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Research on the material composition of Ta-Phoi copper tailings and accompanying gold recovery orientation

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ABSTRACT

Every year, the Ta-Phoi copper processing plant disposes of about 970,000 tons of tailings with an Au grade content of approximately 0.1 g/t. In the operating technology, there has not yet been consideration for recovering useful components such as gold. The amount of gold lost annually in tailing products is about 116.4 kg Au. As of 2023, the amount of sludge is 3,531,682 tons (equivalent to 353.2 kg Au). The amount of tailings after the processing is significantly large, and the Au grade content in the tailings is still relatively high. The amount of tailings is currently stored at the tailing pond, if not treated, it will waste resources and cause a risk to environmental pollution. The article presents the results of research on the chemical composition and characteristics of tailings containing Au using sieve analysis, X-ray diffraction (XRD) analysis, inductively coupled plasma mass spectrometry/atomic emission spectrometry (ICP-MS/AES) analysis and scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM-EDS). The research results provide a technological direction for Au recovery using gravity separation methods (spiral, shaking table, and jig), centrifugal gravity separation (Knelson, Falcon), and flotation method. To increase the processed Au content, the products should be thoroughly treated through the leaching method using suitable chemical lixiviants to meet the safety and environmental protection requirements, following regulations in Vietnam. This is the first time that there are comprehensive studies on the material composition of copper tailings for the purpose of recovering the tailings bearing gold. The study opens up prospects for the recovery of useful minerals in the tailings of copper beneficiation plants, in particular and the tailings of the mineral processing plants in general.

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1. Introduction

The Ta-Phoi copper processing plant officially came into operation in 2019, using flotation technology to recover copper in ore with relatively good technological indicators. The copper concentrate has a grade content of ~23%Cu at actual recovery ≥ 88÷92%, the Au recovery coefficient in copper concentrate also reached ~60% with a grade content of ~5g/t Au. The tailings have a content of ≤ 0.09% Cu. The copper processing plant technology includes three main stages: comminution, grinding-beneficiation and dewatering.

- Comminution includes primary crushing, secondary crushing and tertiary crushing stages. ROM ore of 700 mm size is reduced to 175 mm in the primary crushing stage before taking out small products of 13 mm in the secondary and tertiary crushing stages;

- The grinding-beneficiation consists of two main steps: grinding stage 1 and flotation-grinding stage 2. For the first stage of grinding, the product has a grinding fineness of 65% - 0.074 mm. For the flotation-grinding stage, a pneumatic mechanical flotation machine is used to recover copper with an average Cu content of 25%. The tailings of the flash copper roughing stage go through the rougher 1 and scavenger stages. The product of the scavenger (meets the disposal requirements) flows through the pipeline system to the tailings pumping station and then is pumped to the tailings pond. The concentration product of rougher 1 and the tailing product of the flash flotation enter the stage 2 ball mill for re-grinding and are sent to the rougher stage 2. The froth product goes through the cleaner stage to upgrade the concentrate with a content of 21÷23% Cu. The tailing product of the rougher stage 2 is passed through the scavenger stages to remove tailings and then pumped to the waste pond;

- Dewatering: Use a two-stage dewatering process for copper concentrate, which is a thickener and a filter, to achieve a residual moisture content of copper concentrate of ≤ 10%.

- The tailings pond of the Ta-Phoi copper processing plant has an area of about 36 hectares with a capacity of 11,440,408.78 m^3 for the entire project life. The tailings pond receives tailings (0.05÷0.08% Cu, 0.1g/t Au) from a copper processing plant with an annual capacity of about 970,000 t/year. As of 2023, the amount of sludge is 3,531,682 tons (equivalent to 353.2 kg Au). The amount of sludge has continued to increase rapidly in recent years because the technological line has been operated more and more stably. In the technology of the Ta-Phoi Copper Plant, there is no focus on recovering useful components such as gold, rare earth, etc. In addition, because the plant has just come into operation, there are not many studies on recovering these objects in the tailings. In the context of the increasing demand for gold due to geopolitical instability and the strong development of high-tech industries (electronics, healthcare, aerospace, chemistry, etc.), the world gold price increased to more than 3658 USD/ounce and tends to continue to increase strongly in the coming time, the thorough recovery of this precious metal in minerals and gold-containing tailings not only brings economic efficiency but also contributes to the rational use of mineral resources, stabilizing the supply of strategic metals. In the scope of the article, the authors focus on an overview of Au processing technologies, analysis of tailings sample composition and orientation of processing solutions to recover this precious metal.

2. Research and practices gold processing technology in the world and Vietnam

Gold has been produced on an industrial scale for a long time in the world. The eight countries that produce the most gold have an output of over 150 tons/year. While gold production in the past was mainly from alluvial ores, today gold production is mainly recovered from primary ores. Processing methods are a combination of gravity separation, flotation, chemical separation, or some other special methods.

For primary ores, gold is crushed/ground and flotation combined with gravity separation to obtain a concentrate for metallurgy. Placer ores are usually separated by the gravity method (Surimbayev et al., 2024; Bulatovic, 2007).

To refine and recover gold, the cyanide method is the main chemical leaching method today due to its outstanding advantages of high recovery efficiency, large productivity, low investment capital and the ability to process dispersed gold ores and difficult-to-process ores

(Lotter, 2005; Gold. U.S Environment Protection Agency, 1994).

In Vietnam, the gold ore process technology commonly used is jaw crushers and hammer crushers to crush the ore to a particle size of -2 mm and upgrade it on a manual washing trough. The middling product is crushed again to -0.5 mm and further beneficiation on a shaking table. The fine ore from this process is further treated with mercury to recover the gold. Since 1996, some state-owned enterprises have applied both flotation and gravity separation methods to recover gold (Yan & Hariyasa, 1997). Meanwhile, private mining households often use selective mining methods, then use manual crushing, hammer crushing and sorting on a shaking table. Gold concentrate is mixed with mercury, dissolved with cyanide, or smelted to recover. The recovery with this method is often very low (50÷60% for placer mines; 30÷50% for primary gold). This technology causes great loss of mineral resources.

Major gold mining and processing companies in Vietnam can be listed as: (1) Joint Venture Company 392 has applied underground mining method with a capacity of 300,000÷500,000 tons/year. The processing technology is a combination of flotation separation-gravity separation-cyanidation; (2) Tra-Duong Gold Mining Enterprise mainly applies manual mining technology. The processing technology is gravity separation combined with cyanide leaching; (3) Tra-Nang Gold Mining Enterprise applies mechanical mining technology combined with manual mining with a capacity of 9,100 tons/year. The processing technology is a combination of jaw crushing, hammer crushing and washing on the shaking tables. The recovery rate is only 30÷40%. (4) Bong-Mieu Gold Company (Bogomin) mainly uses open-pit mining technology. The processing technology includes the following stages: crushing-grinding, classification, upgrading on the Jigg machine (1 separator for coarse particle ore, 1 separator for small particle ore) and traditional flotation (for the fine particle size part). Flotation and gravity-separated concentrate products are cyanidized and then gold is recovered, with an actual recovery of about 65%. The factory's technological line and equipment are relatively modern with a treatment system that limits environmental pollution. All factory waste ore is detoxified in a closed loop to reduce the amount of cyanide in the waste dump to below the permitted level of Vietnamese standards before being discharged to the waste storage area. The waste dams are designed and built according to international standards, avoiding seepage into underground water and meeting the requirements of protecting surface water, groundwater and the ecological environment (Tran, 2011; Nguyen, 2009; Rees & van Deventer, 2000)

In 2011, a research team from the National Institute of Mining and Metallurgy Science and Technology (VILUMKI) studied a solution to recover gold in the tailings of the Sin Quyen Copper Processing Plant (Lao Cai). The results of chemical analysis showed that the research sample had a gold content (Au) of less than 0.1 g/t and an iron content (Fe) of 12.8%. The distribution of gold in the fraction size of -0.074+0.045 mm accounted for nearly 50% and within which the fraction size of -0.045 mm also accounted for over 30%. The gold in the experimental sample had a very low content (less than 0.1 g/t), mainly primary gold with very fine particle size and it would be difficult to obtain gold concentrate using normal gravity separation devices. The research team conducted research on the Knelson machine to determine the centrifugal force, water supply pressure and separation cycle with an initial sample of 15 kg and a feed concentration of 60%. The results show that although the gold concentrate content is not high (the highest is 1.78 g/t), the gold recovery degree is also at the allowable level (36.98 g/t). The project has conducted gold recovery using Knelson (in both rougher and cleaner stages) and Knelson concentrate is manually washed. The gold concentrate product has a content of ~40 g/t but the actual recovery is very low, reaching over 16%. Based on the results of particle size analysis, the group has classified to remove the fraction size of +0.125 mm in the experimental sample, then used the Knelson separator to obtain gold concentrate with a content of 14.42 g/t at the corresponding actual recovery of 32.87% (Ngo, 2011).

The research team at the Vinacomin - Minerals Holding Corporation carried out the project: "Completing the production line to recover useful minerals and treat water sludge in the Sin-Quyen copper beneficiation plant, Lao-Cai" from 2014÷2016. Through the research results and design of completed the gold recovery technology line and sand separation technology in the tailing sludge of the Sin-Quyen copper flotation plant, the Corporation deployed construction, installed equipment and conducted trial production on an industrial scale. The gold recovery technology line, after 1 year of trial production, collected 203 tons of gold concentrate, Au content 41.27 g/t and actual recovery of the stage reached 8.25% (Ta, 2016).

3. Sample and Methodology

3.1. Research sample and sampling plan

Tailings samples were taken at the location right after the scavenger stage of the Ta-Phoi copper processing plant using specialized sampling equipment following the cross-flow method. The estimated number of incremental samples is 36. Due to the technical sampling requirements for the study, the sample mass required is 750 kg (dry weight). Therefore, the sample mass at each point taken is: $m_1 = 750/36 = 20.8$ kg (dry weight). The number of incremental samples and the sample mass taken ensure representativeness. Technical samples were taken, dewatered, dried, packaged directly and transported to the Mineral processing laboratory, Hanoi University of Mining and Geology. After carefully mixing, samples were divided and taken for mineral analysis, chemical analysis, SEM-EDS image analysis and sieve analysis to determine particle size composition and use for experiments.

3.2. Methodology

The methods used in the study of material composition are: (1) Statistical and aggregation method to evaluate technology and equipment efficiency for separation at laboratory and industrial scale; (2) Experimental methods at laboratory scale to discover the form of gold in minerals and the prospects for recovery by conventional methods of processing; (3) Calculation, data processing, graphing, comparing results (4) Using analytical methods with modern equipment to determine the composition and characteristics of minerals in tailings, determine the distribution degree of Au in each fraction size; thereby orienting the separation technology to find reasonable parameters that can recover the maximum amount of gold in concentrate. The analyzed samples include:

- X-ray diffraction analysis was performed at the Center for Geological Experimental Analysis - General Department of Geology and Minerals of Vietnam, on the X-ray diffraction system, D8-Advance machine;
- ICP-AES (Atomic emission spectroscopy analysis) was performed at Ta-Phoi Copper Joint Stock Company;
- ICP-MS (Mass spectrometry analysis) was performed at the Center for Geological Experimental Analysis - General Department of Geology and Minerals of Vietnam;
- Scanning electron microscopy analysis combined with specialized detectors (SEM-EDS) at the Center for High-tech Analysis and Experimental Analysis, Hanoi University of Mining and Geology;
- Sieve analysis with a standard sieve set with selected mesh sizes of 0.2, 0.1, 0.074, 0.045, 0.02 mm.

4. Result and Discussion

4.1. Particle size distribution and particle images

4.1.1. Sieve analysis

The tailings samples were analyzed by sieve into the following fraction sizes: + 0.2; 0.1 - 0.2; 0.074 - 0.1; 0.04 - 0.074 and - 0.04 mm. The fraction sizes were dried, weighed, calculated yield and analyzed for Au content at Ta-Phoi Copper Joint Stock Company using the ICP-AES method. The particle size distribution of the tailings samples is shown in Figure 1. The results showed that gold was distributed mainly in the fraction size 0.1÷0.2 mm and fraction size -0.02 mm, with the highest Au content at the +0.2 mm and -0.02 mm fractions.

4.1.2. Image of samples using SEM-EDS

The particle size, particle shape and surface characteristics of mineral particles play an important role in recovery, especially Au recovery by gravity separation. Therefore, the first sample was analyzed by scanning electron microscopy (SEM) combined with energy-dispersive X-ray spectroscopy (EDS) on some highlighted spots of the sample at the Center for Analysis and High-Tech Experiments, Hanoi University of Mining and Geology.

Figure 2 shows that the particle size of the material is relatively uniform, with a small number of coarse particles, mainly in the form of blocks. The particles have a relatively smooth surface with generally fine and ultrafine sizes. This may be the reason for the low efficiency in Au enrichment from the tailing pond by conventional separation methods such as gravity separation.

The detected elements are Ba, Si, Al, O, Fe, Ca and K, which account for a large proportion. The metals Cu and Au are not detected by this method.

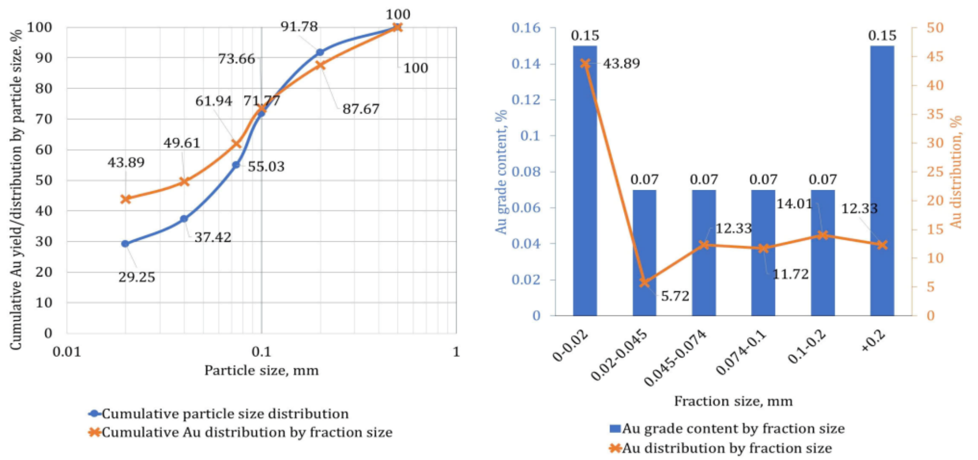

Figure 1. Particle size distribution of the Ta-Phoi cooper tailing.

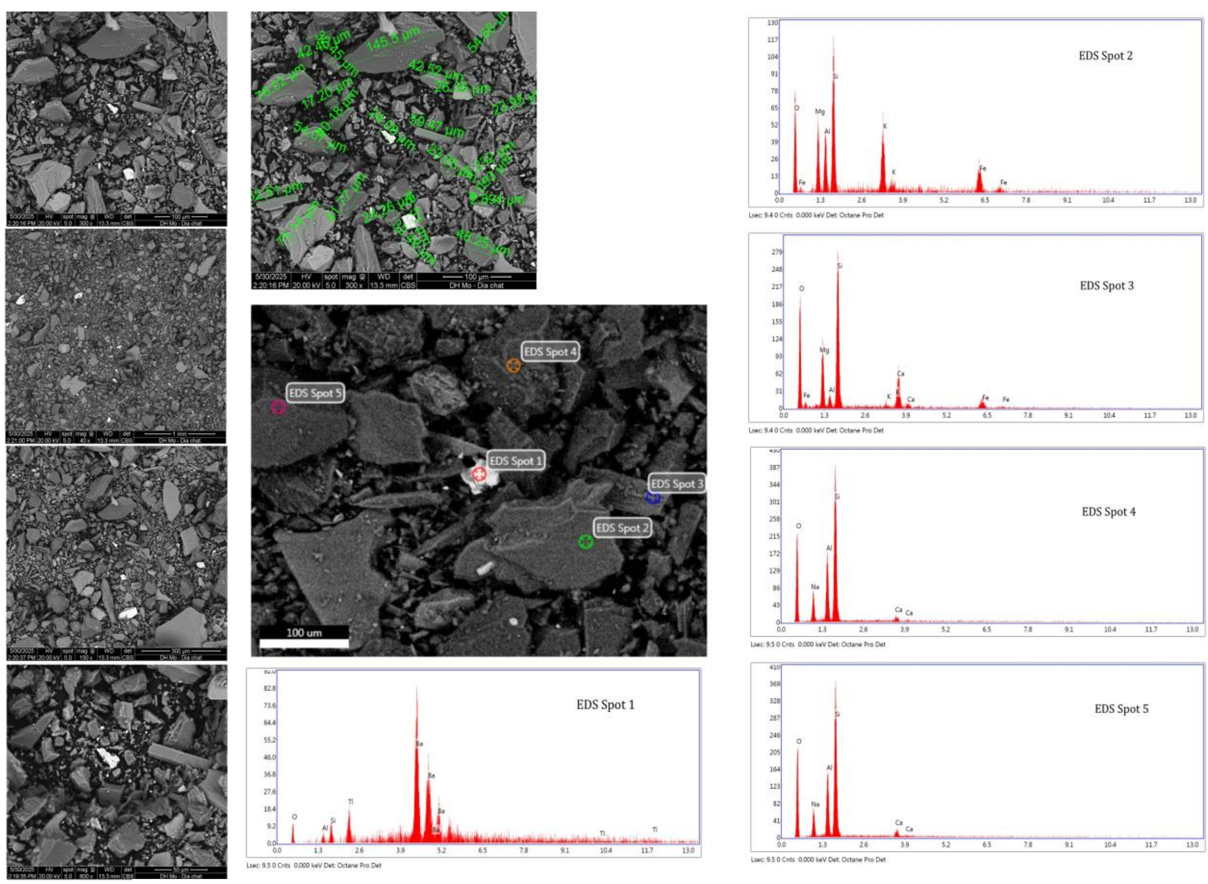

Figure 2. Images of tailing sample using SEM-EDS.

The reason for this phenomenon is that the copper and gold particles have extremely low content, ultrafine particle size and are contaminated with other minerals, so the system cannot detect them. Therefore, the sample is solved in two ways in an effort to explore the existence of gold:

- First way, the sample is then ground to 100% grade - 0.02 mm and analyzed by SEM-EDS image. The results are shown in Figure 3. In general, even when ground to ultrafine particle size, Cu and Au elements are still not detected. This hinders the direction of research on the separation technology because it is impossible to determine the particle shape, contamination and type of gold-containing minerals.

- Second way, the sample is upgraded on a shaking table with the purpose of dividing it into products of different quality. The products obtained from the shaking table include the heavy product (Au content 3.04 g/t), middling 1 (Au content 0.49 g/t), middling 2 (0.06 g/t) and light product (0.08 g/t). The heavy product samples were subjected to electron microscopy and elemental determination using energy-dispersive X-ray spectroscopy. The results of the analysis are shown in Figure 4. Although attempts were made to preliminarily enrich the gold to a relatively high content, all attempts to detect the presence of Au were unsuccessful. Thus, it can be preliminarily determined that gold exists in ultrafine form or

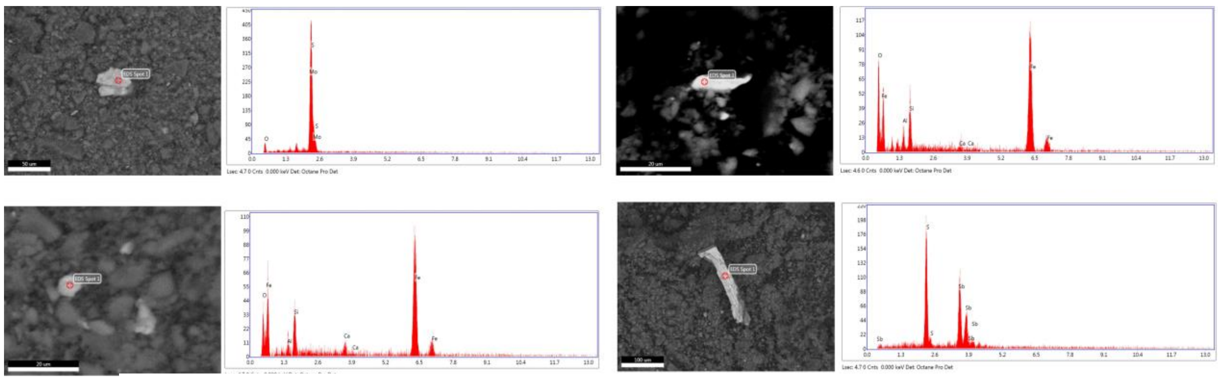

Figure 3. Images of ground sample (100% below 0.02 mm) using SEM-EDS.

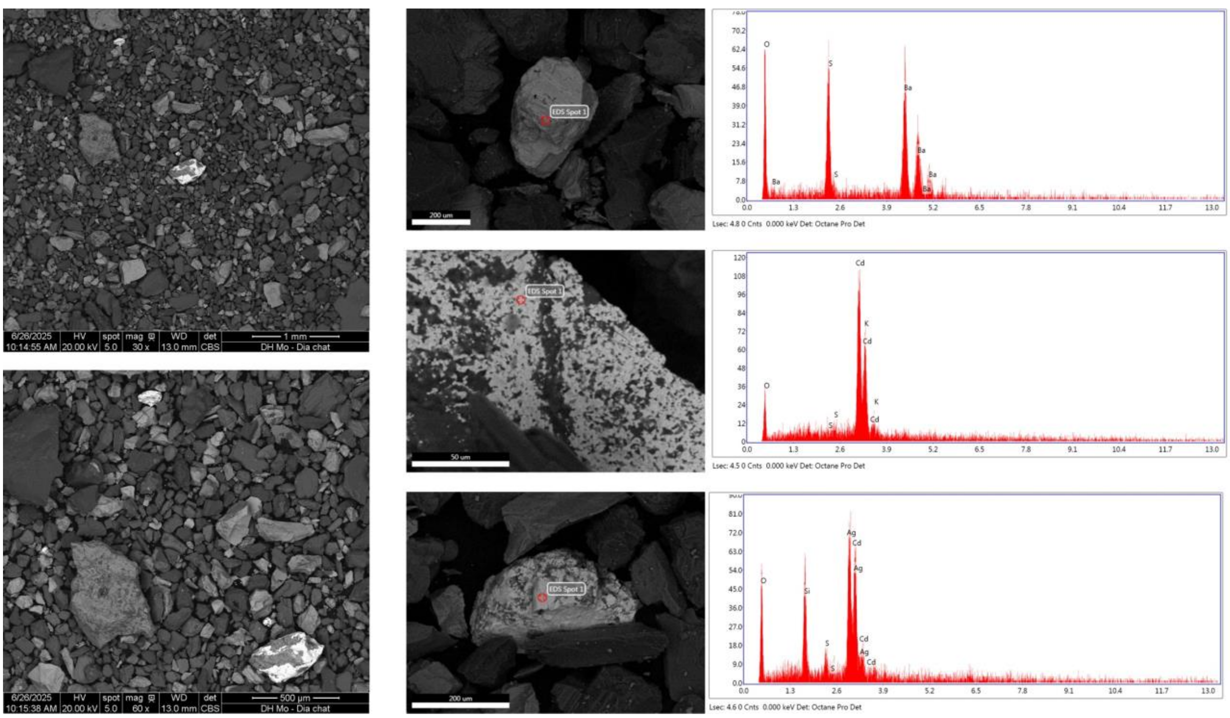

Figure 4. SEM - EDS images of the tailing sample after Au upgrading by shaking table.

special forms such as isomorphous substitution in other minerals or the form of ion adsorption.

4.2. Chemical composition

In order to find out the chemical composition, the Ta-Phoi copper tailings were then analyzed by ICP-MS at the Center for Geological Analysis and Testing. The analysis results are shown in Figure 5. The Ta-Phoi copper flotation plant tailings have a copper content of ~0.057% Cu, 0.1g/t Au.

4.3. Mineralogy composition

The initial tailings sample was subjected to X-ray diffractometer (XRD) analysis at the Geological Testing and Analysis Center to determine the mineralogy composition and direction research in Au recovery technologies. The results are shown in Figure 6.

The analysis results show that the minerals that account for a high proportion of the tailings are quartz, mica, feldspar, amphibole and chlorite. The sample contains a small portion of chalcopyrite. Although ICP analysis methods have detected the presence of gold in the sample, the gold content is very low and it is not possible to determine the form of gold in the minerals as well as the particle size of gold in the sample. The hypotheses based on reference documents and previous processing practices are that (1) gold exists in native forms with extremely fine sizes or in the form of copper-containing minerals; (2) it exists in the form of isomorphic substitution with accompanying rock minerals; or (3) gold exists in the form of ion adsorption. The proposed technology recovery research solution is based on these hypotheses.

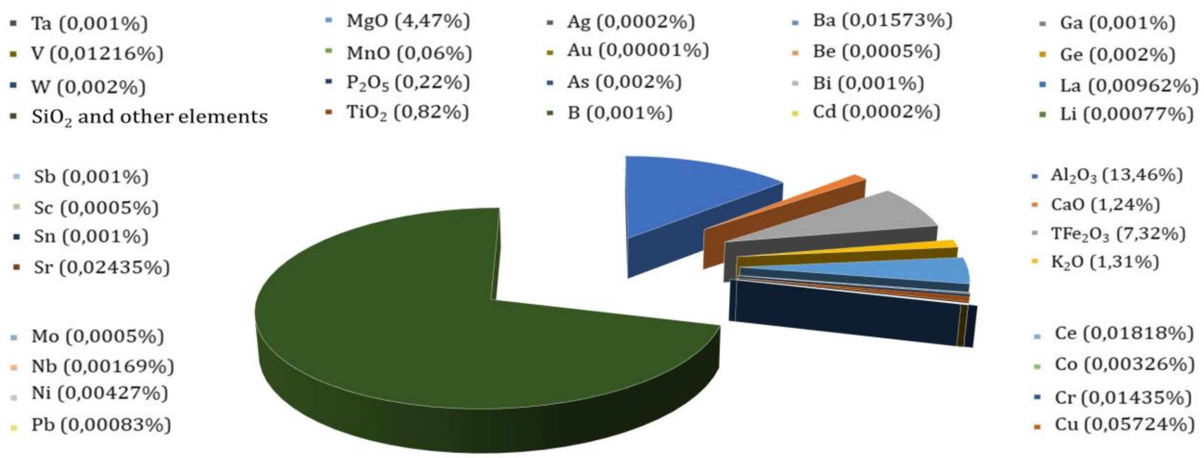

Figure 5. Chemical composition of tailing using ICP-MS.

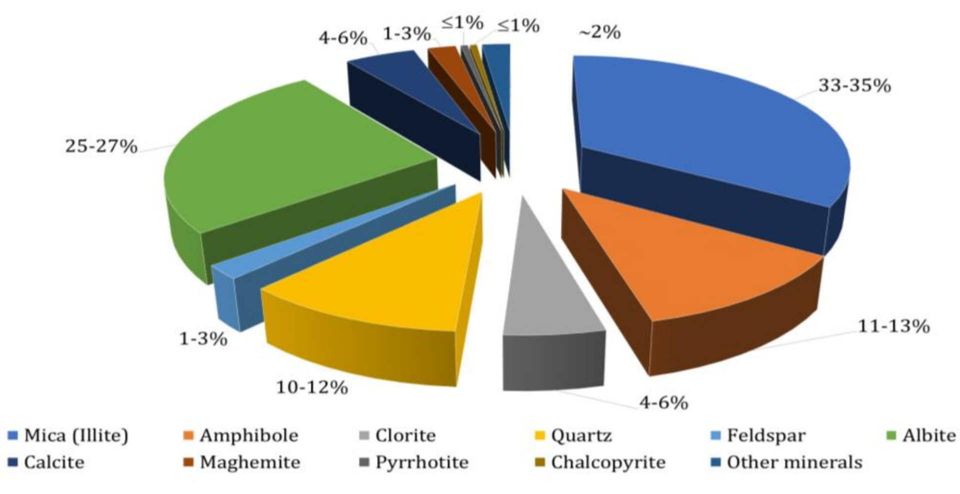

Figure 6. Mineralogy composition using X-ray diffractometer (XRD).

4.4. Research orientation

4.4.1. Using the gravity separation method

Gravity separation is a separation process that relies on the large density difference between gold and its associated minerals. Gold metal has a specific gravity of 19.3 and common rock/ore has a specific gravity of about 2.6. All gravity separation equipment creates relative movement between gold and host rock minerals in a way that separates heavier products from lighter products of material (Wills, 2016). Common gravity separation equipment includes a shaking table, spiral and Jig separator. The efficiency of a gravity separator is closely related to the size and shape characteristics of the gold particles (Mc-Grath, et al., 2015; Jena, 2017). Previous studies have shown that the shaking table equipment is used to increase the gold content of materials with narrow particle sizes of 0.2÷0.8 mm and 0.075÷0.2 mm. Accordingly, the first two materials with particle size composition of 100% - 0.8 mm; and 100% - 0.2 mm were studied using the shaking table. For the 100% - 0.8 mm material, the fraction size of 0.2÷0.8 mm with a content of 13.28 g/t was raised to 15.27 g/t, while the fraction size of 0.075÷0.2 mm increased from 12.76÷24.12 g/t. For 100% grade material - 0.2 mm, the fraction size of 0.075 ÷0.2 mm was increased to 67.74 g/t from the initial ore content of 15.80 g/t. The above research results open up the prospect of applying the shaking table in the treatment of gold-bearing ores with high gold enrichment efficiency (Samah El-Sayed, 2020).

While coarse gold is recovered by the shaking table, fine gold particles smaller than 0.075 mm are recovered by the centrifugal gravity concentrator. Accordingly, three types of primary materials with different particle sizes of 100% fraction - 0.8 mm; 100% fraction - 0.2 mm; 100% fraction - 0.075 mm are studied using the Falcon equipment. For the 100% fraction - 0.8 mm material, gold is enriched from 2.43÷68.51 g/t while for the 100% fraction - 0.2 mm material, the ore with particle size - 0.075 mm is enriched from 11.84÷147.47 g/t. For the material - 0.075 mm material, the concentrate has a content of 52.45 g/t from the primary ore with a content of 12.12 g/t. The results showed that the treatment of fine-grained ores by Falcon was highly efficient, meeting the metallurgical requirements of traditional methods (Samah El-Sayed, 2020; Ernawati et al., 2019; Onel & Tanriverdi, 2016).

For copper processing tailings, the material has a 100% particle size of -0.5 mm with an Au content of 0.1 g/t. The beneficiation method is oriented in two ways: (1) Classify the initial material into three narrow fraction sizes: below 0.074 mm, 0.074÷0.2 mm and above 0.2 mm. The fraction size below 0.074 mm with the Au content of 0.11 g/t can be processed by centrifugal gravity separator (Falcon or Knelson). The fraction sizes 0.075÷0.2 mm (0.07 g/t Au) and above 0.2 mm (0.15 g/t Au) are treated by a fine and coarse sludge shaking table. (2) Ground the material to 100% particle size -0.074 mm and process the ore by centrifugal gravity separator. Those orientations are suggested based on the chemical composition and particle size distribution of the research sample, as well as the previous study of similar objects.

4.4.2. Using the flotation or combine gravity-flotation method

According to current trends, low-grade gold-bearing ores < 6 g/t with particle size < 100 μm were studied using Knelson and conventional flotation equipment. For the Knelson separator, the concentrate had a content of 618.3 g/t with a recovery rate of 41.4%, of which the tailings had a content of 3.1 g/t with a loss of 49.6%, the middling had a content of 9.52 g/t at a recovery ratio of 9.0%. The tailings of the rougher stage were processed in the scavenger stage according to two options: (1) Using the Knelson separator, the concentrate had a content of 184.6 g/t with a recovery rate of 7%; (2) Using flotation with the concentrate having a content of 65.6 g/t at a recovery of 78.1%. In addition, the gold-bearing ore with a grade of 5.02 g/t was flotation-treated to obtain a concentrate of 82.06 g/t at a recovery of 89.9%. The tailings had a grade content of 0.46 g/t with an Au loss ratio of 7.9%. The collector used were Aerophine 3418-A and Aero 208 (50 g/t + 50 g/t), pH adjuster H_2SO_4 (pH = 5.0), depressant Na_2SiO_3 1000 g/t and frother methyl isobutyl carbinol (MIBC) 50 g/t (Gül et al., 2012; Meza et al., 2004; Klein et al., 2010; Aksoy & Yarar, 1989; Yan & Hariyasa, 1997; Yalcin & Kelebek, 2011; Forrest et al., 2001).

For the Ta-Phoi tailings, one problem that should be noted here is the inability to observe the form of existence and particle size of gold in the tailings (even when using the SEM analysis method with a high density of EDS points and XRD analysis). This issue led to difficulty in establishing a beneficiation plan for the purpose of recovering gold-containing minerals. According to previously recorded hypotheses, gold can exist in free form with ultra-fine particle size or disseminated in sulfide minerals such as pyrite, chalcopyrite, etc. For the ultra-fine form of existence, the feasible solution here is supergravity separation with a large sample mass used. For the hypothesis of existence in sulfide minerals, a challenge to the beneficiation process is the phenomenon that the mineral surface can be oxidized due to the long residence time in the tailing pond and the copper flotation process technology has depressed a large amount of pyrite. Therefore, when Au flotation, it is necessary to have a special activator chemical to re-activate the mineral surface before recovering by traditional flotation methods of sulfide ore. The complex composition and existence of gold in tailings, together with previous copper recovery processing procedures, create difficulties for recovery, requiring detailed experimental studies with the combination of many different methods. The suggested option is a combination of centrifugal gravity separator (Knelson equipment) and flotation of tailings or direct flotation of gold-bearing ores. In order to ensure the gold content according to the requirements of metallurgy, the proposed flow sheet should be studied, including the number of rougher, scavenger and cleaner stages and the suitable middling product return points.

4.4.3. Direction leaching method

According to (Maganga et al., 2023), in general, with gold-copper ore subjects, the challenges encountered are (1) increased treatment chemical costs, (2) increased post-leaching chemical treatment costs, (3) low gold recovery, (4) reduced gold adsorption efficiency, (5) reduced electrolysis efficiency, (6) difficulty in measuring the concentration of free leaching chemicals. Examples of gold leaching using cyanide summarized from previous studies have proved these statements. Muir (2011) reported that every 1% of reactive copper in gold ore can consume up to 30 kg NaCN/t of ore. When the ore contains highly soluble copper minerals such as covellite, cyanide consumption can be as high as 51.5 kg/t of ore due to the formation of thiocyanate and copper cyanide compounds (Bas, et al., 2015). On the other hand, typical cyanide consumption observed in stirred leaching systems ranges from 0.25÷0.75 kg/t (Marsden & House, 2006). The use of high cyanide concentrations to offset the impact of copper on gold recovery often increases the cyanide concentration after filtration. To meet international standards and regulations, the degradable (WAD) cyanide threshold (using weak acid) to discharge to a tailings storage facility must be below 50 ppm, requiring a cyanide destruction unit. This increases the operating cost of the cyanidation plant (Estay, 2018). The presence of copper minerals in gold ores often tends to reduce the recovery of gold during cyanidation due to the dissolution of copper and the formation of copper cyanide compounds that create a shortage of free cyanide in the solution to react with gold particles (Barani et al., 2021; Barani et al., 2022). Furthermore, the surface of copper minerals such as chalcopyrite under cyanide-deficient conditions acts as a gold pre-scavenger, thereby reducing the concentration of gold in the solution (Souza et al., 2014). Adsorption of copper cyanide complexes on activated carbon often displaces gold, thereby increasing the amount of gold lost in the solution (Estay, 2018). Under high overvoltage conditions or when the copper concentration is relatively higher than the gold concentration (e.g., 200 ppm for copper versus 5 ppm for gold), co-deposition of copper during gold electrolysis can occur at the cathode, reducing current efficiency, ingot purity and affecting the morphology and adhesion of the plated gold (Steyn & Sandenbergh, 2004).

In the processing of complex gold-copper ores, several processing techniques have been applied in the mining industry, such as ore beneficiation, pre-aeration, pre-leaching and chemical leaching mixtures (Maganga et al., 2023). While the ore beneficiation has been mentioned above, the aeration method aims to reduce the passivation of gold before the gold is leached due to the presence of sulfide minerals in the ore.

Several leaching chemicals such as sulfuric acid, ammonia and iron(III) chloride have been tested as pre-leaching reagents in gold cyanidation with limited success, especially in the processing of low-grade and sulfide ores due to high reagent consumption, the requirement for neutralization before cyanidation and the challenge of recovering copper from the leaching solution (Dai et al., 2012). On the other hand, the study by Tanda et al. (2017) showed that glycine (i.e., a non-toxic amino acid) was able to leach a variety of copper minerals (e.g., malachite, azurite and cuprite) under alkaline conditions with a maximum copper extraction rate of over 80% after 24 hours; this could be a potential pre-leaching reagent for copper minerals prior to gold cyanidation. However, chrysocolla and chalcopyrite showed slow dissolution rates of less than 20% after 24 hours. Additionally, Torres (2020) showed that pre-treatment of complex ores with sodium citrate improved gold recovery from 20 to 70% after leaching with 0.4 mol/L thiourea. The use of lixiviant mixtures for the treatment of gold-copper ores has been reported in the literature to provide various benefits such as reducing reagent consumption and improving gold recovery. Among the lixiviant mixtures tested in the literature include cyanide-glycine extract (Barani et al., 2021; Barani et al., 2022), thiocyanate-glycine extract (Wu et al, 2019) and ammonia-cyanide extract (Hedjazi, 2018; Bas et al., 2015; Jeffrey et al., 2002).

In the context that Vietnam is not encouraging the use of cyanide in gold processing, alternative chemicals can be proposed such as thiosulfate, thiourea, bisulfide, ammonia, chloride, iodide, bromide, glycine, citrate, sodium dicyanamide. For Ta-Phoi copper tailings, studies should focus on preliminary beneficiation before leaching to reduce chemical costs, mixing chemicals together to increase recovery efficiency and reduce the negative interaction of copper on Au leaching efficiency.

5. Conclusion

Every year, the Ta-Phoi copper processing plant discharges 970,000 t/year of tailings with copper content of about 0.05÷0.08% Cu, approximately 0.1 g/t Au. The number of useful substances in it, especially gold, can still be recovered to increase economic efficiency, comprehensive utilization of resources and environmental protection.

The properties of tailings have been studied. The particles of the sample are below 0.5 mm and are pretty uniform in size.

The main minerals are Mica (Illite), Amphibole, Chlorite, Quartz, Feldspar, Albite, Calcite, Maghemite, pyrotite, Chalcopyrite and other minerals.

Gold exists in extremely small amounts and can only be detected by ICP - MS / ICP - AES analysis.

The tailing sample was studied for particle size, particle shape, liberation degree and dominant elements by SEM-EDS system. The results showed uniform particle size and angular block shape. However, due to the very small gold content and complex contamination in other minerals, gold has not been detected by this method. Therefore, based on the discussed hypotheses, the existence of gold needs to be further studied by other modern methods. It is recommended that the tailings be studied for Au recovery using gravity and centrifugal gravity separation methods combined with flotation. The ore after separation can be processed in the direction of leaching, using environmentally friendly lixiviants and following regulations in Vietnam.

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Contributions of authors

Hai Thanh Pham - methodology, test conduction, discussion, writing, review & editing; Dung Kim Thi Nhu - review & editing, supervision; Nhung Thi Pham - sampling & experiment conduction.

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