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Control Technology for Tailings Pond Water Expansion in Copper Hydrometallurgy Based on High-concentration Gravity-flow Ball Mill System

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Abstract: Tailings pond water expansion is a core safety and environmental challenge faced by the copper hydrometallurgy industry, which directly triggers major hazards such as dam failure risks and acidic wastewater leakage. Aiming at the problem that the traditional ball mill-cyclone classification process, restricted by pulp concentration (45–60%), results in excessive system water supplement and continuous rise of water level in tailings ponds, an innovative technical scheme of "wet semi-autogenous mill + wet ball mill series connection with high and low positions + high-concentration gravity flow" was proposed. By eliminating gravity cyclones, optimizing equipment layout and regulating process parameters, the targets of stabilizing pulp concentration at 70% (by ore weight percentage) and achieving minus 200 mesh particle size accounting for ≥70% were realized. Industrial practice shows that the system can reduce external water supplement by more than 28% from the source, significantly alleviate the water expansion pressure of tailings ponds, avoid the terminal treatment cost of acidic wastewater, and simplify the process flow. This scheme provides a water expansion control path of "source water reduction + process water control" for the copper hydrometallurgy industry, which has both safety guarantee and environmental benefits, and possesses remarkable engineering application value.

Keywords: Copper Hydrometallurgy; Tailings Pond Water Expansion; High-concentration Ore Grinding; Gravity-flow Ball Mill System.

1. Introduction

1.1. Safety and Environmental Risks of Tailings Pond Water Expansion

Tailings pond water expansion refers to the phenomenon in which the water supplement of the smelting system far exceeds the natural evaporation and recycling volume, leading to the continuous rise of water level in tailings ponds. It has become a key bottleneck restricting the sustainable development of the copper hydrometallurgy industry [1].

The pulp stored in copper hydrometallurgy tailings ponds contains acidic wastewater (pH<2) and heavy metal ions. Water expansion increases the pressure on the anti-seepage system of tailings ponds, which is prone to anti-seepage membrane damage and leakage. The leaked acidic wastewater will contaminate groundwater and soil, and the dissolved heavy metal ions pose a long-term threat to the surrounding ecosystem and human health. Meanwhile, the acidic environment in tailings ponds is likely to induce Acid Rock Drainage (ARD), which exacerbates the acidification of surrounding water bodies and the migration of heavy metals, resulting in irreversible environmental pollution.

1.2. Conventional Treatment Methods for Tailings Pond Water Expansion

At present, most control measures for tailings pond water expansion in the industry focus on end-of-pipe treatment, which have obvious technical limitations, and the defects of some targeted measures are particularly prominent. The main methods are as follows:

1.2.1. Pulp Thickening and Recovery Technology.

Equipment such as inclined plate thickeners and rakeless high-efficiency thickeners are adopted to increase tailings concentration and recover overflow water for recycling. Inclined plate thickeners can achieve a water recovery rate of over 70%, but the underflow concentration is only 30–40%, which still requires a large amount of supplementary water to maintain system operation. Although the classification-thickening process can improve underflow concentration, it needs to combine cyclones with special thickening equipment, resulting in complex process flow and high equipment investment. Essentially, such technologies belong to "passive recovery" and fail to reduce water input from the source [2].

1.2.2. Acidic Wastewater Neutralization Treatment.

Neutralizers such as lime and pond ash are used to adjust the pH value of wastewater to meet the standards for discharge or reuse. The traditional lime neutralization method consumes a large amount of chemicals, which increases production costs. Alternative neutralizers (e.g., concrete sludge) can reduce costs, but they will generate secondary sludge that requires additional disposal. Moreover, neutralization treatment cannot reduce the total water volume of the system; it only alleviates discharge pressure and fails to fundamentally solve the problem of water expansion.

1.2.3. Combined Leaching Process Technology.

A combined heap leaching-stirred leaching system is adopted to separate fine sludge, optimize pulp permeability, and reduce water consumption in a single process. However, this technology has strict requirements for ore properties, requiring ores to have good permeability. In addition, the fine sludge separation process still consumes water resources, leading to limited application scope. Meanwhile, the combined system has a long process flow and high equipment maintenance costs, making it difficult to promote in small and medium-sized mines [3].

1.2.4. Filter Press Dewatering Technology.

Some small and medium-sized enterprises attempt to use filter presses for solid-liquid separation and recover water for recycling. However, filter presses have low treatment efficiency, with the processing capacity of a single unit only accounting for 1/3–1/2 of that of thickeners, which is difficult to match the smelting capacity. In addition, the equipment investment is relatively high, with the investment of a single high-pressure filter press exceeding 2 million yuan, and its operating energy consumption is 3–4 times that of thickeners, which has become a major restrictive factor for small and medium-sized enterprises.

1.2.5. Stainless Steel Ball Mill Technology.

A small number of enterprises try to use stainless steel ball mills to adapt to acidic media and reduce the consumption of neutral water. However, the investment cost of stainless steel ball mills is 5–8 times that of traditional carbon steel ball mills, with the investment of a single Φ4.2×6.7 m stainless steel ball mill exceeding 10 million yuan. Furthermore, the operation and maintenance cost is high: the replacement cost of stainless steel liners is more than 10 times that of ordinary rubber liners, and the procurement cycle of accessories is long, making it difficult to promote in small and medium-sized projects [4].

1.2.6. Combined Copper-Cobalt Smelting Neutralization Technology

In regions rich in copper and cobalt resources such as the Democratic Republic of the Congo (DRC), some enterprises use the cobalt neutralization process to treat acidic solutions from the copper production system. The alkalization reaction of the cobalt oxide production line is utilized to neutralize acidic wastewater, realizing water resource reuse. However, this technology relies on supporting cobalt oxide production lines and is only applicable to enterprises engaged in combined copper-cobalt smelting. It cannot be adopted in single copper smelting projects, resulting in obvious limitations in its application scope.

1.3. Correlation Between Traditional Ball Milling Process and Water Expansion

The ball milling process is the core water-consuming unit in copper hydrometallurgy. The traditional process adopts a closed-circuit classification design of "ball mill + gravity cyclone", where the normal operation of the cyclone requires the pulp concentration to be controlled within the range of 45–60%. A large volume of neutral make-up water mixes with the acidic wastewater generated during subsequent acid leaching. Since the mixed wastewater cannot be fully discharged, it is entirely diverted to the tailings pond, forming a vicious cycle of "water supplement - acid production - water storage", which becomes the fundamental cause of water expansion. Therefore, breaking through the pulp concentration limitation imposed by cyclones and achieving high-concentration ore grinding is the key to controlling water expansion from the source.

2. Crux of Water Expansion in the Traditional Ball Mill-Cyclone Classification Process

2.1. Process Composition and Water Consumption Characteristics

The traditional ball milling system consists of a wet semi-autogenous mill, ball mill, gravity cyclone, intermediate pulp tank and slurry pump. All equipment is installed horizontally, and the pulp needs to be conveyed under pressure to form a closed-circuit cycle. The process flow is as follows: crushed ore (<200 mm) → rough grinding in semi-autogenous mill → buffering in intermediate pulp tank → delivery to cyclone for classification via slurry pump → fine pulp sent to leaching section → coarse pulp returned to ball mill for regrinding.

The water consumption of this process is mainly reflected in two aspects: first, to meet the operational requirements of the cyclone, neutral water must be continuously supplemented into the ball mill to maintain the pulp concentration at 45–60%; second, water loss occurs during pulp transportation and classification in the closed-circuit cycle, which requires additional water supplement to compensate, resulting in persistently high water consumption of the system.

2.2. Core Cruxes Aggravating Water Expansion

Rigid Concentration Constraint: Cyclones are highly sensitive to pulp concentration. When the concentration exceeds 55%, the classification efficiency drops sharply, forcing the traditional process to maintain low-concentration ore grinding. The make-up water accounts for more than 60% of the total water intake of the smelting system.

Reliance on End-of-pipe Treatment: After low-concentration pulp enters the leaching section, additional thickening equipment or filter presses need to be configured for water recovery, which not only increases investment but also leaves 20–30% of water in the tailings during the thickening process.

Acidic Wastewater Accumulation: Neutral make-up water mixes with wastewater with $pH<2$ after acid leaching, generating a large amount of acidic tailings water that cannot be discharged. Taking an annual ore processing capacity of 1 million tons as an example, the annual accumulated wastewater can reach 150,000–200,000 cubic meters, directly driving up the water level of the tailings pond.

Limitations of Alternative Technologies: Although technologies such as stainless steel ball mills and combined copper-cobalt neutralization can partially alleviate water expansion, they are difficult to promote on a large scale due to constraints in investment, production capacity or process matching.

3. Innovative Technical Scheme Oriented to Water Expansion Control

3.1. Core Design Philosophy of the System

With the core concept of "source water reduction, process water control, and end water conservation", the bottleneck of water expansion is addressed through three major innovations: first, eliminating the cyclone classification unit to remove the limitation on pulp concentration; second, adopting a high-low position equipment layout to realize gravity-driven pulp transportation and reduce water loss; third, optimizing ore grinding parameters to maximize pulp concentration on the premise of ensuring particle size requirements, avoiding the reliance on high-cost equipment such as filter presses and stainless steel ball mills [5].

3.2. System Composition and Layout

As shown in Figure 1, the system adopts a series configuration of "1 wet semi-autogenous mill + 1 wet ball mill". The core layout features are as follows: the semi-autogenous mill is installed in the upper area, and the ball mill is installed in the lower area with a vertical height difference of 4.7 m between the centers of their cylinders. Gravitational potential energy is utilized to achieve gravity-driven pulp transportation without the need for pressurized delivery; the overflow port of the semi-autogenous mill is directly connected to the feed port of the ball mill via a steel structure inclined chute, and the discharge port of the ball mill is connected directly to the leaching workshop through a chute, forming an open-circuit process of "rough grinding - fine grinding - leaching"; the intermediate pulp tank, slurry pump and cyclone are eliminated, reducing equipment floor space and water loss links, with the investment cost only accounting for 1/5 of that of the stainless steel ball mill scheme.

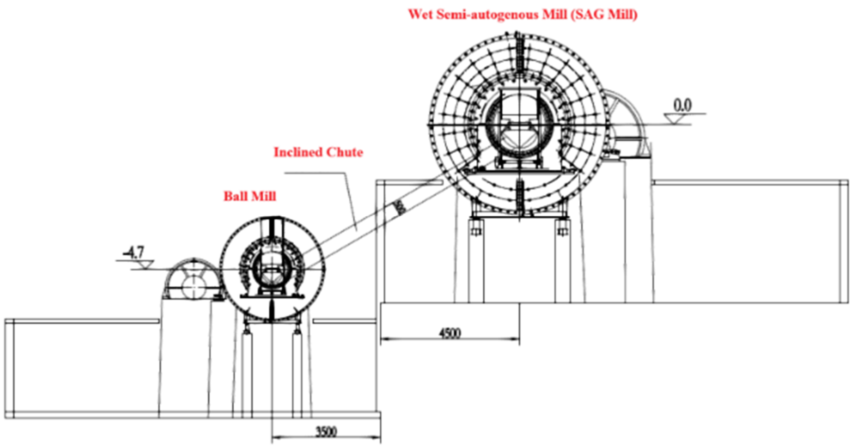

Figure 1. Installation Layout of the High-concentration Gravity-flow Ball Mill System

3.3. Key Parameters and Process Control

3.3.1. High-Concentration Control Parameters

Target pulp concentration: 70% (by ore weight percentage), which is 10–25 percentage points higher than that of the traditional process. Based on the same processing capacity, the water supplement is reduced by more than 28%, and no filter press is required for auxiliary dewatering. Preferred pulp mixing water source: Acidic wastewater such as raffinate is preferred for pulp mixing to replace neutral fresh water. This not only recovers sulfuric acid and copper ions in the wastewater but also reduces the discharge of acidic wastewater, without relying on the cobalt neutralization process.

3.3.2. Particle Size Guarantee Measures

Screen mesh classification: The semi-autogenous mill is equipped with a 16 mm screen mesh to intercept large-grain ore; the ball mill is equipped with a 10 mm screen mesh to control the final pulp particle size. Steel ball regulation: High-chromium steel balls are added to the ball mill with a consumption quota of 0.5 kg per ton of dry ore. Impact grinding ensures that the proportion of minus 200 mesh particle size is ≥70%. Processing capacity matching: Precisely adjust the processing capacity ratio of the semi-autogenous mill and the ball mill to ensure the fine grinding time of ore and avoid substandard particle size caused by high concentration.

3.4. Process Flow

After the raw ore is crushed to <200 mm, it is sent to the semi-autogenous mill for rough grinding and filtered through a 16 mm screen mesh to form pulp with minus 200 mesh accounting for more than 60%. The pulp gravity flows into the ball mill through an inclined chute for precision grinding. After being screened by a 10 mm screen mesh, high-concentration pulp with a concentration of 70% and minus 200 mesh accounting for ≥70% is formed. The high-concentration pulp directly gravity flows into the leaching workshop and mixes with the leaching agent for reaction, requiring no additional dilution or concentration treatment and avoiding the efficiency constraints of equipment such as filter presses.

4. Technical Effects and Water Expansion Control Benefits

This technology has been applied for 12 months in a hydrometallurgical project with an annual processing capacity of 1 million tons of copper oxide ore (without a cobalt production). The data shows that: the pulp concentration of the system was stably maintained at 68–72%; the average proportion of minus 200 mesh particle size reached 73%, which met the requirements of the leaching process; owing to the evaporation capacity exceeding the rainfall, the water level of the tailings pond remained balanced; the water volume increment of the tailings pond per ton of cathode copper produced was only 0.42 m^3/t Cu, representing a 49% reduction in the water volume increment of the tailings pond compared with the traditional process; and no safety or environmental accidents occurred during the application period.

5. Conclusion

The safety and environmental risks caused by tailings pond water expansion in copper hydrometallurgy have become a major constraint on the sustainable development of the industry. Existing measures such as thickening and recovery, filter press dewatering, stainless steel ball mills and combined copper-cobalt neutralization are plagued by defects including high investment, low efficiency and narrow application scope. By eliminating the cyclone classification unit, adopting a high-low position gravity-flow layout and high-concentration ore grinding design, this technology reduces water supplement from the source, and breaks the vicious cycle of "low-concentration ore grinding - high water consumption - aggravated water expansion" in the traditional process, while avoiding reliance on high-cost equipment and supporting processes.

Industrial practice demonstrates that this scheme can increase the pulp concentration to 70%, significantly reduce the consumption of neutral water, and alleviate the water expansion pressure of hydrometallurgical copper production. The tailings pond basically achieves water balance, and the equipment investment and operation and maintenance costs are significantly lower than those of schemes such as stainless steel ball mills and filter press assistance. This technology provides a safe, environmentally friendly, economical and universal path for water expansion control in the copper hydrometallurgy industry, and is particularly suitable for small and medium-sized single copper smelting projects, boasting broad prospects for popularization and application.

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