HYDROMETALLURGICAL TECHNOLOGY FOR GOLD RECOVERY FROM REFRACTORY GOLD-BEARING RAW MATERIALS AND THE SOLUTION TO PROBLEMS OF SUBSEQUENT DEHYDRATION PROCESSES

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ABSTRACT

Development of the gold mining industry is associated with serious problems caused by deterioration of the quality of gold-bearing ore. Since rich ores are gradually depleted, low-grade ores as well as those with more complex composition and concentrates come on stream (are used as raw materials). Therefore, the gold recovery from refractory gold-bearing raw materials becomes the most important problem. This article discusses various processing methods of refractory pyrite-arsenopyrite ores and concentrates, considering their advantages and disadvantages. These methods include the conventional technology, bio-oxidation, as well as high-temperature and low-temperature leaching with subsequent cyanide treatment. The drawbacks of these methods include the problems associated with the separation of the solid and liquid phases. Dehydration processes are an integral part of hydrometallurgical technologies. Ineffective phase separation process can lead to performance degradation of equipment and increased power consumption. The authors consider solutions to the problems related with the efficiency improvement of raw materials and the comprehensiveness of their use.

INTRODUCTION

According to the experts, in this century, it is planned to provide the basic gain of global gold extraction through the wide involvement of complex refractory gold-bearing ores and concentrates (Naboychenko, S.S. et al., 2002). This will result in growing demand for processing of such ores, whose effective treatment requires much more complicated technology and advanced operational process schemes, including gravity separation, flotation, roasting, smelting, and leaching (Zelikman, 1983).

Refractory ores account for more than 30% of the world’s total reserves. There are two main categories of such ores:

• Ores in which the gold is associated with quartz;
• Ores in which the gold is associated with sulphides.

When grinding ore, finely disseminated gold associated with sulphides comes out just fractionally. The bulk remains in pyrite or arsenopyrite. “Obstinacy” of sulphide associated gold ores is explained by the fact that gold is presented in the sulphides not only in the form of finely dispersed particles of native metal, but also in the form of solid solution, namely the colloidal particles (Naboychenko, S.S. et al., 2009).

The aim of the present research was to consider the main advantages of autoclave-hydrometallurgical stripping technology of complex raw materials such as refractory pyrite-arsenopyrite ores and
concentrates, as well as the study of the effects of some parameters on the subsequent dehydration processes of finely dispersed pulps after autoclave oxidative leaching. Based on the review of existing processing methods, we were able to assess the benefits of autoclave processing technology applied to the stripping of refractory sulphide gold-bearing raw materials, in particular, low-temperature leaching, and reveal the number of features inherent to the pulp after this type of leaching, as well as define factors that contribute to the complexity of the subsequent dehydration processes of the oxidized pulps. Optimal conditions proposed, ensure the acceptable performance indicators of thickening and filtration processes.

METHODS

Based Processing methods of refractory sulfide gold-bearing products with fine inclusions of gold are determined by many parameters, such as, for example, material composition, technological and mechanical-and-physical properties. At the moment, there are many technologies for gold stripping from sulfide gold-bearing raw materials. These are thermo-chemical (roasting), chemical (leaching), and mechanical (grinding) processes, as well as their combinations.

The conventional method of extracting gold from refractory gold-bearing ores involves flotation thickening, oxidizing roasting of the concentrate, obtained by flotation, and subsequent cyanidation of the roasted product (Zelikman, 1983). This method is quite simple, yet it has serious disadvantages:

- The inevitable contamination of the environment by sulphur and highly-toxic arsenic emissions;
- The relatively low gold recovery due to the formation of low-melting compound films on the surface of gold grains, and the subsequent entrainment of the particles into the arsenic sublimations;
- The need for expensive disposal of highly-toxic arsenic oxide.

Currently, the conventional method of gold extraction from refractory gold-bearing pyrite-arsenopyrite ores is replaced by hydrometallurgical technology. Due to the lack of gas emissions of sulfur and arsenic compounds, and the withdrawal of the latter in form of low-toxic compounds, whose discharge could be carried out to the tailing pond, these technologies meet the requirements of environmental protection to the greatest extent. In addition, hydrometallurgical technologies ensure a higher gold recovery compared to other methods.

At the present time, treatment of complex refractory gold-bearing raw materials is dominated by methods such as bacterial and autoclaved stripping with subsequent cyanidation of the fixed residue (Naboychenko, S.S. et al., 2002; Naboychenko, S.S. et al., 2009; Ladeichishkov, 1999; Samikhov, 2006). The advantages of these methods lie in the integrity of raw materials processing and high recovery rate of all valuable components.

The developed bacterial leaching technology is applicable for gold bearing ores, in which gold is finely disseminated in sulfide minerals such as pyrite and arsenopyrite. This technology involves bacterial decomposition of sulfide minerals, the purification of bacterial solutions after leaching with their recycling, and cyanidation of leach cakes (Kuzyakina, et al., 2008; Shamin, 2005). Gold recovery by means of bacterial leaching based on the decomposition of sulfides by acidophilic bacteria can be increased by tens of percent. Therefore, tank leaching has been widely used in different gold-mining countries (South Africa, Australia, China, etc.).

Technical procedure for gold-bearing concentrate processing using bacterial oxidation is presented in Fig. 1.

Research has revealed the huge role of microorganisms in the formation and change of ores, their ability to oxidize and dissolve sulfide minerals in natural conditions.

Bacterial leaching technology consists of repulping of source gold-bearing float concentrate in the recycled liquor with the addition of ammonium sulfate solution, as well as sulfuric acid, up to the content of solid component in the slurry not less than 15%. Prepared slurry enters tanks with mechanical stirring and aeration for subsequent leaching.

Bacterial oxidation of sulfide minerals results in the formation of sulfuric and arsenic acids according to the reactions (Shamin, 2005):

\[ 2FeS_2 + 6O_2 = Fe_2(SO_4)_3 + S^0 \]  
\[ S^0 + 1.5O_2 + H_2O = H_2SO_4 \]  
\[ 4FeAsS + 13O_2 + 6H_2O = 4FeSO_4 + 4H_3AsO_4 \]  

The degree of oxidation of arsenopyrite after 60 hours of bacterial leaching reaches 80-90%. The efficiency of bacterial stripping is comparable to that of autoclave processes and superior to oxidative roasting. However, autoclave stripping provides a
more complete oxidation of sulphide minerals and therefore a higher recovery of gold. In addition, bacterial leaching requires using bulky equipment that increases capital costs.

Autoclave hydrometallurgical technologies allow improving the direct recovery of non-ferrous metals and enhancing the selectivity of their extraction, as well as obtaining new compounds, which provide simpler processing of pulps (Shneerson and Naboychenko, 2011). Also, the use of these technologies eliminates the loss of gold dust and the need for sophisticated dust exhausters and purification systems.

Autoclave oxidative leaching in the acidic medium of sulfide minerals, namely arsenopyrite and pyrite, can be conducted through the following reactions (Naboychenko, S.S. et al., 2002):

\[ 4\text{FeAsS} + 13\text{O}_2 + 6\text{H}_2\text{O} = 4\text{FeSO}_4 + 4\text{H}_3\text{AsO}_4 \]  
(4)

\[ 2\text{FeS}_2 + 7\text{O}_2 + 2\text{H}_2\text{O} = 2\text{FeSO}_4 + 2\text{H}_2\text{SO}_4 \]  
(5)

or:

\[ 4\text{FeAsS} + 7\text{O}_2 + 4\text{H}_2\text{SO}_4 + 2\text{H}_2\text{O} = 4\text{FeSO}_4 + 4\text{H}_3\text{AsO}_4 + 4\text{S}^0 \]  
(6)

\[ \text{FeS}_2 + 2\text{O}_2 = \text{FeSO}_4 + \text{S}^0 \]  
(7)

Elemental sulfur is an undesirable component, because sulphur melts at a temperature above 112°C, enveloping the particles of non-oxidized sulfides with finely disseminated gold. This does not allow the complete oxidation of particles and results in forming an insoluble residue.

To avoid the formation of elemental sulfur, the process is conducted at quite high temperatures ranged from 180 to 300°C. This temperature range ensures complete oxidation of sulphide sulphur to form the sulfate-ion.

Flow-sheet of the hydrometallurgical processing of refractory gold-bearing pyrite-arsenopyrite concentrates by the high-temperature autoclave leaching method is shown in Fig. 2.

The general flow-sheet of pyrite and arsenopyrite concentrates processing includes the following main process stages: grinding of float gold-bearing concentrate, decarbonization (acid treatment), i.e., the process of preliminary removing carbonate compounds from the float concentrate, autoclave oxidative leaching, solid and liquid separation processes (thickening and filtration of the oxidized

Fig. 1 Processing flow-sheet of gold-bearing concentrate using bacterial leaching.
pulp), neutralization of the solution with lime or limestone, and final sorption cyanidation of cake.

In the framework of existing technologies based on the autoclave oxidative leaching of gold-bearing sulfide raw materials, oxidation processes require strict physical and chemical conditions, such as, for example, use of sufficiently high temperatures that is directly related to the need to avoid the formation of elemental sulphur, which reduces process performance indicators. However, high costs and the complexity of the technology based on high-temperature leaching of refractory raw materials, make it barely acceptable. In this regard, possibilities of reducing sulphide materials oxidation parameters and temperature in particular, are currently being studied (Lapin, et al., 2011).

The flow-sheet of refractory gold-bearing pyrite-arsenopyrite concentrate processing using low-temperature oxidative leaching technology is shown in Fig. 3 (Ivanik, 2002).

The conditions required to the process of low-temperature oxidative leaching include the following: the ratio between the liquid and solid phases must be equal to 3, oxidation temperature – 130°C, partial oxygen pressure – 1.0 MPa, the process time of the autoclave oxidation leaching is estimated by the cessation of oxygen uptake.

For refractory gold-bearing pyrite-arsenopyrite concentrates, preliminary removal of carbonate compounds (decarbonization) out of their composition is indispensible stage, because presence of these compounds in autoclave process leads to the release of gaseous CO₂, reduces the partial pressure of oxygen, and considerably decreases the degree of its use. Carrying out the decarbonization process requires the fulfillment of the following conditions: process temperature should be 60-65°C, sulfuric acid with a volumetric dilution of 1:1 should be used as reagent. Acid is supplied in separate doses for 20-30 minutes until the pH level stabilizes at 2.0–2.2.

Leaching of pyrite and arsenopyrite at relatively low parameters differs from the oxidation process at high temperatures by the fact that part of sulphide sulphur is oxidized to sulfate-ion, while another part is oxidized to elemental sulfur that adversely affects cyanide consumption in the subsequent cyanide treatment of the material.

The dehydration of the pulp after low-temperature leaching is another problem. To initiate the autoclave leaching process at relatively low parameters, a necessary condition is fine or ultra-fine grinding of
the source material for the most complete stripping of gold-bearing sulfide minerals. Grinding process in a planetary ball mill should be carried out at the following parameters: 180 metal balls, rotation velocity of 343 rpm, grinding time of 7 hours. With this ultra-fine grinding, 80% of the particles have a size of less than 10-15 microns that leads to a high degree of strain in the crystal lattice of minerals. This increases their activity and contributes to more effective leaching process. However, ultra-fine grinding of the source concentrate down to the micron-sized particles leads to very low sedimentary characteristics of subsequent thickening and filtration processes (Sizyakov, et al., 2012). In addition, fine pulps obtained in the low-temperature leaching process are characterized by a high content of salts in the liquid phase that increases pulp viscosity. Arsenic, sulphuric acid and iron are the main solution components after autoclave leaching of pyrite-arsenopyrite concentrates.

**RESEARCH INSIGHTS**

In consequence of the conducted research, the advantages of the technology based on the decrease of the oxidative process temperature, i.e., low-temperature leaching, were revealed (Korans and Angew, 1993). These advantages are as follows:

- Low cost of autoclave facility;
- Lower capital costs required to implement the industrial process;
- Reduced harmful effects of organic carbon and chlorides;
- A Beneficial effect on gold extraction in the hydrometallurgical cycle.

However, despite of all the advantages of concerned technology there are some drawbacks related to the process parameters and some characteristics of pulps produced in the low-temperature leaching process, which have an impact on the subsequent separation process of liquid and solid phases. The complexity of the pulp dehydration problem after low-temperature leaching is due to the high dispensability of the solid phase and fairly high concentration of salts in the liquid phase that does not allow carrying out the process at acceptable performance parameters.

The efficiency of the thickening process is influenced not only by mineral and granulometric compositions of the solid phase, but also solid content in the original pulp and the thickened product, the viscosity of liquid phase, density of the solid and liquid phases, pulp temperature, pH of the medium, the presence in the pulp of reagents and specially

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**Fig. 3** Flow-sheet of autoclave processing of refractory gold-bearing pyrite-arsenopyrite concentrate at relatively low leaching parameters.
introduced additives, as well as design features of used thickeners.

The following methods can be applied to enhance dehydration of pulps with saturated saltwater viscous liquid phase (Ivanik, 2002):

- Reduction in salt content by dilution;
- The use of synthetic polyacrylamide flocculants;
- Partial or complete neutralization of the pulp after autoclave oxidative leaching by limestone. The neutralization process will allow not only reducing the content of salts in solution, but also removing the arsenic in the form of low-soluble iron arsenate, which may be disposed in the tailing dump;
- Increasing temperature that increases the specific productivity of thickening.

The effect of flocculant consumption on sedimentation characteristics of the pulp was studied by conducting a series of experiments on the pulp thickening after autoclave oxidative leaching with different flocculant consumption. As known, viscosity of liquids decreases with increasing temperature. Therefore, to study the effect of temperature factor, we carried out special experiments in a water thermostat at different temperatures. Thickening parameters were improved when increasing temperature from 25°C to 80°C. Thus, at the flocculant consumption of 300 g/t of solids at room temperature, the specific thickening capacity was 3.17 t/m²-day, whereas at a temperature of 80°C it was equal to 3.75 t/m²-day. The ratio between the liquid and solid phases in the thickened product at a temperature of 80°C was by 20% lower than that at a temperature of 25°C.

DISCUSSION

The technology based on the process of autoclave leaching of sulphide materials at relatively low parameters is widely developing in recent years. The implementation of this process requires ultra-fine grinding of raw materials that leads to low sedimentation rates of the oxidized pulp. In addition, the process is worsening due to the high content of salts in the oxidized pulp solution. In consequence of conducted research, it is established that Praestol 2510 (manufactured by LLC “Chemical Company”, Saint Petersburg) is the most effective optimal flocculant for carrying out the pulp dehydration process after autoclave oxidative low-temperature leaching of pyrite-arsenopyrite concentrates. This flocculant allows carrying out the sedimentation process most effectively, and achieving high enough quality of overflow. At that, the consumption of flocculant is 300-450 g/t, because less consumption does not allow a rapid deposition of solid component and effective thickening of the sediment. While increasing a temperature up to 80°C and reducing the salt content of the liquid phase of autoclave pulp down to 1-1.9 mol/l, it is possible to reach the specific productivity of the thickening process to a level of 1.2-3.75 t/m²•day, and the specific yielding capacity of the filtration process – to a level of 38-40 kg/m²•h (Ivanik 2002).

CONCLUSION

Thus, the main trend in the development of raw materials base in gold mining industry is the quality degradation of the original mineral raw materials, as well as involvement into the treatment of ores dealing with hydrometallurgical processing of rare, nonferrous and precious metals reaches about 30% of the total processing cost that significantly affects the production cost of the resulting concentrates. In addition, the area occupied by the thickening agents is about 25% of the total area of the enterprise. The intensification of thickening and filtering processes allows reducing material loss with overflow of thickeners, and increase the recovery of valuable components. This allows manyfold increase the enterprise productivity without installing additional equipment. Optimizing thickening and filtration process parameters is possible both by improving existing and creating new high-performance thickening equipment. Furthermore, the use of various synthetic reagents will allow increasing the deposition rate of the solid phase of the suspension. Such substances can include electrolytes, water-repellent agents, as well as synthetic high-molecular flocculants. Synthetic polyelectrolytes are composed of active hydrophilic functional groups such as -CONH₂ and -COOH. Such polymeric compounds in solutions are ionized, and their macromolecules acquire positive or negative charge depending on the kind of ion groups. The availability of such substances in disperse hard to thicken systems contributes to rapid and efficient sedimentation of suspended particles through the formation of aggregates, i.e., floccules.

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and gold-bearing concentrates with gold finely disseminated into crystal lattice of main sulfide minerals. The application of advanced autoclave-hydrometallurgical technology allows not only achieving comprehensive use of low-grade and complex (in terms of processing) refractory gold-bearing pyrite-arsenopyrite raw materials, meeting the problems of environmental protection, but also preserving natural resources. Problems arising in the process of autoclave-hydrometallurgical processing of such ores can be solved through an integrated approach, based on the combined use of enrichment and metallurgical methods.

REFERENCES


