, particularly sulfidation agents, on the flotation of copper oxide minerals, and to explore the influence of grinding on the recovery of copper from the scavenger circuit tailings, flotation tests were conducted on the tailings of the scavenger circuit (see Table 3 - tests No. 2 and 3).

In test No. 2, aimed at floating copper oxide minerals alongside their sulfides, the scavenger circuit tailings were subjected to flotation. Sulfide collectors Z11 and Flomin C7240 were employed, along with sodium alkyl hydroxamate (AM28) as oxide collectors, and A70 and A65 as frothers. As shown in Table 4, the recovery of copper oxide minerals exceeded 48%, while the recovery of copper sulfides was reported to be over 35%. To recover the interlocked copper minerals, the scavenger circuit tailings underwent milling in a rod mill for 15 minutes, followed by a flotation test (see Table 3 - test No. 3). The results indicate that this approach resulted in a recovery of sulfide minerals exceeding 62%. Additionally, the recovery of copper oxide minerals was more than 33%. Consequently, grinding followed by flotation yielded the most favorable outcomes in terms of recovering lost copper minerals in the total scavenger circuit tailings.

A microscopic examination of the concentrate from the aforementioned tests, focusing on the grinding and subsequent flotation of scavenger tailings, revealed that approximately 5% of the composition comprises copper sulfide minerals. Chalcopyrite constitutes the majority of these minerals, exhibiting a liberation degree of about 90%. This finding suggests that through the process of grinding followed by flotation of scavenger circuit tailings, copper sulfide minerals can be effectively recovered into the concentrate once they achieve the desired liberation degree of over 90%. An interesting observation in the concentrate from this flotation test is the volume ratio of copper sulfide mineral particles, which stands at 90% for particles sized between +25 to -25 µm. This ratio indicates that one of the reasons for the increase in copper grade observed in flotation tailings is the loss of fine particles of copper sulfide minerals. Additionally, oxide minerals constitute only about 5-10% of the copper minerals present in the concentrate, with the majority of them being discharged as tailings (see Fig. 3).

Table 3. Conditions of flotation tests for optimization of scavenger circuit of the Sungun copper concentration.

Test No.	Feed	Grinding	d_{80} feed (µm)	Reagents (g/ton)						
				TC15	Z11	Flomin	A65	A70	Na_2S	AM28
1	Scavenger Tailing	No	28	-	20	10	10	5	-	-
2	Scavenger Tailing	No	28	-	20	10	10	5	-	20
3	Scavenger Tailing	Yes	15	-	20	10	10	5	-	-
4	Scavenger Tailing – cell 2	No	35.50	-	33	22	5	-	400	-
5	Scavenger Tailing – cell 2	No	35.50	-	33	22	5	-	1000	-
6	Scavenger Tailing – cell 2	Yes	10	-	20	10	10	5	-	-
7	Scavenger feed	No	35.00	-	65	45	-	-	200	-
8	Scavenger feed	No	35.00	-	65	45	-	-	400	-
9	Scavenger feed	No	35.00	-	65	45	-	-	1000	-
10	Scavenger concentrate	Yes	11	25	-	-	-	-	-	-
11	Scavenger concentrate	Yes	9	25	-	-	-	-	-	-

Table 4. Grade, recovery and, separation efficiency values of the flotation tests of the scavenger circuit tailings.

Test No.	Grade Cu %			Recovery %	Separation efficiency %
	Feed	Concentrate	Tailing		
1	0.24	0.47	0.15	55.31	27.06
2	0.16	0.28	0.12	37.36	24.61
3	0.14	0.18	0.10	50.12	18.81

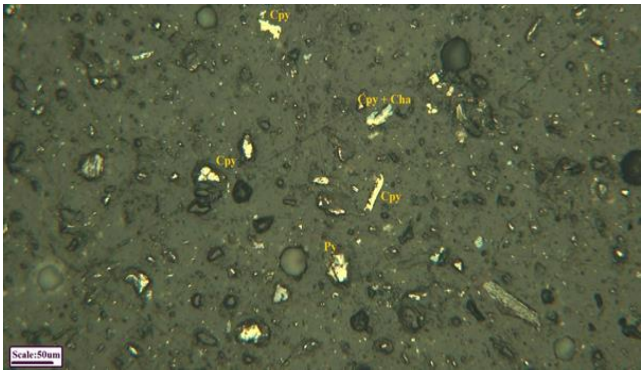

Fig. 3. Abundance and distribution of copper minerals in flotation test concentrate obtained from the scavenger circuit of the Sungun copper concentration plant (Cpy: chalcopyrite, Cha: chalcocite, Py: pyrite).

3.2. Optimization with changes in operational condition of cell No. 2 – scavenger circuit

Microscopic studies and chemical analyses have revealed issues with the functionality of cell number 2 within the scavenger circuit, leading to the loss of a significant portion of copper minerals into the final tailings. Another potential solution with the potential to significantly enhance scavenger circuit recovery at the Sungun copper plant involves exploring modifications to the chemicals utilized in cell number 2 of this circuit.

In this regard, a combination of sulfide and oxide collectors, along with sulfidation, could be employed for the flotation of copper oxide minerals. This approach is expected to have a notable impact on the recovery of copper oxide minerals within the concentrator circuit. To assess the effects of sulfurization and mitigate the impact of fineness on the feed of cell number 3 of the scavenger circuit (similar to cell tail 2), flotation tests were conducted on the tailings of cell number 2 of the scavenger circuit. Table 5 presents the results of these tests.

Based on the results, an increase in recovery to 9% was achieved by adding 1000 g/ton of sodium sulfide (refer to Table 3 - test No. 5). This increase in recovery resulted in only a slight reduction in separation efficiency by 0.5%. However, it significantly improved the overall circuit performance, considering the copper grade. The slight decrease in separation efficiency is deemed negligible given the notable improvement in recovery. Furthermore, through grinding followed by flotation of the tailings of cell 2 of the scavenger circuit (refer to Table 3 - test No. 6), the recovery of copper sulfide minerals exceeded 46.50%, while for copper oxides, it exceeded 41.50%.

Table 5. Grade, recovery and, separation efficiency values of the flotation tests tail cell No. 2 of the scavenger circuit tailings.

Test No.	Grade Cu %			Recovery %	Separation efficiency %
	Feed	Concentrate	Tail		
Plant test	0.56	1.48	0.24	67.96	42.75
4	0.50	1.15	0.21	70.65	40.37
5	0.58	1.28	0.21	76.12	42.22
6	0.41	0.94	0.27	45.31	24.27

3.3. Optimization with changes in feed characterization and reagents of scavenger circuit

Based on the monitoring of copper grade fluctuations in the scavenger circuit, it's evident that changes in the copper grade in the scavenger circuit tailings are closely associated with variations in the copper grade of the scavenger circuit feed. In this context, flotation tests were conducted on the circuit's input feed to determine the optimal conditions for enhancing the circuit's recovery at the Sungun copper concentration plant. To mitigate the effects of fineness on the scavenger stage of the flotation circuit and to enhance the recovery of copper oxide minerals into the scavenger circuit concentrate, three flotation tests (refer to Table 3 - tests No. 7-9) were conducted on scavenger feed samples by adding different amounts of sodium sulfide as a sulfuration agent. The retention time for these tests was calculated to be 12 minutes, with four cells in the scavenger circuit and a residence time of 3 minutes for each cell. Additionally, considering the four cells in the scavenger circuit, four stages of frothing were performed. Table 6 displays the results of this series of flotation tests. As per the findings presented in Table 6, in flotation test No. 7, employing 400 g/ton of sodium sulfide led to an increased copper grade of 6.69%, surpassing the grade obtained under plant conditions. However, in test No. 8, the copper grade in the concentrate decreased, likely due to the low amount of dispersants used for fines dispersion and sulfuration of oxide minerals. Conversely, in test No.

Hence, in this scenario, there's a higher mass transfer to the subsequent stage, namely the cleaner stage, compared to other instances. Moreover, as per the separation efficiency data provided in Table 6, tests involving sulfuration and dispersant addition exhibited higher separation efficiency than the flotation test conducted based on plant conditions. The highest separation efficiency was achieved in test No. 7, reaching 52.25%. Overall, to enhance the efficiency of the scavenger circuit at the Sungun copper concentration plant, sulfidation of the input feed to the scavenger circuit by adding 400 g/ton of sodium sulfide results in a one percent increase in copper grade and an 11% improvement in separation efficiency for the scavenger circuit concentrate.

3.4. Optimization with re-grinding the concentrate of scavenger circuit

In the Sungun copper flotation circuit (depicted in Fig. 1), the fine nature of particles within the scavenger stream, particularly evident in the final concentrate of the circuit (with a d50 of 8.72 μm), results in the direct transfer of copper particles interlocked with fine-grained silicate minerals to the overflow of the secondary hydrocyclone and subsequently into the cleaner circuit. Owing to the mechanism of the cleaner cells and the interlocking nature of copper minerals, these minerals become entrapped in the cleaner stage, eventually entering the cleaner tailings and re-entering the scavenger circuit. This cyclical process adds to the circulating load. Implementing a grinding step on the final scavenger concentrate to achieve the appropriate degree of liberation is essential. This step enhances flotation efficiency, thereby reducing the circulating load. In order to release the interlocked copper minerals present in the scavenger circuit concentrate, two flotation tests were conducted on the products obtained from grinding for 5 and 10 minutes (refer to Table 3 - tests No. 10 and 11).

Table 6. Grade, recovery, and separation efficiency of flotation tests of the scavenger circuit feed.

Test No.	Grade Cu %			Recovery %	Separation efficiency %
	Feed	Concentrate	Tail		
Plant test	3.14	5.70	0.22	97.30	41.49
7	3.24	6.69	0.25	95.87	52.25
8	3.24	5.62	0.24	96.73	43.28
9	3.24	6.94	0.29	95.62	41.43

The values for grade, recovery, and separation efficiencies for the final flotation tests of the scavenger circuit concentrate are presented in Table 7. The results indicate that grinding the scavenger circuit concentrate for 5 minutes (yielding a product with a d80 of 11 μm) resulted in an increase in copper recovery and grade by 5% and 1%, respectively, compared to the basic flotation test conducted based on plant conditions. This improvement is attributed to the liberation of copper minerals. However, further grinding of the concentrate for 10 minutes led to the generation of fine particles, resulting in a recovery increase of over 17%.

Upon examining the microscopic sections obtained from the concentrates of flotation tests No. 10 and 11, it was observed that the predominant copper minerals recovered from the flotation concentrate were of the sulfide type, constituting approximately 95% of all copper minerals, while only 5% of the copper minerals volume comprised oxides (refer to Fig. 4). The major copper sulfides identified in the concentrate included chalcopyrite, chalcocite, bornite, and to a lesser extent, covellite, tennantite, and enargite. Notably, more than 95% of the copper minerals in the concentrate were found to be in the size range of +25 µm. This indicates that fine particles of copper minerals (-25 µm) do not exhibit optimal flotation behavior and are consequently entrained in the tailings. Furthermore, fine-grained copper particles (-25 µm) in the concentrate were predominantly free. This suggests that the interlocking of copper minerals with tailings in the size range of -25 µm is the primary reason for their loss to flotation tailings.

Table 7. Grade, recovery, and separation efficiency of flotation tests of the scavenger circuit concentrate.

Test No.	Grade Cu %			Recovery %	Separation efficiency %
	Feed	Concentrate	Tailing		
Plant test	9.14	11.48	5.01	80.14	19.31
10	8.39	12.44	4.19	85.90	22.90
11	9.19	12.98	5.63	68.43	23.59

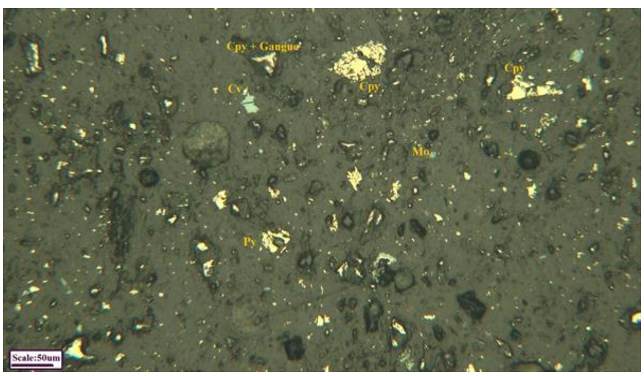

Fig. 4. Copper minerals and their distribution in the flotation test concentrate - Sungun copper scavenger circuit (Cpy: chalcopyrite, Mo: molybdenite, Py: pyrite).

4. Conclusion

The loss of copper mineral particles into the tailings of the scavenger flotation circuit at the Sungun copper concentration plant has significantly diminished the overall efficiency of the copper flotation circuit. This loss primarily stems from the presence of fine-grained particles of copper sulfide minerals, fluctuations in the ratio of copper sulfide to oxide in the circuit's input feed, and the interlocking of copper sulfide minerals with tailings, notably pyrite and silicates. Through a series of flotation, comminution, and sulfidation tests aimed at enhancing the performance of the scavenger circuit at the Sungun copper concentration plant, it was determined that rerouting the tailings stream from the scavenger circuit back to the rougher cells could mitigate copper loss, consequently increasing the total recovery of the circuit by over 4%. Moreover, redirecting the final tailing flow from the scavenger circuit to the underflow of the primary hydrocyclone for grinding through ball mills, to liberate interlocked copper minerals, and subsequently reintroducing this flow to the rougher stage, would lower the copper grade in the final circuit tailings. Another effective strategy identified to enhance circuit efficiency is sulfidation of the input feed to the scavenger circuit. This process ensures optimal conditions for the recovery of copper oxide minerals within the scavenger circuit. Notably, sulfidation using sodium sulfide, particularly in cell No. 2 of the scavenger circuit, aids in improving recovery by dispersing molecules, resulting in a notable 9% increase in recovery. Lastly, grinding the final concentrate of the scavenger circuit to achieve liberation of valuable copper minerals is projected to boost recovery by 5% and increase copper grade by 1%. To this end, it is recommended to directly transfer the scavenger circuit concentrate to the underflow of the secondary hydrocyclone and subsequently introduce it to the secondary ball mill.

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