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GOLD RECOVERY FROM FLOTATION TAILINGS IN COPPER METALLURGY: A SUSTAINABLE APPROACH TO RESOURCE VALORIZATION

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Abstract

Flotation tailings generated during copper ores beneficiation processes are often regarded as waste byproducts, although they may contain valuable trace amounts of gold, particularly in ores with gold-bearing copper and iron sulphides. Traditionally, the recovery of gold from this type of tailings has been overlooked due to low concentrations and high costs associated with conventional recovery methods. However, the increase of gold price and the growing emphasis on resource optimization and sustainability in the mining and metallurgical industry have prompted renewed interest in the recovery of gold from flotation tailings.

Actual methods used for gold extraction from flotation tailings in copper metallurgy are reviewed in this paper, including cyanide leaching, gravity separation, bioleaching, and flotation reprocessing. It explores the technical challenges involved, such as the fine particle size of gold and the complex mineralogical composition of flotation tailings, which can hinder efficient recovery. Additionally, the environmental and economic benefits of integrating more sustainable methods, such as bioleaching and non-toxic leaching agents, like thiourea, are highlighted.

Industrial case studies from a few global operators demonstrate the practical application of these techniques and their potential for improving resource recovery and minimizing waste. Future directions in the field were also reviewed, emphasizing the importance of technological innovations for enhancing the recovery of gold from flotation tailings, thus contributing to a more sustainable and circular industrial economy.

***Keywords**: Gold Recovery, Flotation Tailings, Copper Metallurgy, Resource Valorization*

1. INTRODUCTION

Copper mineral processing is a cornerstone of global industry, but it also produces large volumes of flotation tailings as a byproduct. These tailings, primarily composed of fine particles from the beneficiation process, are often regarded as waste and consequently overlooked by many producers. On the other hand, these tailings can still hold significant value, especially in the form of residual gold. Although copper is the primary target, flotation tailings from copper processing often contain trace amounts of gold. Over the years, there has been growing interest in recovering this precious metal from tailings, both as a resource recovery strategy and a mean for reduction the environmental impact of tailing ponds.

Historically, gold extraction from flotation tailings didn't have priority because the gold concentrations were too low to justify the cost of extraction. But with the rising demand for gold and a push for more sustainable mining practices, extracting gold from flotation tailings has become an increasingly viable option.

This paper reviews the potentials for gold recovery from flotation tailings in copper metallurgy, exploring the applied methods and technological challenges, adding some examples from actual industrial practice. The topic discussed here is well-explored in the available literature. Numerous studies and case reports relate to the recovery of gold from flotation tailings in copper metallurgy, employing various methods such as cyanide leaching, gravity separation, bioleaching, and flotation reprocessing. Research by Hoang et al. [1] investigated recovery of fine gold in tailings using advanced pneumatic flotation reactor Imhoflot^{TM}. Studies on cyanide leaching of copper-bearing flotation tailings are documented in the paper of Medina and Anderson [2]. Additionally, bioleaching techniques for gold recovery from mine tailings was explored in paper of Falagan et al. [3]. Bioleaching of gold in mine tailings by *Alcaligenes faecalis* is reported by Pineda et al. [4]. Thiosulphate leaching emerges as an alternative to cyanide leaching, offering a non-toxic method for gold recovery from flotation tailings [5]. Innovative methods, such as microwave-assisted comminution and mechanochemical activation, as two advanced material processing techniques that aim to alter the physicochemical properties of ores or minerals to improve efficiency in downstream processes, show promise for enhancing the liberation of gold from flotation tailings.

1.1 Gold in Copper Flotation Tailings: A Hidden Resource

Flotation tailings in copper metallurgy are produced after separation of copper minerals from gangue material in the flotation process. They are typically considered as low-grade material and are stored in tailing ponds. Gold, although present in small quantities, is often found in flotation tailings, especially in ores that contain gold-bearing copper- and iron sulphide. In many cases, gold exists in these tailings as free particle-liberated gold or as gold associated with sulphides or silicates (encapsulated gold). Gold concentration in flotation tailings can range from as low as 0,1 g/t to higher values, depending on the ore body. Tailings from some copper operations have been reported to contain gold concentrations between 0,2 to 0,5 g/t. Although it seems low, the cumulative amount of gold locked in these tailings can be significant, making its recovery profitable. Due to the fine nature of the gold particles in tailings, ranging from submicron- to 5 μm size for gold locked in very fine inclusions, up to 5-50 μm for liberated gold [5], along with their association with other minerals, recovery is often challenging and demands a complicated extraction process. As a result of high processing costs and low recovery rates, the recovery of gold from flotation tailings was not in the producers' focus of interest in the past. Nevertheless, advances in processing technologies and the continuous growth of gold price have spurred new approaches to gold extraction, for this type of secondary resource.

2. METHODS FOR GOLD RECOVERY FROM FLOTATION TAILINGS

Several methods are employed to recover gold from flotation tailings, ranging from traditional cyanide leaching to more modern and innovative techniques. Each method has its advantages and disadvantages, and the choice of technique depends on the mineralogy of the tailings, the occurrence and concentration of gold, and the overall cost-effectiveness.

2.1 Cyanide Leaching

Cyanide leaching is the most widely used method for extracting gold from ores and tailings. The process involves dissolving gold from the ore using a cyanide solution, followed by gold recovery through processes like activated carbon adsorption (CIP/CIL) or zinc precipitation. For flotation tailings, cyanide leaching can be an effective way to recover gold, especially if the gold is free or only weakly associated with sulphide minerals [6]. On the other hand, cyanide leaching poses significant environmental and safety concerns due to the toxic nature of cyanide, which can contaminate surrounding ecosystems if not managed properly. To mitigate these risks, many operators have turned to more sustainable alternatives, such as cyanide recycling or using less toxic leaching agents like ammonium thiosulphate [7]. Practical insights show that thiourea alone can leach gold [8] and moderately leach copper, but efficiency improves when paired with other reagents (e.g., glycine, thiocyanate), controlled pH (~1.5–2), temperature (~30 °C), and adequate agitation [9].

2.2 Gravity Separation

Gravity separation is another widely used method to recover gold from flotation tailings, especially in cases where the gold is in a free or coarse form. Techniques like centrifugal concentrators or shaking tables are used to separate gold particles based on density differences. This method is environmentally friendly as it does not require chemicals, making it an attractive option for some operators [10]. In some copper flotation tailings, gravity separation can recover a significant portion of the gold content. For example, at the Zijin Mining Group’s operation in China, tailings from copper flotation were treated using a combination of gravity separation and flotation, resulting in a recovery rate of over 60% of the gold content [11].

2.3 Bioleaching

Bioleaching, or usage of microorganisms for breaking down sulphide ores and releasing gold, has emerged as a promising alternative to traditional methods. This process involves the use of bacteria that naturally oxidize sulphide minerals and release metals like gold into solution. Bioleaching has been used to recover gold from complex ores and flotation tailings, with the added benefit of being more environmentally friendly [8,12]. Bioleaching for gold recovery from flotation tailings is still in the pilot and experimental stages, but the potential for scaling up this method is significant. A study conducted on samples from several flotation tailings in Romania demonstrated the feasibility of bioleaching in recovering both copper and gold from tailings. Still, challenges like longer processing times and variable recovery rates still need to be addressed [13].

2.4 Flotation

Tailings reprocessing through flotation and size classification can be applied as a way to avoid ‘whole stream’ processing. Tailings are reintroduced into the flotation circuit to separate the gold from the remaining gangue minerals. Process can be enhanced by regrinding, thus increasing mineral liberation and adjusting flotation reagents to optimize gold recovery, such as using collectors that selectively bind to gold-bearing particles or remove hydrophilic surface layers from fine, free, gold particles [14].

3. EXAMPLES FROM THE INDUSTRIAL PRACTICE

Thanks to advancements in technology, such as sensor-based sorting, data analysis and chemical advancement, tailings reprocessing became more efficient and cost-effective. Several mining and metallurgical companies have demonstrated the viability of gold recovery from mine and flotation tailings in copper metallurgy.

Las Cruces mine (Spain) has successfully reprocessed copper flotation tailings using a flotation circuit to recover gold [15]. At the Olympias mine (Greece), previously mined tailings were reprocessed in the existing concentrator plant, refurbished for tailings processing, with production of 20.000 oz/year of gold during 2012-2016 [16]. This method has the advantage of utilizing existing flotation infrastructure, making it a cost-effective way to boost gold recovery.

At El Indio mine (Chile), after processing the high-grade copper, gold, and silver ores, flotation tailings are treated using a cyanide leach, followed by carbon-in-pulp (CIP). The cyanide leach/CIP circuit was implemented primarily as a scavenging step, improving overall recovery [17].

BIOX® Process is used in Fairview mine (South Africa) for pretreatment of refractory gold ores and flotation concentrates. It is also recently applied for treatment of their flotation tailings containing pyrite and arsenopyrite with gold. BTRP (Barberton Tailings Retreatment Plant) was designed to treat 100.000 t/month of tailings. Basic principle of the BIOX® process is the use of bioleaching organisms like *Acidithiobacillus ferrooxidans* and *Leptospirillum ferrooxidans* to oxidize sulphides, thus liberating encapsulated gold for further cyanidation. The results showed more than 90% of gold was recovered after biooxidation and cyanidation [18]. BIOX® is also implemented as state-of-the art process in the plant for gold extraction from complex copper ores in Navoi Mining and Metallurgical Company in Uzbekistan, as one of many successful projects realized by Engineering Dobersek GmbH (project planning, delivery and commissioning) [19].

4. CONCLUSION

Gold production from flotation tailings in copper metallurgy is an increasingly viable and sustainable approach to resource recovery. With advancements in processing technologies such as gravity separation, flotation reprocessing and bioleaching, gold recovery from tailings has become more efficient and environmentally friendly. Mining operations around the world, including Olympias, El Indio and Fairview mines, have demonstrated the potential of this practice, turning waste into a valuable resource. As the demand for gold continues to rise and environmental concerns intensify, the recovery of gold from flotation tailings will likely play an essential role in the future of copper and precious metal production. One of the primary obstacles is the fine nature of gold particles in tailings, which often makes it difficult to achieve high recovery rates. Environmental concerns, particularly with cyanide use, also continue to be a major issue in gold recovery. As such, there is a strong push for alternative, less toxic methods such as bioleaching or thiosulphate leaching. Research into these greener technologies is ongoing, and their future implementation could dramatically improve the sustainability of gold recovery from flotation tailings.

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