International Journal of Academic Multidisciplinary Research (IJAMR)
ISSN: 2643-9670
Vol. 5 Issue 4, April - 2021, Pages: 356-361

Development of Promising Technologies in the Production of Non-Ferrous Metals and Improvement of Existing Technologies

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***Abstract**: The article describes the current problems of modern non-ferrous metallurgy, their causes and ways to find rational solutions to these problems. It is known that 85% of the world's copper is obtained by pyrometallurgy and 10-15% by hydrometallurgy. The choice of technology for the production of copper depends primarily on the mineral nature of the copper in the ore. For example, if the ore contains copper in the form of complete sulfides, then pyrometallurgical methods must be used. If in the form of oxides, then hydrometallurgical or combined methods are used. In addition, metallurgical production also depends on the natural, economic and geological potential of the region, i.e. the availability of coke, natural gas and similar natural resources required for production.*

Keywords— *metallurgy, copper, gold, recycling, hydrometallurgy, pyrometallurgy, concentrate, reducing-sulfiding complex.*

1. Introduction

Currently, in the world in the mining and metallurgical industries and, in particular, in Uzbekistan, it has become necessary to solve a whole range of complex problems. This is, first of all, the all-round depletion of rich and easily exposed ore deposits, increasing requirements for environmental protection, increasing the complexity of the use of raw materials, the development and implementation of low-waste technologies [1,2,3,4,5].

Despite the richness of mineral resources, effective forecasting of the development of the economy of Uzbekistan is impossible without taking into account the involvement of the mining and metallurgical industry in the processing of waste, in which the content of valuable components is often significantly higher than in the extracted primary raw materials [6,7,8,9].

The waste and semi-products of the Almalyk Mining and Metallurgical Combine have accumulated a large amount of tailings from concentrating plants, copper production slags and clinker from the processing of zinc cakes. These materials contain a large amount of non-ferrous, precious metals and are actually outside the production cycle. Their involvement in processing will allow the plant to significantly expand the raw material base without increasing capital costs for geological and mining operations [10,11,12].

So, at present, about 1 billion tons of tailings from concentrating plants with a copper content of 0.07 - 1.112% have been accumulated in tailing dumps. They contain over 800 thousand tons of copper, 20 thousand tons of molybdenum, 182 tons of rhenium, 500 thousand tons of zinc and many other valuable components [13].

With the pyrometallurgical method of copper production, a large amount of slag is formed with a copper content of 0.60 - 3.50%. These slags are partly reloaded into the smelting furnaces, part is stored, and a significant part is processed by flotation. In the best case, the recovery of copper during flotation is 40 - 60%, the rest of the copper, as well as gold and silver, are irretrievably lost with slag tailings [14].

Zinc production clinker contains over 2.2% copper, 2.40% zinc, 0.01% cadmium, 5-8 g / t gold, 250-500 g / t silver and many other valuable components. Some of the clinker is fed to smelting furnaces, and a significant part is stored in slag storage facilities [15,16].

The involvement of these materials in production will allow the plant to additionally obtain thousands of tons of copper, a significant amount of precious metals and other valuable products [17].

Tailings ponds and, especially, slag dumps encroach on natural territory, occupy thousands of hectares of farmland, pollute the air basin and disfigure the landscape. Assessment of damage from environmental pollution leads to a significant expansion of the boundaries of economic feasibility of creating and using low-waste technology. Given this circumstance, the economic efficiency of the combination of production undoubtedly increases and new criteria arise for the formation of production structures in industry related to the impact on the environment [18].

In this regard, the task of creating a rational and comprehensive technology for processing slags and secondary technogenic formations of local industrial enterprises is very urgent [19].

2. Development Of Low Waste Technology Of Copper Production

Most enterprises around the world, such as the Almalyk Mining and Metallurgical Combine (AMMC, Uzbekistan), use the classic pyrometallurgical scheme of crude copper production. Accordingly, copper sulphide ores are first enriched by flotation to obtain a concentrate containing 16-20% copper. The obtained copper concentrate is loaded into metallurgical furnaces for thermal processing at high temperatures. Metallurgical plants have several types of smelting furnaces designed to process copper raw materials. Examples include smelting furnaces such as the

Reverberatory, Oxygen-Flare, and the Vanyukov Furnace [20]. Although the principles of operation of these smelting furnaces are different, the products are similar, such as copper matte (30-50% Cu), slag and industrial gases. The intermediate product is a copper matte conversion process, in which crude copper (96-98% Cu) is obtained by oxidizing the unwanted elements in the matte in the presence of atmospheric oxygen. The crude copper is then poured into anode molds for electrolysis during flame cleaning, resulting in high quality copper cathodes (99.99% Cu) [21].

This classic technology has its advantages and disadvantages. For example, smelting furnaces and converters generate large amounts of waste - slag, which requires a large area to dispose of [22]. Additional equipment, space and funds will be required to recycle this waste slag. If the slag is not recycled, it will become more and more harmful to the environment and the environment. In addition, the Reverberatory, Vanyukov, and Fire-refining furnaces use large amounts of fuels, such as natural gas and fuel oil, to maintain high temperatures [23]. This increases the cost of extracted copper and reduces the net profit left over from copper production. It should be noted that the content of copper in the slag from some furnaces is much higher, for example, the content of copper in the oxygen-flame furnace slag is about 1%, and the content of copper in the converter furnace slag is about 3%. This is much higher than the allowable amount for waste [24]. Now the processing of these slags is mandatory and cannot be used as a building material. Because these wastes contain large amounts of precious metals such as copper, gold and silver. So the question is, can these metals be separated from slag? In response, we can say that when the slag cools slowly, it forms a very strong crystal lattice, which requires a great deal of strength and energy to break down the solid structure. In addition, large amounts of copper in slag are oxidized and cannot be separated by flotation. As a result, the process of crushing hard slag is very difficult and requires a lot of effort, energy and money. As a result, the cost of the finished product in copper production increases, and the technology is not economically viable [25].

In some countries, copper ores in the form of oxides or mixtures (i.e., oxides and sulfides) are found, so the technology of copper extraction is based on a combined method. For example, ore or concentrate is first burned by oxidation and then separated by hydrometallurgical methods [26]. Alternatively, crude copper can be obtained by reducing the oxidized copper concentrate formed after firing in coke ovens in the presence of coke [27]. This technology is preferred in that it is less phased than its predecessors. However, the main disadvantage of this technology is that it cannot be used in plants in countries with low coke reserves or no coke at all (including Uzbekistan). In addition, when oxidized copper concentrate is recovered in a blast furnace in the presence of coke, large amounts of iron are transferred to the crude copper, which degrades the quality of the crude copper [28]. Crude copper requires additional oxidation to separate iron from iron, as well as additional fluxes. As a result, more slag is formed, and the problem of wastage of copper with slag arises [29].

These shortcomings have led to the conclusion that copper production should be minimized and that the metals in the ore should be completely extracted. As a result of many years of research, the authors proposed a technology for thermal processing of sulfide copper concentrates in the presence of coal and lime as a solution to the problem. Accordingly, the process is carried out in a rotary kiln at temperatures between 800 and 1100 ^{o}C [30]. The chemical reactions of the process are as follows:

$$CuFeS_2 + 2C + CaO = Cu + Fe + CaS + 2CO\uparrow$$
$$CuS + C + CaO = Cu + CaS + CO\uparrow$$
$$Cu_2S + C + CaO = 2Cu + CaS + CO\uparrow$$
$$SiO_2 + CaO = CaSiO_3$$

This process is used instead of liquefaction furnaces in the pyrometallurgical production of copper. The advantages of this technology are:

- Very little slag is formed as a result of the process;
- It is possible to separate iron powder with metallic copper;
- Crude copper is obtained during the process;
- Low waste production increases the rate of separation of copper into finished products, which in turn increases the productivity of the enterprise.

A magnetic separation process is used to separate the metallic copper and iron mixture formed by the process. The resulting metallic copper powder is sent to the refining process, and the iron powder is sent to produce the steel briquette [31].

3. Complex Use Of Raw Materials In The Production Of Non-Ferrous Metals

The purpose of summarizing gold extraction is to use ball mills in the grinding process, and the dispersed gold particles in the cores of the balls, which are cracked due to strong deformation during grinding, broken in certain places under the influence of strong blows, have a very high density. resulting in mechanical adhesion. As a result, during the magnetic separation of the bush, gold is released with these fragments of crushed balls. Until it is possible to extract gold from this magnetic fraction, these crushed ball fragments are stored in special places without being sent for processing [32].

It is now possible to extract gold from these spheres by dissolving the spheres and its fragments in a dilute or moderately concentrated solution of sulfuric acid (H_2SO_4) in the presence of air:

$$4Fe + 3O_2 + 6H_2SO_4 \rightarrow 2Fe_2(SO_4)_3 + 6H_2O$$

During this leaching process, the gold separates into pure metal and sinks to the bottom of the vessel, causing the gold to be insoluble in sulfuric acid. The reason why this process is not carried out at the moment is that the reaction produces a large amount of iron (III) sulfate ($Fe_2(SO_4)_3$) solution. Because the extraction of iron from it is not economically viable [33].

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The aim of this study is to use the reaction solution of iron (III) sulfate as an oxidant for the hydrometallurgical production of copper.

Copper production at the Almalyk Mining and Metallurgical Combine (AMMC) is based on pyrometallurgical technology. This is due to the fact that copper in the ore is in the form of sulfide minerals. Sulfide minerals are insoluble in mineral acids. However, in the presence of liquid oxidants, the dissolution of sulfides is accelerated. Only in this case, the lack of oxidizing agent and the high cost of copper hinder the improvement of hydrometallurgical technology of copper production. This situation requires the search for cheap and local alternatives to oxidizing agents. One such oxidizing agent is a solution of iron (III) sulfate from gold production [34].

As a result of hydrometallurgical processing in the presence of oxidizing sulfide copper concentrates, minerals in the concentrate, such as chalcopyrite, pyrite, covellin and chalcocite, are oxidized and dissolved [35]. The chemical reactions of the selective leaching process are as follows:

$$CuFeS_2 + 2Fe_2(SO_4)_3 \rightarrow CuSO_4 + 5FeSO_4 + 2S$$
$$Cu_2S + Fe_2(SO_4)_3 \rightarrow Cu_2SO_4 + 2FeSO_4 + S$$
$$Cu_2SO_4 + Fe_2(SO_4)_3 \rightarrow 2CuSO_4 + 2FeSO_4$$
$$CuS + Fe_2(SO_4)_3 \rightarrow CuSO_4 + 2FeSO_4 + S$$
$$FeS_2 + Fe_2(SO_4)_3 \rightarrow 3FeSO_4 + 2S$$

After the chemical process, the resulting solution is filtered to separate it from unwanted rocks. Selective leaching of sulfide copper concentrate in the presence of oxidants also results in the formation of additional elemental sulfur. Because the elemental sulfur is a hydrophobic material, it rises to the surface of the solution and forms a yellow layer. It is recommended to separate this sulfur layer before filtering. After the removal of sulfur, when the filtered solution is heated, chemical reactions take place in the second stage, i.e., copper (II) sulphate and iron (II) sulphates undergo a chemical reaction that results in the formation of metallic copper and iron (III) sulfate is formed:

$$CuSO_4 + 2FeSO_4 \rightarrow Cu\downarrow + Fe_2(SO_4)_3$$

In this chemical reaction, at high temperatures, divalent copper ions (Cu^{2+}) oxidize divalent iron ions (Fe^{2+}) in solution because they exhibit strong oxidizing properties. As a result of the reaction, copper ions are returned by receiving electrons from iron ions. The metallic copper formed in the system sinks to the bottom of the vessel, forming a layer of copper sludge. The resulting metallic copper is fed directly to the refining process [36].

The copper extraction process in this method has several advantages and conveniences, for example:

- As a result of the initial oxidation of sulfides and the interaction of these sulfides, an additional relatively inexpensive and strong oxidizer - iron (III) sulfate is formed and its reserves increase;

- Another advantage of hydrometallurgical copper extraction over pyrometallurgical method is that hydrometallurgical equipment is relatively simple and convenient;

- Selective smelting of sulfide copper concentrate in the presence of oxidants also produces elemental sulfur in the system, which allows to separate sulfur as a by-product along with copper;

- Due to the high content of quartz (SiO_2) in the cake, which is formed after filtration during the hydrometallurgical separation of copper from sulfide copper concentrate, this cake is made of refractory and acid-resistant materials (chamotte, dinas or quartz bricks) it is possible to use as a starting raw material in production;

It is no secret that the global production of copper by pyrometallurgical methods is currently causing great damage to the environment. Proof of this can be found in the waste dumps, which occupy large areas around the enterprises of the non-ferrous metallurgy industry. Due to the complexity of processing this slag, additional economic costs are required. In addition, the release of sulfur dioxide and trioxide directly into the atmosphere, which are continuously emitted from metallurgical furnaces but are not suitable for the production of sulfuric acid, leads to the formation of "acid rain". is happening. This is a great tragedy for the flora and fauna of the region. Many pyrometallurgical plants burn tons of carbon dioxide every day, releasing large amounts of carbon dioxide (CO_2) into the air. As a result, the global warming process is accelerating all over the world. These problems have become the most actual problems in the world today [37].

Based on a number of problems of traditional pyrometallurgy mentioned above, it can be concluded that the use of hydrometallurgical methods instead of pyrometallurgical methods in copper production is more cost-effective and environmentally safe [38].

4. Increasing Efficiency By Partial Changing The Ore Grinding Process

It is well known that the process of processing common ores is basically the same, in which ores containing different metals are first crushed and ground in an aqueous medium when they arrive at concentrators [39]. Grinding and grinding are different processes and vary depending on the size of the product. Ore sizes for crushing range from 1,500 mm to 10-15 mm. It is available in sizes from 10 mm to 0.074 mm (or 74 μm) [40]. In addition, these processes are differentiated by the equipment used, for example, the use of jaw or cone crushers for grinding gold ore, and ball and rod mills for grinding [41]. The aim of this study is to slightly change the principle of operation of ball mills by taking a more scientific approach to the grinding process and machine to further improve these preparation processes [42]. It is known that today the balls of the mill are made of steel and sometimes cast iron. In an aqueous medium, when these balls hit the raw material, the ore is mechanically deformed, crushed, and resized. Because the balls are made of steel or cast iron, they are highly malleable and can be used to grind ore [43]. However, there is a shortcoming in this process, in which the balls repeatedly hit the gold in the ore, resulting in a mechanical alloy. As the process continues, when the balloons become unusable, they are replaced with new ones [44]. When the steel balls of mills used to grind other types of ore become unusable, they are liquefied and processed in metallurgical furnaces [45]. However, after crushing gold ores, deformed (broken and fragmented) steel balls cannot be processed due to the presence of gold in the remnants. Today, such products are collected until the efficiency of production is discovered. In general, the remnants of these unusable spheres can be dissolved in sulfuric acid (in which iron dissolves and gold precipitates), but we have dumped a very large mass of iron in the waste. To avoid this problem, this study proposed a method of using high-quality cement balls instead of steel balls during the grinding process. Studies have shown that grinding with balloons is much more effective. This is because the price of cement is much lower than the price of steel and there are more reserves. In Uzbekistan, there are enough cement plants to produce such balloons [46]. Cement, a product of the silicate industry, is one of the most popular brands today, with an alloy of water and stone with a density of 4,000 kg/m^3 and a mechanical hardness of 1.86-1.89. It is true that the physical properties of cement alloys may not be as good as those of cast iron, but the chemical properties are very useful to us. The chemical composition of the cement alloy is very close to that of the ore, and the rate of gold recovery increases during enrichment. In addition, the technological scheme is somewhat simplified by removing the magnetic separation process from the main technological scheme. Due to the grinding process with balls made of cement alloy, the transfer of iron ions to the solution during the selective melting period is relatively reduced. This increases the saturation of the resin with gold during sorption.

5. Conclusion

The metallurgy of copper and other heavy non-ferrous metals is the leading link in the domestic non-ferrous metallurgy. The share of heavy non-ferrous metals in Uzbekistan accounts for a significant part of the gross output of the industry. The value of copper is increasing from year to year, especially in connection with the rapid development of energy, electronics, mechanical engineering, aviation, space and nuclear technology. This paper will consider the technology for reducing the loss of copper with slags during smelting processes. Numerous parameters affect the copper content in slags, of which the following should be considered the most important: preparation of the charge, parameters of the technological mode of smelting, physicochemical properties of melts, design of units, organization of work, etc. It is very difficult to give an unambiguous assessment of the influence of all parameters acting separately or in aggregate, and is hardly possible at all. In this regard, we will try to assess individual process parameters from the point of view of their influence on the depletion indicators and the possibility of changing their values in real metallurgical smelting.

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