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Research Paper

Characterization of Flotation Tailings of Iron Concentrate Lines 5, 6, and 7 of Golgohar and Feasibility of Copper and Iron Pre-processing from it

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Abstract: Today, the reprocessing of mineral processing plant tailings is important from an economic point of view (as a secondary source of valuable elements) as well as environmental issues. The purpose of this research is to characterize the flotation tailings of iron concentrate lines 5, 6, and 7 in Golgohar and their pre-processing in order to maximally separate copper and iron minerals and increase their grade. Therefore, after preparing representative samples from flotation tailings, instrumental chemical analysis, particle size analysis, and microscopic studies were performed on them. Then, using magnetic separation and classification methods, iron and copper separation and enrichment were done. The characterization results of the tailings showed that its main minerals are pyrite, magnetite, and talc, and the iron and copper grades are about 30% and 0.11%, respectively. The results of the pre-processing tests showed that by performing magnetic separation at a field intensity of 2000 Gauss, the grade of iron in concentrate and copper in the tailings increased to 47.8 and 0.18%, respectively. By adding a classification step before magnetic separation and discarding the coarse-grained part of the sample and then performing magnetic separation on the fine-grained part (-38 microns) in the field intensity of 2000 Gauss, the grade of iron and copper in the concentrate and tailings, respectively, is 53.6 and improved by 0.21 percent. Therefore, pre-processing can return the iron in the flotation tailings as an intermediate product to the iron concentrate production circuit and prevent its wastage. On the other hand, by discarding more than half of the flotation tailings, increasing the copper grade, and reducing iron in the rest, this operation created many technical and economic benefits for the copper extraction process in the next stages. Classification and magnetic separation methods are operationally simple and cost-effective and can be implemented in lines 5, 6, and 7 of Golgohar with minimal changes and costs.

Keywords: Flotation tailings, Tailings characterization, Pre-processing, Magnetic separation, Classification.

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INTRODUCTION

Today, one of the ways to supply raw materials for various industries, especially for basic and strategic metals such as copper, is to use low-grade resources and tailings [1,2]. In the past, due to a lack of appropriate technology and high processing costs, the tailings could not be reprocessed. But nowadays, with the development and application of new and efficient technologies, they may be able to be used economically. In addition, the accumulation of tails from processing plants around mineral complexes usually causes environmental problems due to the presence of high sulphur content as well as high concentrations of heavy metals [3]. Therefore, the reprocessing of mineral tailings with the aim of producing by-products, in addition to creating added value, reduces the environmental problems caused by their storage. To process mineral tailings, depending on the purpose, various methods are used to recover what element it is. For example, if iron recovery is a priority, gravity processing and magnetic separation methods are effective. If the goal is to recover the valuable copper element, hydro-metallurgy and flotation methods are considered. In the meantime, the flotation method is widely used in the mining industry for the selective separation of minerals (especially sulphide minerals) from each other. Extensive studies have been conducted in the field of reprocessing valuable elements such as iron, copper, nickel, and cobalt from mineral tailings. In these studies, various methods such as magnetic separation, flotation, leaching, bio-, and sometimes a combination of them have been used [3-7].

Preliminary investigations of the flotation tailings of iron concentrate production lines 5, 6, and 7 of Golgohar Mining and Industrial Company showed that this tailing contains valuable elements of iron and copper. The presence of two valuable elements, iron and copper, the high volume of produced tailings (about 243 thousand solid tons per year), and the micron particle size of the desired tailings have led to the elimination of operational costs such as exploration, extraction, crushing, and grinding, as well as a possible increase in price, especially copper, due to the development of technology and increasing attention to green energy, can lead to the economic justification of mineral tailings reprocessing. Therefore, in the present research, the identification and characterization of the flotation tailings of lines 5, 6, and 7 of Golgohar are first addressed, and then a suitable solution to increase the iron and copper content in the tailings is presented as a pre-processing step.

METHODS

In the iron concentrate production plant of Lines 5, 6, and 7 of Golgohar Mining and Industrial Company, the ore entering the factory enters the magnetic separation process after going through the crushing and grinding stages and achieving the degree of liberation of magnetite. The product from this process enters four 50-cubic meter flotation cells for desulfurization. In these lines, the flotation is of the reverse type, so that the sulfur-containing minerals (pyrite) are floated and the valuable material (iron concentrate) is removed from the bottom part of the last cell. In the flotation circuit, potassium amyl xanthate (PAX) is used as a collector, and methyl isobutyl carbinol (MIBC) is used as a frother agent. The floated part of flotation (reverse flotation tailings) is sent to the tailings thickener along with the tailings of different stages. After reaching the permissible limit of sulfur content in the flotation stage, the iron concentrate enters the low-intensity magnetic separators for better dewatering and for increasing the solid percentage of the pulp before being sent to the belt filters. The concentrate from this section is sent to the belt filters as the final concentrate. According to the design documents, the amount of solid tail produced from these lines is 243000 tons per year.

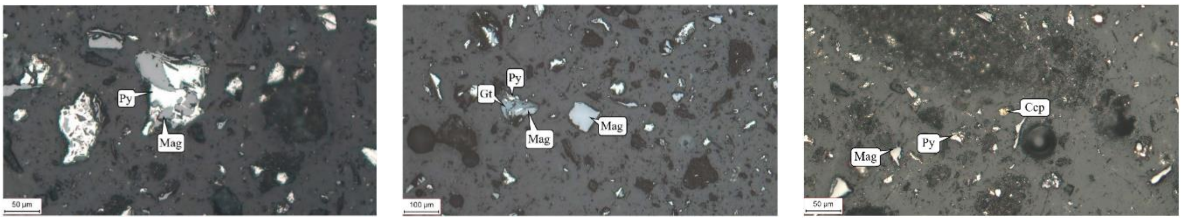
Sampling of flotation tailings was done daily from all three concentrate production lines 5, 6, and 7. After 30 days of sampling, the dried samples of flotation tailings were mixed and homogenized, and representative samples were used for different analyses (such as XRD, XRF, ICP, Fire Assay and study of polished sections with an optical microscope and SEM), particle size analysis and pre-processing tests were prepared. Davis tube tests were performed on a representative sample of flotation tailings at two magnetic field intensities of 700 and 2000 gauss. The purpose of conducting these tests was to investigate the separation of iron from copper and leave part of the sample as magnetic concentrate in the pre-processing stage.

FINDINGS AND ARGUMENT

Based on the results of XRF and ICP-MS analysis, it was observed that elements of iron (30%), sulfur

(11%), silicon (10.1%), magnesium (9.2%), sodium (5%), and calcium (6.1%) constitute a major part of the sample. In addition, the copper grade is 0.11%. Other valuable elements such as nickel, cobalt, and zinc with values of 663 ppm, 274 ppm, and 214 ppm are also present in the sample, but due to their relatively small amounts, their enrichment was not considered at this stage of the research. Based on the results of Fire Assay, the amount of gold in the current sample was reported as 19 ppb. In the study that Khoshdast and Zeidabadi Nejad also conducted on the samples obtained from the tailings dam of the processing lines of Goharzamin Iron and Steel Company, the amount of gold was very small, about 7 ppb [8]. Therefore, it seems that the various mines in the Golgohar region do not have sufficient amounts of gold in terms of economic value. Based on X-ray Diffraction (XRD) analysis of the sample, the main minerals, including pyrite (FeS_2), talc ($Mg_3Si_4O_{10}(OH)_2$) and magnetite (Fe_3O_4) were identified. Considering the hydrophobic nature of talc minerals, it seems logical that during the flotation process, some talc minerals will also float along with sulfurous minerals such as pyrite. The separation of talc minerals along with pyrite during the flotation process has already been reported by other researchers [9-11]. Also, efforts have been made to separate and concentrate these two minerals from each other by flotation in some studies [12, 13].

Based on the microscopic studies of the tailings sample, the main metal minerals were magnetite and pyrite (as the results of XRD studies also showed). The frequency of magnetite in the sample was about 25-30%, and that of pyrite was about 30-35%. Other metal minerals in the sample were chalcopyrite ($CuFeS_2$) and goethite (FeOOH), whose abundance is about 2 and 0.5%, respectively. The involvement rate of magnetite with pyrite in this sample is about 45-50%. The images of the studied sections are shown in Figure 1.



(A) (B) (C)

Figure 1. A: Magnetite and pyrite involvement, **B:** Free particles of magnetite along with involvement between particles of magnetite, pyrite, and goethite, **C:** Free particles of magnetite, pyrite, and chalcopyrite

Investigations related to dimensional analysis also showed that almost 80% of the sample had dimensions smaller than 80 microns. Therefore, common gravity methods cannot have high efficiency for preprocessing or processing in this dimensional range, but they are suitable for preprocessing with magnetic separation. Examining the distribution of iron grade in different dimensional fractions of flotation tailings showed that iron grade does not change in different dimensional fractions. According to the microscopic studies, a part of the magnetite mineral (as the main iron mineral), which is in the fractions above 38 microns, is involved in the form of magnetite with the pyrite mineral and therefore floated along with it and entered the flotation tailings, and a part of the magnetite, which is in the fractions below 38 microns, contains fine particles that were probably transferred to the flotation tailings due to the tailing phenomenon. Investigations of copper grade in different dimensional fractions are associated with noticeable changes, and the existing changes follow a constant trend so that the copper grade increases as the particle size decreases. The results showed that about 64% of the copper metal in dimensional fractions is below 38 microns.

According to the characterization results of the sample, iron was the main element in the sample with a grade of about 30%, and the magnetite mineral (Fe_3O_4) was also the main mineral in it. Therefore, with the aim of separating iron phases from other parts and producing a high-quality magnetic product of iron and non-magnetic tailings containing copper, a magnetic separation process with intensities of 700 and 2000 Gauss was used. The results of the best conditions showed that in the separation with a magnetic field intensity of 700 gauss, about 36.9% by weight of the sample with an iron grade of 50.5% and a copper grade of 0.06% entered the concentrate, and 63.1% by weight of the sample with an iron grade of 17.4% and a copper grade of 0.17% entered the tailings. In this experiment, iron recovery in concentrate was about

62.1%, and copper recovery in tailings was 97.5%. These results show that despite discarding 36.9% of the sample as magnetic concentrate, almost all the copper in the sample has reached the tailings resulting from magnetic separation, which shows the potential of copper pre-processing by the magnetic separation method. In addition, the obtained concentrate can be returned as an intermediate product to the concentrate lines 5, 6, and 7 of Golgohar (before the ball mill), and due to the involvement of about 50% of magnetite with pyrite, it can be subjected to crushing and magnetic separation again.

Based on the results of the distribution of iron and copper grades in different dimensional fractions, it was concluded that by performing classification on the original sample and removing the low-grade copper part in fractions larger than 38 microns, it could lead to an increase in the copper grade in the fine grain sample (-38 microns). In a series of experiments, by performing a classification step, particles larger than 38 microns were discarded, and the fine-grained part with copper and iron grades of 0.14 and 31.5% was obtained. Then, with magnetic separation, magnetic phases were separated from non-magnetic phases. Then, with magnetic separation, magnetic phases were separated from non-magnetic phases. The results of magnetic separation on the -38 micron part of the sample showed that the copper grade increased from 0.14% in the flotation tailings to 0.21% in the magnetic tailings, and the iron grade also improved in the magnetic concentrate to 53.6%. This increase in grades was higher than the values obtained from previous experiments that only used the magnetic separation method. Although classification causes more than half of the flotation tailings to be discarded as coarse particles (+38 microns), this issue is more suitable for copper pre-processing, and in addition to improving the copper grade, it causes the removal of a large part of the flotation tailings (about 75 percent) of copper from downstream processes. If iron recovery is also important, magnetic separation can be performed for fractions coarser than 38 microns (rejected by classification) to recover the maximum iron from the flotation tailings. With the production of coarse-grained magnetic concentrate of suitable grade, this product, along with fine-grained magnetic concentrate, is returned to the production circuit as an intermediate product.

CONCLUSIONS

The main elements of the flotation tailings of iron concentrate lines 5, 6, and 7 of Golgohar include 30% iron, 11% sulphur, 10% silicon, 9.2% magnesium, and 5% sodium, and the secondary elements and valuable samples include 0.11% copper, 663 ppm nickel, 274 ppm cobalt, and a small amount of 19 ppb gold. The results of mineralogical studies showed that the main metal minerals included magnetite (Fe_3O_4) and pyrite (FeS_2). Other metal minerals in the sample were chalcopyrite ($CuFeS_2$) and goethite (FeOOH). Talc mineral ($Mg_3Si_4O_{10}(OH)_2$) was one of the main non-metallic minerals in the flotation tailings.

The results of this research showed that the pre-processing of flotation tailings using magnetic separation and classification will be possible. This has two major advantages: firstly, that the iron wasted in the flotation tailings has the capability of primary enrichment and return to the iron concentrate production circuit as an intermediate product, and secondly, that in the remaining non-magnetic part of the flotation tailings, the copper grade can be increased by an acceptable amount, which increases its attractiveness for the purpose of extracting copper in the later stages due to its granularity and the major removal of iron-bearing minerals.

REFERENCES

[1] Suppes, R., and Heuss-Aßbichler, S. (2021). *"Resource potential of mine wastes: A conventional and sustainable perspective on a case study tailings mining project"*. Journal of Cleaner Production, 297: 126446.

[2] Lottermoser, B. G. (2010). *"Mine Wastes: Characterization, Treatment and Environmental Impacts"*. Third Edition, Springer, Berlin, pp. 400. DOI: 10.1007/978-3-642-12419-8.

[3] Ahmadi Amele, A., Khezri Khabisi, M., Abdollahzade, A., and Askari, M. (2014). *"Recovery of copper, nickel and cobalt from sulphide tailings of Golgohar Sirjan hematite recovery plant by flotation method"*. The 7th Conference & Exhibition on Environmental Engineering, Tehran, Iran. (In Persian)

[4] Brest, K. K., Henock, M. M., Guellord, N., Kimpiab, M., and Kapiamba, K. F. (2021). *"Statistical investigation of flotation parameters for copper recovery from sulfide flotation tailings"*. Results in Engineering, 9: 100207.

[5] Xie, Y., Xu, Y., Yan, L., and Yang, R. (2005). *"Recovery of nickel, copper and cobalt from low-grade Ni–Cu sulfide tailings"*. Hydrometallurgy, 80(1): 54-58.

[6] Zhang, R., Hedrich, S., Römer, F., Goldmann, D., and Schippers, A. (2020). *"Bioleaching of cobalt from Cu/Co-rich sulfidic mine tailings from the polymetallic Rammelsberg mine, Germany"*. Hydrometallurgy, 197: 105443.

[7] Drobe, M., Haubrich, F., Gajardo, M., and Marbler, H. (2021). *"Processing Tests, Adjusted Cost Models and the Economies of Reprocessing Copper Mine Tailings in Chile"*. Metals, 11(1): 103.

[8] Khoshdast, H., and Zeidabadi Nejad, M. (2019). *"Qualitative and quantitative investigation of tailings from processing lines of iron ore complex of GoharZamin (Sirjan) using laboratory methods and statistical monitoring"*. International Conference on Innovation and Research in Engineering Sciences, Tbilisi, Georgia. (In Persian)

[9] Beattie, D. A., Huynh, L., Kaggwa, G. B., and Ralston, J. (2006). *"Influence of adsorbed polysaccharides and polyacrylamides on talc flotation"*. International Journal of Mineral Processing, 78(4): 238-249.

[10] Beattie, D. A., Huynh, L., Kaggwa, G. B. N., and Ralston, J. (2006). *"The effect of polysaccharides and polyacrylamides on the depression of talc and the flotation of sulphide minerals"*. Minerals Engineering, 19(6): 598-608.

[11] Leung, A., Wiltshire, J., Blencowe, A., Fu, Q., Solomon, D. H., and Qiao, G. G. (2011). *"The effect of acrylamide-co-vinylpyrrolidinone copolymer on the depression of talc in mixed nickel mineral flotation"*. Minerals Engineering, 24(5): 449-454.

[12] Jin, S., Shi, Q., Feng, Q., Zhang, G., and Chang, Z. (2018). *"The role of calcium and carbonate ions in the separation of pyrite and talc"*. Minerals Engineering, 119: 205-211.

[13] Deng, W., Xu, L., Tian, J., Hu, Y., and Han, Y. (2017). *"Flotation and Adsorption of a New Polysaccharide Depressant on Pyrite and Talc in the Presence of a Pre-Adsorbed Xanthate Collector"*. Minerals, 7: 40.