Influence of water quality on the autoclave leaching process (on the example of the Bereznyakovsky gold recovery factory)

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Abstract. For the first time this article provides a benchmarking analysis of water consumption while using modern technologies of gold recovery from ore; the best ore-processing technology for refractory sulphide ores is identified; and recommendations are given on water and energy saving in the process of autoclave leaching. The authors found that the most efficient technologies for extracting gold for certain geological conditions (gold is embedded in a complex mineral) are: autoclave leaching and bacterial oxidation. They allow you to save water resources, especially if these technologies use mills. The authors give recommendations for using the combined method. The calculation of surface runoff from the sites of the gold processing plant showed that using them, you can save from 3 to 8 percent of the make-up water.

1. Introduction
The bereznyakovsky Deposit and gold recovery factory are located in the Etkul district of the Chelyabinsk region, 3 km Northwest of the village of Bereznyaki. The field was discovered in 1990 by geologists of the Poletaevsky geological survey party. The factory is one of the first in Russia to use autoclave leaching technology. The peculiarity of the ore is that gold is contained in a complex mineral. Its release from the crystal lattice occurs by high-pressure oxidation in the presence of large amounts of oxygen and water.

As a rule, gold recovery plants work along ore-processing routes using environmentally hostile cyanides and need a lot of water. The ramp up of production at the Bereznyakovsky gold recovery factory (further - BGRF) has resulted in an increased anthropogenic impact on the environment. In this context the issues of searching for various ways to save water and resources, and improving the quality of gold recovery during ore processing, as well as the efficiency of the enterprise itself become relevant.

The work’s objective is the optimization of the process of autoclave leaching and the search for various ways to save water and resources.

In order to achieve the objective, a number of tasks need to be solved:
- examining and analyzing the water resources available at the BGRF;
- conducting field and laboratory study of the enterprise’s production feed and recycle water used during autoclave leaching, and suggesting the ways of improving its qualitative and quantitative characteristics; and
finding possible options of saving water and resources during gold ore autoclave leaching in order to optimize the water resources management.

The scientific originality of the study is as follows. For the first time, a comparative analysis of water consumption in various modern technologies for extracting gold from ore was performed by the authors; a recommendation is given for the use of surface runoff from the territory for water and resource conservation in the process of autoclave leaching; the best technology for ore enrichment in the presence of persistent sulfide rocks is determined.

The research has been conducted using the materials of the expert review [1], information from various literature and Internet sources, and samples taken from the enterprise’s feed and recycle water to perform the experimental part of the work.

The analysis of the available information has revealed that:

- the BGRF works along the processing routes using cyanides; and
- surface discharge from the recycle water supply sites is not used [2,3].

Therefore, the necessity has arisen to:

- search for more environmentally-friendly and less water-consuming methods of gold ore processing; and
- conduct field and laboratory studies aimed at revealing the quality indicators of the used water in order to optimize the autoclave leaching process and water and resources saving.

2. Methods

The main methods of research included:

- Analysis and synthesis of literature and information sources on the primary issue;
- Benchmarking analysis;
- Geo-ecological field research;
- Laboratory study of the water quality; and
- Analogue extension method.

The authors also established methods that are modern alternatives to cyanide leaching:

- Gravity-flotation method;
- Ammonia-thiosulfate leaching;
- Thiocarbamide leaching of gold;
- Coal-sorption technology;
- Application of the reagent Flotent GoldSC_570 (China);
- Albion-process;
- Bacterial oxidation;
- Autoclave leaching.

3. Results

The benchmarking analysis of water consumption while using modern technologies of gold recovery from ore in order to identify the best ore-processing technology for refractory sulphide ores has shown that the most frequently used technologies of gold recovery from ore allowing to reduce or avoid the use of cyanides are the technologies [4-10] presented in Figure 1.

The chart on economic indicators of the cost of refractory gold ores processing has been built and analyzed by the author to choose the most optimal processing route of ore leaching.

This figure shows that it is more rational and cost-effective to use autoclave leaching and heap bacterial leaching.

Within this work we also assessed the quality of water used – at the BGRF in order to test its safety for the environment.

According to Table 1, the concentration of chemical ingredients in different samples taken on the factory’s territory practically does not vary and does not exceed the maximum permissible concentration, with the exception of copper and hardness [11].
Figure 1. Economic indicators of refractory gold ores processing; 1 – Heap bacterial leaching of ore, 2 – ultrafine grinding of concentrate, 3 – ultrafine grinding of ore, 4 – Albion Process grinding of concentrate, 5 – bacterial leaching of concentrate, 6 – autoclave leaching of concentrate.

Table 1. Concentration of chemical ingredients in water.

| No | Ingredient (substance) | Concentration, mg/l in sample* 1 | Concentration, mg/l in sample* 2 | Maximum permissible concentration |
|----|------------------------|----------------------------------|----------------------------------|----------------------------------|
| 1  | Salt content           | 540                              | 540                              | 1000                             |
| 2  | Cl⁻                    | 78                               | 71                               | 350                              |
| 3  | Total hardness         | 8,0 mg-equiv/L                   | 8,0 mg-equiv/L                   | 7,0 mg-equiv/L                   |
| 4  | Ca hardness            | 5,0                              | 4,7                              | –                                |
| 5  | Ca²⁺                   | 100,2                            | 94,2                             | 180                              |
| 6  | Mg²⁺                   | 36,5                             | 41,6                             | 40                               |
| 7  | SO₄²⁻                  | 320                              | 340                              | 500                              |
| 8  | Permanganate oxidizibility | 1,06                          | 2,00                             | 5,0                              |
| 9  | NH₄⁺                   | 0,41                             | 0,35                             | 1,93                             |
| 10 | NO₃⁻                   | 0,05                             | 0,11                             | 3,3                              |
| 11 | Total Fe               | 0,03                             | ND                               | 0,3                              |
| 12 | pH                     | 7,33                             | 7,23                             | 6,5–8,5                          |
| 13 | P₂O₅                   | 0,02                             | 0,02                             | 3,5                              |

Note: *sample taken in a well; **sample taken in recycle water.

Due to the fact that elevated concentrations of copper and magnesium have been detected in water in the laboratory conditions, we recommend to perform advanced treatment of water, directly before the process of autoclave leaching, through conditioning [12] using the method of subsequent Na-H-cationization [13], as the best available technology for the certain case under study. This will increase the rate of chemical reaction between water and ore mass, and increase the percentage of gold. The method of conditioning suggested by us will allow to stabilize water, and decrease the hardness indicator to 2–4 mg-equiv/L.
Another factor of the enterprise activity, which is no less important, is the using of the technology of saving water and resources, and reducing of the impact on the environment from cyanides.

The authors proposed the use of surface (planar runoff) from sites for water conservation purposes. The runoff was calculated for this purpose (table 2).

**Table 2. The calculation of the surface (in-plane) flow.**

| №  | Name of the drain | Water volume in low-water years (m³/ year) | Water volume in high-water years (m³/ year) | Low-water year/high-water year (% of recycled water) |
|----|-------------------|------------------------------------------|-------------------------------------------|-----------------------------------------------|
| 1  | White water BGRF  | 29 000 000                               | 29 000 000                                | 100                                           |
| 2  | Estimated surface runoff from BGRF sites in summer | 18,800                                   | 37,600                                    | 0.7/1.4                                       |
| 3  | Estimated surface runoff from BGRF sites in winter | 7,200                                    | 14,400                                    | 0.3/0.6                                       |
| 4  | Estimated surface runoff from quarry sites and dumps in summer | 65,000                                   | 130,000                                   | 2.4/4.8                                       |
| 5  | Estimated surface runoff from quarry sites and dumps in winter | 23,000                                   | 46,000                                    | 0.9/1.8                                       |
|    | **Total**         | **116,000**                               | **232,000**                               | **4.3/8.6**                                   |

According to Table 2, we can save from 4.3 to 8.3 % of water.

4. **Findings**

1. The analysis of the water resources of the BGRF has shown that the enterprise works along the ore-processing routes using environmentally hostile cyanides and significant amounts of water.
2. The analysis of the best available technologies has revealed that the most rational technologies of gold recovery for certain geological conditions (the gold is embedded in a complex mineral) are: autoclave leaching, bacterial oxidation, and Albion Process. These allow to save water resources, especially if mills are used in these technologies. Table 3 provides recommendations for using the combined method.

**Table 3. Recommendations for using the combined method.**

| №  | Technologies                  | Capital expenditures, in millions of US dollars | Operating expenses, in millions of US dollars | Cost reduction relative to autoclave leaching (%) |
|----|-------------------------------|-----------------------------------------------|---------------------------------------------|-----------------------------------------------|
| 1  | Autoclave leaching,           | 72                                            | 400                                         | 0                                             |
| 2  | Bacterial oxidation,          | 56                                            | 400                                         | 9-10                                          |
| 3  | Albion process *              | 52                                            | 370                                         | 16-18                                         |

Note: *the method is not used in the presence of persistent sulfide ores.

Thus, taking into account the costs of installation, operation of equipment, as well as measures aimed at improving the quality of the environment, we recommend using a combined method. It is dominated by autoclave leaching and bacterial oxidation.

3. In order to reduce the water- and resources-consuming aspect of the process of autoclave leaching, we have suggested using a combination of autoclave leaching and bacterial oxidation. Bacterial oxidation reduces the costs of using chemical agents, electric power, and heating plants (the temperature during bacterial oxidation does not exceed 60–90 degrees).

4. The conducted laboratory study of the chemical composition of the recycle and feed water at the gold recovery factory has shown that the maximum permissible concentration is significantly
exceeded for copper (9 times higher) and for total hardness (by 10–15%). Solution: before the process of autoclave leaching and in order to improve the water quality (reduce hardness and concentration of heavy metals), it is recommended to perform subsequent Na-H-cationization and remove suspended solids (through filtering or sorption technology).

The method of conditioning, that we suggest, has been implemented at the BGRF (the act of implementation) and has allowed to minimize salt deposits on autoclaves and equipment, and improve process conditions for gold recovery from gold concentrate; it will also enhance the equipment’s resistance to wear in the future.

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