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The Predictive Control System of Gold Dissolution by Grinding Gold Ore

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Abstract: Cyanidation of gold allows to reach up to 70% of the extraction subject to the ratio of the concentrations of cyanide oxygen. The proposed control system is based on the MPC that allows optimizing this process taking into account character of the ore, oxygen content, pH and ORP. The control system is based on the predictive model allows to intensify the process of dissolution of gold, to reduce reagent consumption, to prevent the formation of hydrocyanic acid and to reduce the formation of passivating films on the surface of the gold. To increase operational characteristics and improve the accuracy in addition to the control system can be applied the device of measuring the concentration of gold and the increase of oxygen concentration in solutions.

Key words: Gold, grinding, gold-containing ore, dissolution cyaniding, dissolved oxygen monitoring, passivating films cyanide, supply control system

INTRODUCTION

Over the past decades, the share of gold extracted from technologically simple gold ores has been steadily declining. At the same time, the share of gold extracted from the so-called refractory ores is increasing, the effective treatment of which requires much more complex and developed schemes involving operations of gravity concentration, flotation, roasting, melting, pressure oxidation, bio-oxidation, etc. Practically there are no such deposits in the ore of which there were no components that could lead to a decrease in recovery during processing

At the present time the main method of extracting gold from ore is the cyanide leaching process. The essence of this process lies in the leaching of precious metals using dilute solutions of cyanide salts of alkali or alkaline earth metals in the presence of oxygen.

Problem statement: The dosage of the reagent (cyanide) is carried out according to the calculated data of the technologists, without taking into account the nature of the change of the composition of the ore, the absorption rate of NaCN and O_2 (Koblov and Dementiev, 2010). Whereas in order to conduct the process in a mode close to the optimum, it is necessary to observe a certain ratio of oxygen and cyanide corresponding to the given composition of the raw material (Bellec *et al*., 2009), if not taking into account which can lead to the opposite effect, the formation of hydrocyanic acid and passivating films which leads to the creation of unfavorable conditions, both for maintenance personnel and for the conduct of the technological process (Bubeev *et al*., 1999).

It is established that preliminary cyanidation is effectively carried out together with the grinding process (Kolodin and Elshin, 2013). And at present, this practice of adding cyanides during grinding is applied at a number of gold recovery factories. In the grinding process due to the high speed formation of a new surface there is an increase in potential energy of a substance and increase its chemical activity. Thus, the combined cyanidation process with grinding in the presence of oxygen allows to achieve recovery of up to 70%. And grinding is only the first stage of extraction. The disadvantages of this approach lie in the absence of process control and evaluation of the state of the process in particular, control of the oxygen, cyanide and gold content in the grinding process and possibly some other components that could describe it in detail.

One of the solutions to this problem is the creation of a control system for such a multiparameter object as the process of cyanidation during grinding. It is possible to allocate the following effects of the control system:

- Increase the recovery rate
- Reducing the consumption of reagents
- Prevention of the formation of hydrocyanic acid
- Prevention of the formation of passivating films

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MATERIALS AND METHODS

Theory: The use of the most common closed-loop control technology PID control is not always able to provide sufficient control quality for nonlinear, weakly defined, multiply connected objects. Therefore, one of approaches to solution of the problem suggested the use of control based on predictive models Model Predictive Control (MPC) (Muller and De Vaal, 2000). MPC algorithms use numerical optimization to find optimal control at some time horizon in the future, based on the process model (predictive model) (Camacho and Bordons, 2007).

The monitoring system must take into account, for a certain period of time, the composition of the ore mass, monitor the oxygen, cyanide and gold content (Kolodin and Elshin, 2013). Thus, the control system based on this method takes this into account and according to the forecast, make adjustments to the process control flow of cyanide while the main controlling parameter remains the dissolved oxygen content. The largest uncertainty in control system is the composition of the ore. Along with relatively inert minerals (quartz, silicates, iron oxides) which practically do not interact with cyanide solutions, minerals actively reacting with cyanide and dissolved oxygen are often present in gold ores. The accompanying side reactions increase the consumption of reagents (cyanide and oxygen) and in some cases reduce or slow the extraction of gold into a cyanide solution. The products of these reactions can cause complications in subsequent operations. One of these components are sulfides. A small amount of which can lead to a significant decrease in the efficiency of cyanidation of ores (Fig. 1-3). In-depth analysis of the combined leaching and grinding process, the following parameters can be distinguished.

Grinding:

- d-the size of the material at the inlet (mm)
- Co_2in the dissolved oxygen content in water (mg/L)
- Wo ore consumption (t/h)
- Fw-water flow to the mill (m^3/h)
- Co_i content of ore components (g/t)

Cyanide leaching processes:

- C_{NaCN} concentration of cyanide in solution entering the mill's head (mg/L)
- F_{NaCN} NaCN flow to the mill (m^3/h)

Output parameters of the control object:

- CO_2out oxygen content in the slurry (mg/L)
- C_{Au} the gold concentration in the slurry (mg/L)
- pH the pH of the slurry
- RO reduction-oxidation potential of the slurry
- q_0 number of finished class (%)

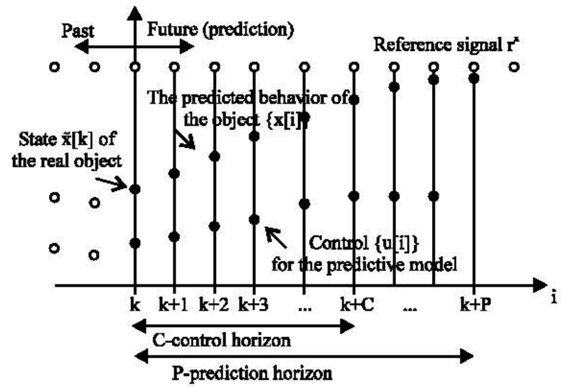

Fig. 1: The principle of control system based on the predictive model

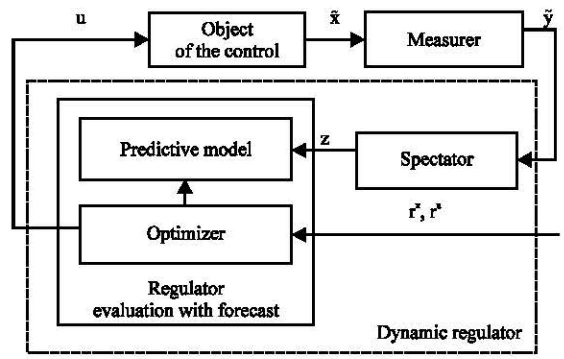

Fig. 2: The overall structure of the control based on MPC

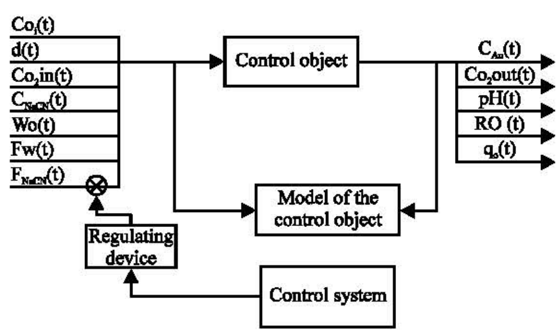

Fig. 3: In-depth analysis of the combined leaching and grinding process

The target corrective function can be a quantitative indicator of the concentration of dissolved gold in the slurry. Maximization is carried out by maintaining a certain ratio of oxygen: Cyanide. But this equilibrium can be violated due to the large uncertainty of the composition of the ore and impurities in the circulating solutions. Based on the literature data and our experimental studies (Elshin *et al*., 2013), the most "harmful" impurities and components of the ore mass are identified these are minerals of iron, copper, antimony and arsenic. Also, minerals of zinc, mercury, lead and some others can exert their influence. As a result of chemical interaction of impurities with the surface of noble metals and by adsorption of surface-active substances present in the slurry, the formation of dense passivating films on the gold surface leads to a slowing down of the dissolution process.

RESULTS AND DISCUSSION

Practical significance: Figure 4 shows the adsorption of oxygen dissolved in water by certain sulphides. Oxidation of sulphides under the influence of water and oxygen goes in several stages. The final product of sulfur oxidation is the SO_2 anion which is confirmed by a change in pH of the medium (Fig. 5).

Our studies show that sulphides unequally absorb dissolved oxygen in water. Thus, arsenopyrite adsorbs part of the oxygen much faster than sphalerite, chalcopyrite and pyrite and sphalerite is more intense than pyrite and chalcopyrite. Recovery of oxygen is slow and also depends on the composition. For example, the fastest recovery takes place in sphalerite. But in the presence of chalcopyrite, visible restoration does not occur at all (Kolodin and Elshin, 2013). The formation of passivating films is affected by:

- Redundancy of oxygen
- Dissolved copper
- Arsenic
- Antimony
- Sulphides
- "Tired" cyanide solutions

Sulphide compounds of iron actively absorb dissolved oxygen and cyanide. The presence of copper significantly increases the consumption of cyanide. As mentioned above, the resulting byproducts of the oxidation reactions and interactions can cause the formation of passivating films on the gold surface which in turn can lead to ineffectiveness of subsequent cyanidation steps. These data allow us to identify corrective effects on the predictive model of the process.

Additional adjustments are made by pH and ORP. In the process of oxidation and cyanidation greatly reduced the pH of the environment. In acidic and neutral solutions of cyanide salts are unstable and undergo hydrolysis with the formation of hydrocyanic acid, HCN is prone to volatilization. Inhalation of it is dangerous for maintenance personnel. According to the safety conditions, the degree of hydrolysis of NaCN should not exceed 0.01 and pH of industrial cyanide solutions should not be below 10 units! To maintain the desired pH value, it is necessary to regulate the supply of lime to the process. The ORP indicator of the slurry serves to determine the ongoing processes when combining the leaching and grinding. With the mutual influence shown in Fig. 6, the following components can be distinguished:

- N0 costs of cyanide on the reaction of gold dissolution
- K0 costs of O_2 on the reaction of gold dissolution

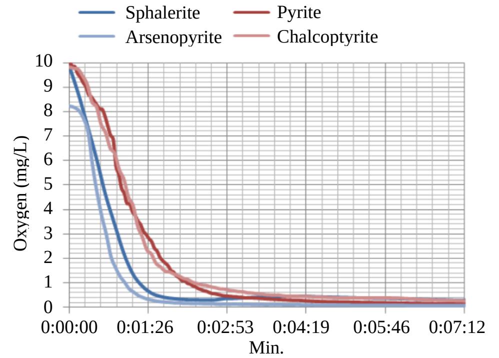

Fig. 4: The adsorption of oxygen dissolved in water

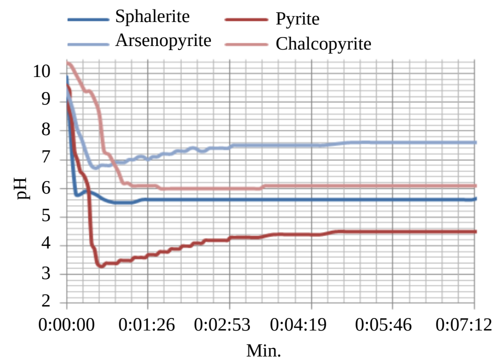

Fig. 5: Change in pH of the medium

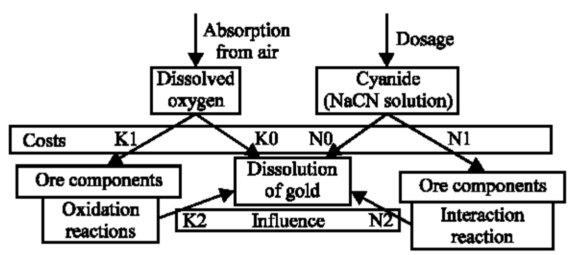

Fig. 6: Mutual influence of oxidation and cyanidation on the process of dissolution of gold

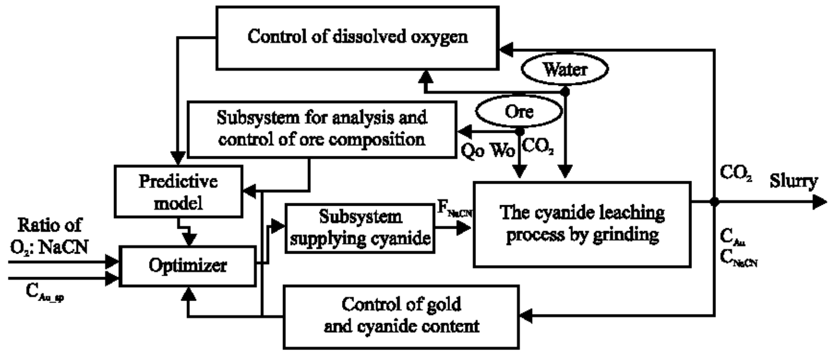

Fig. 7: Structural scheme of a method for controlling the process of dissolution of gold-bearing ores during grinding based on a predictive model

- N1 total costs of cyanide on interaction reactions with ore components
- K1 total costs of O_2 on the oxidation reaction of ore components
- N2 influence of reaction products with cyanide on the process of dissolution of gold
- K2 influence of products of oxidation reactions on the process of dissolution of gold

Thus, the mathematical model of the process of leaching during grinding is a system of differential equations that take into account the effect of various components (not more than 5) of ore on the dissolution process, the residual cyanide content, oxygen uptake, gold concentration at the output from the grinding unit, pH, ORP, etc. The predictive model is built on the basis of the obtained model of the object. The introduction of a predictive model is necessary because any mathematical model only approximately represents the actual object. This is due to such unaccounted factors as parameter variations, external influences, nonlinearities, etc. At the same time, a fixed model with any variations of unaccounted factors allows to approximately predict its behavior. Usually the predictive model is chosen rather simple, so that, it can be integrated in real time and directly used in the control loop (Birol and Ucurum, 2016) (Fig. 7).

CONCLUSION

On a certain forecast horizon, the optimal control action relative to the previous ones is calculated, taking into account all the above measurements and corrections. At the next step the process is repeated again but with the actual parameters. The following effects can be distinguished from the application of this control system:

- Increase the recovery rate by maintaining the optimal oxygen: cyanide ratio, according to the predictive model
- Reducing the consumption of reagents
- Prevention of the formation of hydrocyanic acid
- Forecasting and preventing the formation of passivating films

IMPLITATIONS

In addition, it can be safely implemented on any enterprise applying cyanide processes without violating existing processing schemes. Further intensify the process of gold dissolution possible by increasing the concentration of dissolved oxygen in the water supplied. Thus, the control system maintains the optimal ratio of oxygen: cyanide. Based on the residual oxygen content, the composition of the ore, pH, ORP, adjustments are made in the prediction model.

Along with the listed parameters in the model can introduce a direct adjustment for the product obtained the concentration of cyanaurate. For such purposes it is possible to apply the device of the automatic control of the maintenance of gold (Elshin *et al*., 2010, 2013). It allows online measurement of the content of the final valuable component and it is easy to integrate into the process control system to the grinding and slurry after grinding, for example, by means of a beam hydroacoustic emitter (Bobozoda *et al*., 2015; Boboyev and Kasatkina 2016).

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