# Effect of oxygen-enriched recycle water on the gold ore cyanidation in the grinding circuit

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**Abstract.** The paper presents the results of the research on the intensification of the cyanidation process of low sulphide gold bearing ore from the Burgunda deposit with relatively simple material composition. To intensify the process, it is proposed to conduct comparative research on three methods: direct cyanidation and cyanidation in the grinding cycle, including the supply of oxygenated recycled water. The results of the kinetic research showed high efficiency of the third method - cyanidation in the grinding cycle with supply of recycled water pre-saturated with oxygen up to the concentration of 15.8 ppm. It made it possible to achieve both high levels of gold recovery and transition of the gold dissolution rate to the kinetic range.

## 1 Introduction

Currently, the main method of gold extraction is the cyanidation process, which makes it possible to extract up to 95% of gold in industrial conditions from primary ores. The main disadvantages of this method include the process time (up to 3 days and more). In this regard, the number of equipment used increases significantly, requires large areas for their installation and high maintenance costs. The process time depends on the agitation rate and dissolved oxygen concentration, which are insufficient in industrial conditions.

Low agitation rate is the reason for the formation of a diffusion layer. This in turn reduces the penetration of the solvent required for dissolution (CN-) and oxidizing agent (O2) to the metal surface. Reducing the film thickness or preventing its formation at all can be achieved by increasing the agitator rotation speed. However, in practice it is not possible to exceed agitator agitation speeds above 7 rpm in tankers larger than 3 m by 6 m when using the stirred cyanidation method. In this context, cyanidation in a grinding cycle [1] is the most preferred option, where the agitation rate of the slurry is increased.

During grinding, in addition to increasing the contact area due to the collision of ore pieces with each other and balls, turbulent flow is created in the wet medium. This also contributes to the destruction of the diffusion layer during its formation. However, it was found [1] that during cyanidation in the grinding cycle, most of the dissolved oxygen is spent on interaction with rapidly oxidizing components of the ore, and only a small part

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remains for reaction with gold according to formula 1. Therefore, even in this case, the rate of gold dissolution decreases

$$2Au + 4CN^- + O_2 + 2H_2O \rightarrow 2Au(CN)_2^- + 2OH^- + H_2O_2 \quad (1)$$

Theoretically, gold dissolution (reaction 1) is possible when the ratio of $CN^-$ to dissolved oxygen concentration (DOC) near the surface reaches 6. DOC is always low in solutions and in pulps due to changes in physicochemical properties (changes in salinity, density, surface tension, etc.). It is for this reason that the cyanidation process time is directly related to DOC.

Thus, the most cost-effective way is the pre-saturation of recycled water with oxygen to a concentration of 15.8 mg/dm³ using a hydroacoustic emitter [2-5], and its subsequent feeding into the grinding cycle with cyanide [6, 7], which was the purpose of this research. The objectives of the research were studying the dependence of gold recovery rate on process time, $CN^-$ concentration and temperature at different methods of cyanidation and establishing the limiting stage of the gold dissolution reaction process.

## 2 Materials and methods

### 2.1 Material and reagents

Low-sulfide gold-pyrite ore of Burgunda deposit, which has a relatively simple material composition, was used as an initial raw material. According to the data of mineralogical composition of the ore, the main part of the ore is made up of the conglomerates (Table 1): pyrite and marcasite, followed by iron sulfates, malachite and azurite. According to the chemical composition data, the valuable component of the ore is gold with the content of 3 ppm.

**Table 1.** Mineralogical ore composition

| Ore Minerals | Content, % | Barren Minerals | Content, % |
|---|---|---|---|
| Getit, jarosite | 5.4 | Quartz | 37.78 |
| Pyrite, marcasite | 4.3 | Carbonates | 18.16 |
| Iron hydroxides | 2.01 | Clay minerals (kaolin) | 9.40 |
| Ferrous sulphates | 1.62 | Iron hydrosilicates | 7.50 |
| Malachite, azurite | 1.2 | Sericite, muscovite | 6.87 |
| Others | 3.72 | Others | 2.04 |

According to the phase composition data, the gold in this ore is 66.7% in cyanidizable form at a grain size of 0.074 mm after dry milling.

Analytical NaOH (Damao, Tianjin, China) was used for pH adjustment. Sodium cyanide (NaCN) with purity greater than 98% was obtained from OOO Pokrud. Deionized water was used in all experiments.

Direct cyanidation. The process was carried out in agitation mode using top-drive type agitator on hydrocyclone drain slurry with density of 1.34 kg/dm³ from the production process, directed cyanidation process at grinding - 0.074 mm. The pH of the medium was maintained in the range of 9.3-10.5 and the process time was 24 hours.

Cyanidation in the grinding cycle and in the supply of recycled water and water pre-saturated with oxygen. The scheme of staging was chosen similar to the industrial one (Fig. 1). In the second stage of grinding was fed drain classifier of the first stage, conducted

without cyanide due to the coarseness of incoming pieces and the presence of absorbers of alkali and oxygen, due to which their concentration decreases, which is not desirable. Thus, the feed material for the second stage was pulp with a density of 1.95 mg/dm$^3$.

For cyanidation in the grinding cycle at the classifier drain of the first stage of grinding was used ball mill with a volume of 2 liters with a working zone of 50-70%. The mass of balls was 1.4 kg with a size ranging from 10 to 30 mm. The rotational speed was 90 rpm with more than 76 % of the theoretical critical speed.

To increase the temperature, the pulp was heated 5 degrees above the required value before feeding and during the process the mill was heated by supplying heat to its surface. The constant parameters were pulp density - 1.34 kg/dm$^3$, pH of the medium - 9.3 - 10.5, process time - 30 minutes.

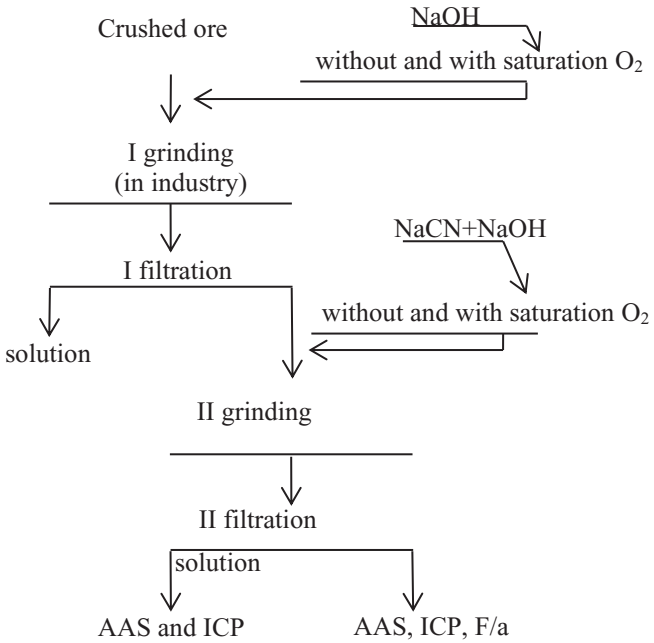


**Fig. 1.** Technological scheme for laboratory research

## 2.2 Plant for oxygenation of recycled water

For saturation, an installation was assembled (Figure 2), in which a hydroacoustic transmitter (Figure 3) consisting of a cylindrical resonator chamber 2 was mounted. Due to the design of the resonator chamber of the transmitter, when feeding the pulp in it creates a zone of discharge (4), from where the air is sucked. Further, the air is broken into micro-nanobubbles, the solubility of which is high, by the turbulent slurry flow.

Thus, the centrifugal pump pumps the solution out of the tank and feeds it at a pressure of 3 bar into the inlet bore of the emitter. The output is micro-nanobubbles dispersed into micro-nanobubbles, some of which dissolve in the solution, increasing the DOC, and the other part (mostly nano-bubbles), being in a stable form, keeps the DOC at a high level for a long time. This unit makes it possible to increase DOC in recycled water up to 15.8 mg/L when saturated with air and up to 39 mg/L when saturated with pure oxygen.

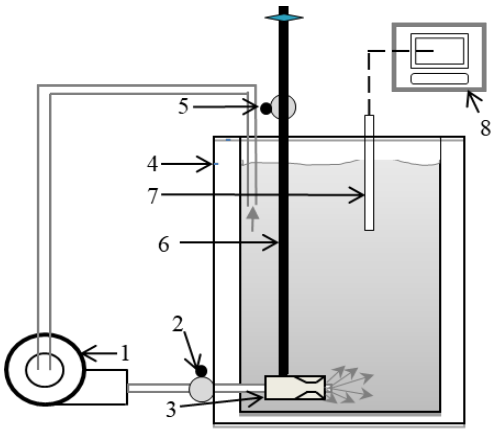


**Fig. 2.** Installation for saturation: 1 - centrifugal pump; 2 - pressure gauge; 3 - double beam emitter; 4 - reactor; 5 - gas flow meter; 6 - gas supply connection; 8 - valve, 9 - pH meter.

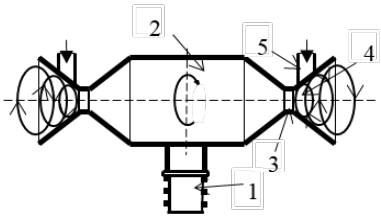


**Fig. 3.** Double-beam emitter: 1 - solution inlet fitting; 2 - resonator chamber; 3 - output nozzle; 4 - minus pressure zone; 5 - gas fitting

Throughout the experiment, the pH of the medium, cyanide concentration (by titration with silver nitrate in the presence of rhodanine as an indicator) and dissolved oxygen (Extech DO600 oximeter) were checked. These values were manually monitored at nominal values that were pre-selected for the experiment.

### 2.3 Product filtration and analysis

After the leaching process, the pulp was immediately filtered under low vacuum and the liquid phase was used for gold analysis by AAS. The remaining solid phase was then washed well with alkalinized demineralized water, dried and analyzed by Fire assay or ICP. In some experiments, both solid and liquid phases were analyzed by AAS.

## 3 Results and discussion

In order to select the best method, comparative kinetic research was carried out in three ways, described in Table 2 and the results are presented in Table 3.

**Table 2.** Methods and their descriptions

| Method | Title | Note |
|---|---|---|
| A | Direct cyanidation | At the outlet of the hydrocyclone |
| B | Cyanidation in grinding cycle | At the classifier drain after the first grinding stage. Waste water is not oxygenated. |
| C | Cyanidation in grinding cycle at supply of preoxygenated recycled water | At the hydrocyclone drain after the second grinding stage. The recycling water supplied both to the first stage and during cyanidation of the classifier drain in the mill is saturated with oxygen. |

**Table 3.** Effect of CN- concentration and process time on gold recovery

| Method | $CN^-$ concentration, % | Gold recovery at different cyanidation process times (min), % | | | | | |
|---|---|---|---|---|---|---|---|
| | | 5 | 10 | 15 | 20 | 25 | 30 |
| A | 0.002 | 0.1 | 0.4 | 0.9 | 1.3 | 1.6 | 2.1 |
| | 0.004 | 0.9 | 1.4 | 1.9 | 2.3 | 2.8 | 3.0 |
| | 0.006 | 1.2 | 2.1 | 2.7 | 3.3 | 3.8 | 4.2 |
| | 0.008 | 1.6 | 2.3 | 2.6 | 3.1 | 3.6 | 4.0 |
| B | 0.004 | 0.9 | 1.8 | 2.5 | 3.1 | 3.5 | 3.6 |
| | 0.008 | 1.5 | 2.3 | 3.1 | 3.9 | 4.6 | 5.5 |
| | 0.012 | 2.1 | 4.2 | 5.8 | 6.6 | 7.0 | 7.4 |
| | 0.019 | 3.6 | 4.4 | 5.6 | 6.1 | 6.6 | 7.0 |
| C | 0.02 | 10.3 | 12.0 | 17.4 | 21.6 | 24.7 | 28.2 |
| | 0.04 | 23.6 | 30.9 | 36.3 | 41.2 | 48.6 | 52.6 |
| | 0.06 | 28.5 | 35.1 | 43.8 | 52.3 | 58.5 | 63.0 |
| | 0.07 | 31.4 | 38.7 | 42.7 | 49.2 | 56.1 | 62.7 |

As can be seen from the table, increasing the concentration of $CN^-$ proportionally increases the gold recovery in all experiments. However, the highest gold recovery rates are achieved using method C. For instance, gold recovery at a concentration of $CN^-$ - 0.06% reaches 63% at a process times of 30 min, which significantly increases the effectiveness of the cyanidation process compared to methods A and B significantly. Thus, the introduction of oxygenated recycled water intensifies the process of cyanidation by method C in relation to methods B by 9 times, and A by 15 times.

To establish the limiting stage of the gold dissolution reaction in order to calculate the activation energy, research was conducted at different temperatures for all methods (Figure 4), which showed the temperature dependence of the degree of gold extraction.

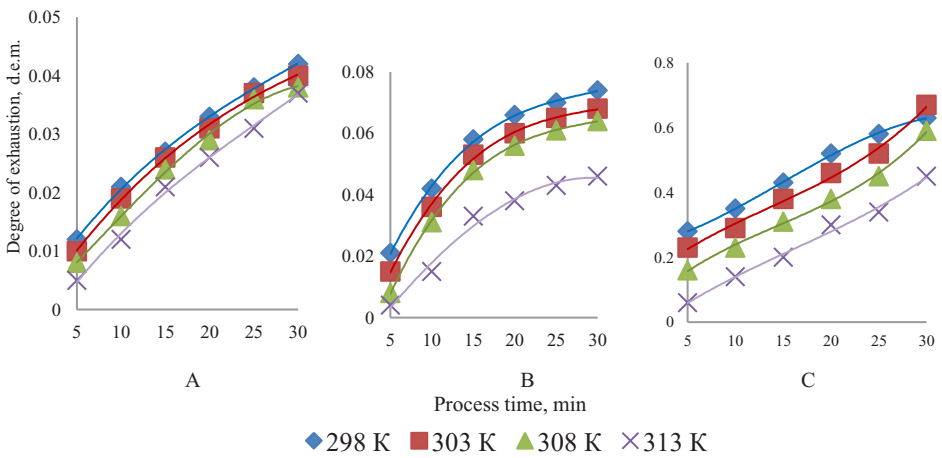


**Fig. 4**. Effect of temperature on gold recovery: CN- concentration for method A - 0.006%, B - 0.012%, C - 0.06%.

As can be seen with increasing temperature the degree of gold recovery decreases, which is due to the low solubility of oxygen corresponding to Henry's law, which states that the solubility of gases is inversely proportional to temperature, which is the cause of slowing down the rate of dissolution of gold.

To calculate the activation energy using the Arrhenius equation, logarithmic curves of transformation and inverse temperature were plotted based on the data in Table 3 and Figure 4. Then, by crossing the tangent of the angle of slopes of the curves, the reaction order by reactant and activation energy were determined (Table 4).

**Table 4.** Results of reaction order and activation energy calculations

| Method | Reaction order (n) | Activation energy (Ea), kJ/mol |
|---|---|---|
| A | >1 | 23.7 |
| B | ≥1 | 28.15 |
| C | <1 | 87.80 |

The results showed (Table 4) that (1) methods A and B with activation energy less than 30 kJ/mol indicate the reaction of gold dissolution in the diffusion region, which is associated with both low DOC and agitation rate. (2) Method C featured an activation energy much higher than 40 kJ/mol indicating that the reaction proceeds in the kinetic region.

## 4 Conclusions

1. Gold recovery at the level of 63 % is achieved at a much shorter process time by the method of cyanidation in the grinding cycle at the concentration of dissolved oxygen at the level of 15.8 mg/dm$^3$ in the recycled water fed to the mill of the second stage of grinding and concentration of CN- 0.06%, respectively.

2. In comparison with direct cyanidation and cyanidation in the grinding cycle without saturation, in which gold dissolution occurred in the diffusion region, cyanidation in the grinding cycle with saturation made it possible to intensify the process of gold dissolution by 9-15 times. This led to the transition of the reaction area into the kinetic region.

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