Technological and environmental features of heap leaching of Delmachik gold-bearing ores deposit

KK Razmakhnin1,2*, PA Vasiljuk1
1Chinakal Institute of Mining, Siberian Branch, Russian Academy of Sciences, Novosibirsk, Russia
2Transbaikal State University, Chita, Russia
E-mail: *igdranchita@mail.ru

Abstract. The problem of gold ores hydrometallurgical processing with using sodium cyanide is evaluated. The prospects for the development of the use of cyanide-free reagents for leaching gold from ores are studied. The possibility of introducing a cyanide-free environmentally friendly reagent instead of the widely used sodium cyanide was determined. The results of experimental studies on the comparability of the processing of gold ores using sodium cyanide and a reagent based on sodium cyanoate are obtained. The optimal parameters of the technological process for the extraction of gold from ores using a cyanide-free reagent are established.

1. Introduction
Heap leaching of gold from ores, deep-lying placers and technogenic mineral raw materials using sodium cyanide requires special control over the environmental friendliness and safety of the process. It is known that the greatest damage to human health, as well as environmental damage to the natural environment, can be caused by the formation of vapors of hydrocyanic acid, filtration of reagent solutions into the soil, ground and surface waters [1]. Possible negative consequences due to the use of sodium cyanide in hydrometallurgical processing technologies determine the relevance of the search for the least hazardous reagents for extracting gold from ores. At the same time, less aggressive substances such as thiocyanate, cyanate, hypochlorite, etc. can be used to transfer gold to the liquid phase. [1–3]. However, with all the possibilities of domestic chemical production, the proposed reagents have not received wide industrial application and are limited only to laboratory experiments. In this regard, it is of particular importance to study the possibility of using sufficiently effective and environmentally friendly reagents for leaching gold, including those of foreign production, as well as determining the technological features of their use on an industrial scale in the climatic conditions of Siberia and the Far East.

It should be noted that when choosing an effective reagent for leaching gold and the technology in which it will be applied, a number of factors should be taken into account. First of all, such factors include ore properties such as bulk density, specific gravity, angle of repose, porosity, porosity coefficient, filtration coefficient and loosening coefficient, gold content by size class, etc.

2. Methods of the research
The object of research was the gold-bearing ores of the Delmachik deposit located in the Transbaikal Region in the Shilkinsky District, 25 km north-west of the district center of Shilka. According to the
data of diffractometric analysis, the main minerals that make up the ores are: quartz, feldspars and a complex of clay-mica minerals. The main ore minerals are pyrite (about 2–2.4% in primary ore samples) and arsenopyrite. Oxidized minerals in the samples are represented by iron hydroxides, arsenic oxides (scorodite) are also noted, the amount of which is 0.8–1.4%.

In the course of the research, the factors influencing the efficiency of gold leaching from ores were studied.

The study of the process of leaching of gold from oxidized ores of the Delmachik deposit was carried out by bottle leaching using two reagents: sodium cyanide NaCN (TU 2151-001-6406 2211-2011 with amendment 1) and an ore-dressing reagent produced in China, which is based on sodium cyanate. The scientific experiment was carried out under the following conditions: ore cyanidation at a particle size of -10 mm; concentration of NaCN – 1 g/l; weight 3 kg; density 50% solid; pH 10–10.5; agitation time 72 hours, control of parameters after 2, 4, 8, 12, 24, 36, 48, 60 hours and at the end of research; leaching of ore with a size of -10 mm; the concentration of the complexing agent of the regent produced in China – 1 g/l; weight 3 kg; density 50% solid; pH 10–10.5; agitation time 72 hours, control of parameters after 2, 4, 8, 12, 24, 36, 48, 60 hours and at the end of the experiment.

As a result of tests carried out on bottle leaching with different complexing agent were obtained indicators for the extraction of gold and silver (Table 1).

Table 1. Indicators for the extraction of gold and silver from the ores of the "Delmachik" deposit using sodium cyanide and a reagent produced in China

| Reagent                        | Extraction Au,% | Extraction Ag,% |
|--------------------------------|-----------------|-----------------|
| Sodium cyanide (NaCN)          | 77.24           | 52.30           |
| Reagent made in China          | 73.49           | 52.37           |

When analyzing the data on gold leaching from the ores of the Delmachik deposit, fairly similar indicators were obtained for the extraction of silver with cyanide and a reagent produced in China, the convergence in recovery is lower (discrepancies in the recovery of gold 0.5%, silver 2.5%). It should be noted that with cyanide leaching, gold recovery is higher by 4.2% in comparison with the substitute reagent, and the cyanide consumption is 20% lower.

In order to determine the effectiveness of the use of a cyanide-free reagent produced in the PRC for leaching gold from the ores of the Delmachik deposit, studies were carried out in percolation columns using a processing reagent (PRC) based on sodium cyanate in compliance with the following parameters: ratio W: T = 1.55 concentration of cyanide-free reagent – 0.5 g/l; the pH of the solution was 10.5–11.5; sorbent – activated carbon.

The ore was loaded into the percolation column in portions in order to prevent its segregation by size classes, while the feed rate of the leaching solution was 4.1 ml/min with permanent monitoring of the state of the ore surface in the column, which ensured uniform irrigation of mineral raw materials. In the course of the research, the liquefaction, the gold content in the solution, as well as the hydrogen index (pH) and the residual concentration of the reagent in the productive solution were monitored. The duration of ore leaching depended on the indicator of the concentration of gold in the productive solution and its decrease below the level of 0.05 mg/l. The main conditions and results of studies on ore leaching from the Delmachik deposit are presented in Table 2.

As a result of the research, it was established that it is possible to process oxidized gold-bearing ore from the Delmachik deposit by heap leaching using an environmentally friendly cyanide-free reagent produced in China. At the same time, the extraction of gold into solution with an ore size of -10 mm reaches 84.0%, and the gold content in the leaching cake is 0.38-0.41 g/t.
Table 2. Results of studies on leaching of ore from the Delmachik deposit in percolation columns

| Options experiment | Experiment number | 1 | 2 | 3 | 4 | 4/1 | 5 | 6 |
|--------------------|-------------------|---|---|---|---|-----|---|---|
| Content in the original ore Au, g/t | 0.71 | 0.86 | 0.86 | 0.88 | 0.92 | 1.06 | 1.26 |
| Size, mm | +25-40 | -40 | +10-25 | -10 | -10 | -10 | -10 |
| CaO addition, kg / t | - | - | - | - | - | 10.77 | 3 |
| Research period, days | 18 | 36 | 18 | 15 | 41 | 21 | 21 |
| Period of active transition of gold into solution, days | 18 | 36 | 18 | 15 | 41 | 18 | 21 |
| L:S | 1.55 | 2.5 | 1.02 | 1.87 | 3.75 | 3.43 | 3.43 |
| Leaching agent consumption, kg / t | 0.6117 | 0.9552 | 0.4572 | 0.7479 | 1.1264 | 0.5805 | 0.8485 |
| Content of Au leaching cake, g/t | n/a | 0.31 | n/a | - | 0.38 | 0.3 | 0.41 |
| Extraction, % | 51.9 | 58.73 | 43.69 | 79.5 | 65.4 | 84.0 | 76.1 |

Based on the experimental data obtained as a result of the research, it was found that a change in the size of the oxidized ore of the Delmachik deposit from -40 mm to -10 mm leads to a significant increase in the extraction of gold into the productive solution, which determines the need to use material with a particle size of -10 mm in the technological process. At the same time, the highest gold recovery rates were obtained by adding lime to the original ore in a proportion of 10 kg per 1 ton of ore, which ensures that the pH level of leaching solutions is maintained at least 10.5 for 8 days from the start of irrigation, after which the mother liquor requires reagent re-saturation. The dependence of gold recovery on the leaching duration at an ore size of -10 mm and a lime consumption of 10 kg/t is shown in the Figure 1.

![Figure 1. Graph of the dynamics of gold extraction into solution with an ore size of -10 mm and a lime consumption of 10 kg / t.](image)

In the course of research, it was determined that the active transition of gold into solution ends (for ore with 10 kg/t of lime and a size of -10 mm) after 18 days of leaching, while 50% of the recovery is achieved already on the 3rd day, and 80% of the recovery for 11 days. Based on the results obtained for the process of leaching gold from ores of the Delmachik deposit using a cyanide-free reagent, the following optimal parameters have been determined: ore crushing size -10 mm; ore...
pelletizing with a lime consumption of 10 kg/t; irrigation density 200 l/(m²•day) at L:S not lower than 3.5; the consumption of cyanide-free reagent is not less than 0.58 kg / t; with a decrease in the pH level in the production solution, as well as the timely addition of caustic soda to the irrigation solution to stabilize the pH level within 11.

Thus, as a result of the research, a technology for cyanide-free heap leaching of gold from oxidized ores of the Delmachik deposit was developed based on the use of an environmentally friendly reagent produced in China, the effectiveness of this reagent was substantiated and the main parameters of the technological process were determined. In combination with the use of advanced technologies in the formation of a network of irrigation systems, stacking ore in a pile, preventing leaching solutions from entering ground and surface waters, the use of a sodium cyanate-based reagent provides a significant reduction in the negative impact on the environment and human health, including due to the absence of the release of vapors of hydrocyanic acid and filtration of cyanide into surface and groundwater.

3. Conclusions
As a result of the research, it was found that the gold-bearing ores of the Delmachik deposit can be efficiently processed by heap leaching. At the same time, sodium cyanide used in the processes of hydrometallurgical processing of mineral raw materials can be replaced with more environmentally friendly reagents based on sodium cyanate or other analogs, which eliminates the negative impact on humans and environmental components.

The conducted studies of the possibility of using an environmentally friendly cyanide-free reagent for heap leaching of gold from oxidized ores of the Delmachik deposit, substantiated the effectiveness of this reagent and determined the main parameters of the technological process. The introduction of the proposed technology in combination with the rational use of ore preparation processes, ore stacking, ensuring the efficiency of the irrigation system, especially in winter, reduces the environmental load on the environment while maintaining the main indicators of gold ore processing.

Acknowledgements
The work was carried out within the framework of the project of the Scientific Research Foundation, Project No. 121051900145-1.

References
[1] Shumilova LV 2012 Effective method of hard gold-containing ore preparation to leaching European Journal of Natural History Vol 6 pp. 60–61
[2] Naumov VA, Naumova OB and Osovetskiy BM 2013 Transforming the leaching of gold ore // Modern problems of science and education RANS Vol 6 pp. 32–43
[3] Lobanov VG, Timofeev EI 2017 Development and Introduction of Contemporary Technology of Gold Cyanide Leaching From Gravitational Concentrates Metallurgist pp. 491–497