Optimization of the combined beneficiation scheme and increase in the performance of highly efficient refractory gold-bearing ores under development

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Abstract. The growth in consumption and cost of precious metals is forcing gold mining companies to expand their raw material base and study and develop processes aimed at increasing the recovery of gold from ores and concentrates. The reserves of rich, easily-enriched gold-bearing mineral raw materials are practically exhausted. To maintain the volumes of extraction of precious metal, the domestic gold-extracting industry constantly involves new gold deposits in processing, resumes operation of previously abandoned and "mothballed" quarries and landfills, mines and mines, processes man-made dumps of many mining and processing plants containing a certain amount of metals (in as associated components or not completely extracted during primary processing).

1. Introduction
In many cases, the ores of such deposits are classified as refractory and highly refractory. According to some estimates, the share of these ores is more than 80% of all reserves, therefore, due to the wider involvement of refractory gold and complex gold-bearing ores in the current century, a significant increase in gold production can be provided [1]. Schemes and modes of ore processing significantly depend on the mineral composition of ores, their degradability, the presence or absence of impurities that complicate the extraction of gold, as well as on the size of gold particles. These and some other properties of ores are mainly determined by their origin, according to which gold ore deposits are divided into two main groups - primary and alluvial. About 75% of gold is mined from primary deposits, and 25% from alluvial deposits.

The gold resource base of the republic is characterized by a very low degree of development. The volume of mining of ore gold in Kazakhstan decreased by 2 times compared to 1989, and the degree of development of reserves fell to 0.6%.

At the same time, the decline occurred due to a decrease in production from the actual gold deposits, which contain 66% of all explored gold reserves of the country. The active development of this particular part of the gold resource base, and first of all the largest deposits of Vasilkovsky and Bakyrchiksky, can provide a significant increase in gold production in Kazakhstan. The main problem of large-scale industrial development of these objects is the difficult enrichment of relatively poor
ores in terms of gold content (from 4 to 9 g / t), which require the use of expensive, efficient and environmentally friendly processing technologies.

A significant part of the primary gold reserves are refractory ores, in which gold is in a finely disseminated state in sulfides and rock-forming minerals. The particle size ranges from tens to thousandths of a micron. Gold is mainly associated with pyrite and arsenopyrite, therefore, it does not dissolve during cyanidation at a standard grinding size of 80 - 95% of the -0.074mm class and even at ultrafine grinding, without the use of preparatory technologies before cyanidation.

Also, a preparatory stage is needed, which will improve the indicators of further extraction to acceptable values. The preparation consists in opening the dispersed dissemination of gold, in various ways, to provide access to it for cyanide solution. At the same time, various combinations of special processes of flotation and hydrometallurgy are used, in particular, in combination with sulfidation processes in order to transfer minerals from an oxidized form (sulfates, carbonates) to an easily floatable sulfide one.

Combined technologies for processing oxidized and mixed ores, for example, use a combination of flotation processes. The object of research is the refractory clayey ore of the weathering crust. Most of the free gold particles in this ore have a particle size of less than 20 microns [2].

Forecast proposals for the development of the object, incl. competitiveness of work:
The developed method of processing gold-bearing raw materials, in terms of processing refractory gold-bearing ores of the weathering crust, can be competitive among similar developments.

The economic efficiency of the project lies in increasing the degree of gold recovery by capturing finely dispersed gold and improving the quality of gravity and flotation concentrate.

2. Experimental
The Vasylkovskoye deposit is classified as gold-sulfide quartz and moderate sulfide. The rocks containing mineralization are mainly granitoids, as well as gabbro and gabbro-diorite. The most important and characteristic minerals of the primary rocks are gold, arsenopyrite, bismuth minerals. Arsenopyrite predominates among the listed minerals. Sulphides such as pyrite, chalcopyrite, fahlore, sphalerite, galena, pyrrhotite are predominantly confined to the marginal parts of the deposits and are found in insignificant quantities in the bulk of ores. Gold is represented by native metal and is associated with arsenopyrite-quartz veins containing bismuth minerals [3].

For research, ores of the largest gold-ore Vasylkovskoye deposit were used, sampled at a horizon of 120 m from the surface. On the basis of the research carried out, the mode of crushing and grinding of ore was established. The bulk of gold in ore currently mined is in sulphide and rock intergrowths of 40.52%. Free gold content is 31.91%.

This indicates that it is possible to isolate free gold by gravity methods at the beginning of the technological scheme, followed by regrinding of the intergrowths. Of the ore minerals, in addition to the useful component - gold, arsenopyrite and pyrite are found in significant quantities, pyrrhotite, bismuthine, chalcopyrite, marcasite, fahlore and native bismuth are much less common.

The aim of the research is to select and substantiate the combined gravity-flotation method of enrichment of refractory gold-bearing raw materials and hydro- and pyrometallurgical method of processing enrichment products based on studying the technological properties of the feedstock and enrichment products.

In recent years, great progress has been made in the technology of gravity concentration of gold ore raw materials. In recent years, great progress has been made in the technology of gravity concentration of gold ore raw materials. This is manifested, first of all, in the creation of new devices capable of extracting not only large, but also very small particles of metallic gold released during the grinding of ore, such as centrifugal concentrators and centrifugal jiggers, in which the intensity of separation of particles of gold and other minerals is less the density of grains increases many times [4]. In the vast majority of cases, gravity is used in combination with cyanidation, flotation, or both. For Simple ores, the most typical schemes are gravity and gravity-flotation concentration with cyanidation of flotation tailings, and in some cases also gravity concentrates. The main purpose of
gravity in these options is the removal of large free gold from the ore into products (concentrates) processed in a metallurgical cycle separate from the bulk of the ore.

In addition to increasing (as a rule, by 2-4% of the total gold recovery), this makes it possible to prevent or at least significantly reduce the accumulation of gold in grinding and mixing apparatus.

Flotation, like gravity concentration, refers to methods of mechanical beneficiation, when concentration and separation of mineral components is carried out without disturbing their crystal structure and chemical composition.

Studies have established the following: the gold extracted from the concentration products of the free particle has a size ranging from 10 to 50 microns, and the main part has a size less than 20 microns, this indicates that the bulk of the studied ore is very finely dispersed. Such gold, when enriched by jigging, concentration on the table, is poorly extracted. Extraction by jigging and concentration on the table is in the range of 8.7-10%. The objective of the invention is to increase the completeness and complexity of the use of refractory gold-bearing sulfide ores by involving in the processing of previously unused waste of sorption cyanidation.

The problem is solved by the fact that in the method of enrichment of refractory gold-bearing sulphide ores, including grinding ore concentrate with a size of up to 55% of the class - 0.020 mm to a size of 98-99% of the class - 0.020 mm and its sorption cyanidation, before grinding the ore of the specified size is conditioned and flotation, and the waste is conditioned with a sulphhydryl collector and a foaming agent, followed by the separation of non-ferrous metal sulfides containing finely disseminated gold into the foam product, and the sorption cyanidation waste is conditioned at a sodium cyanide concentration in the pulp from 0.04% to 0.23% [1-4].

Then we carried out flotation methods of concentration.

The basis of flotation enrichment, carried out, as a rule, in an aqueous medium, is based on the principle of imparting hydrophobic properties to the grains of the extracted component, due to which they are not wetted with water and are "pushed" to the interface between the liquid and gas phases, even if the density of these grains is many times higher than the density water.

Reagents-collectors (collectors), introduced into the suspension and fixed on the surface of the extracted particles, for example, sulfides, impart hydrophobicity to mineral grains. The process of separating the latter from the rest of the ore mass (flotation "tailings") is intensified by aerating the pulp with air, using special foaming agents and reagents that depress flotation of gangue minerals, and also by regulating the pH value, i.e. creating an acidic, alkaline or neutral pulp environment.

Owing to an extremely wide range of flotation reagents, the total amount of which is about 6-8 thousand, opportunities have been created for the concentration of virtually any minerals by flotation. On the same basis, the principles and methods of separation (selection) of various mineral mixtures to obtain individual products (concentrates) that meet market requirements and the conditions for their subsequent use or chemical and metallurgical processing have been developed. Flotation plays a rather important role in the beneficiation of gold ore raw materials. The greatest effect from the use of flotation is provided when extracting gold from ores with predominantly sulfide mineralization.

Flotation is rarely used for oxidized gold-bearing ores, since it does not provide satisfactory indicators of metal recovery into concentrates, being much inferior in this respect to the process of direct ore cyanidation. However, the use of flotation turns out to be very useful in the process of mineralogical research for the separation of fine grains of free gold from oxidized ores for their subsequent microscopic examination in order to establish the size and morphology of gold grains.

As a rule, the process of flotation of gold-bearing ores is carried out in a slightly alkaline medium (pH = 7-9). To create such an environment, soda or lime is used (the latter is used less often, because it has a weakly expressed depressing property in relation to gold-containing pyrite, and to some extent to native gold).

Ethyl or butyl xanthates are used as collectors (collectors), T-80 is usually used as a foaming agent. To activate pyrite, copper sulfate is fed to the pulp (during grinding).
Depression of gangue minerals, including clays, is produced by silicate and (less often) sodium sulfide. The latter is also used for sulfiding the surface of particles of oxidized minerals (malachite, azurite, cerussite, anglesite, smithsonite, etc.) in order to impart flotation activity to them.

Flotation has become an extremely diversified process in terms of the reagents and equipment used, which makes it possible to use it much more widely than before, including in poor and complex ores. Due to flotation, it is possible to increase gold recovery and ensure an acceptable profitability of field development. At the same time, the multivariance of the process requires versatile and thorough laboratory and technological research of ores, as well as a great deal of experience and knowledge to find exactly the option that will provide the best effect for specific conditions [1-4].

Further, by the method of planning the experiment (the Box-Wilson method) the optimal flotation mode was determined.

The flotation regime for gravity tailings was adopted based on the results of steep ascent experiments:
- coarseness of grinding ore - 70% class - 0.074 mm;
- consumption of butyl xanthate - 150 g / t;
- consumption of foaming agent T-80 - 70 g / t;
- consumption of copper sulphate - 150 g / t;
- consumption of soda - 125 g / t;
- the duration of the main flotation is 15 minutes;
- the duration of the control flotation is 25 minutes;
- duration of cleaning flotation - 5 min.

The selection of the optimal mode of flotation concentration for ore was carried out according to the method of the planned experiment (steep ascent) with variables: grinding size, consumption of butyl xanthate and T-66 and T-80 foaming agent, consumption of copper sulfate and soda. A fractional replica of a four and five factor experiment was implemented. According to the results of the experiments, it was found that it is not possible to obtain flotation tailings of the original ore with a gold content of less than 1.0 g / t with a grinding size of ore up to 80-85% of class less than 0.074 mm. The yield of the flotation concentrate depends on the consumption of the foaming agent and was 8-12%. Flotation is rarely used as the only technological process. Basically, these are enterprises processing complex ores, which, along with gold and silver, contain other non-ferrous metals (copper, lead, zinc, antimony) in concentrations and mineral forms that allow the possibility and economic feasibility of the associated extraction of these metals into marketable products.

The implementation of flotation in a special reagent mode makes it possible to extract copper, lead, zinc and antimony concentrates from gold-bearing ores, which are sent for further processing to specialized metallurgical plants. During flotation, a significant part of the precious metals present in the feedstock is also transferred to these concentrates. The possibilities of their subsequent extraction are determined by the technology of the main metallurgical production [5-6].

The main strategy of gold mining enterprises, carrying out complex processing of polymetallic ores, in addition to obtaining standard concentrates of non-ferrous metals during flotation, it is to ensure the maximum possible extraction of gold on site using other technological processes, in particular, gravity concentration and cyanidation. Most enterprises practice this kind of combined gravity-flotation-cyanide technology in the processing of complex ores.

Favorable objects for the use of flotation are technologically refractory ores, in which gold is closely associated with iron sulfides and cannot be recovered by cyanidation without the use of rather complex and expensive preparatory processes: oxidative roasting, autoclave or biochemical oxidation of sulfides.

Flotation allows not only to concentrate gold-containing sulfides (pyrite, arsenopyrite) in a small volume of concentrate sent for metallurgical processing, but also to separate these sulfides, for example, pyrite and arsenopyrite or pyrites of various generations, differing in gold content.
3. Results and discussion

Therefore, in order to increase gold recovery by flotation, it is necessary to study other options, for example, with finer grinding of ore or staged flotation. The following experiments were carried out in this direction: flotation of the initial ore and stage flotation. Flotation of the original ore with a finer grinding than it was accepted when setting up the planned experiments of 85% class 0.074 mm.

The results of the experiments are presented in table 1. In the experiments, the consumption of the T-80 foaming agent was increased to 110 g / t, the xanthogenate to 175 g / t, the flotation time was up to 25 minutes.

Table 1. Gold recovery according to the scheme of gravity concentration – flotation.

| Product                        | Exit, % | Gold content, g / t | Distribution, % |
|--------------------------------|---------|---------------------|-----------------|
| Extracted into gravity concentrate | 0.97    | 108                 | 11.10           |
| To flotation concentrate       | 11.15   | 71.4                | 79.93           |
| Total extraction               | 12.12   | -                   | 91.03           |
| Lost in flotation tailings     | 87.88   | 1.0                 | 8.97            |
| Ore                            | 100     | 9.6                 | 100.0           |

A feature of flotation as a method of gold recovery is the ability to extract gold into concentrate not only free, but also in close association with sulfides [6].

An important area of using the cyanide process is the processing of refractory ores. The technological advantages of cyanidation carried out using solutions with a very low concentration of cyanide (0.3-1 g / l and below) is, first of all, that it is produced in a slightly alkaline medium (pH = 9.5 ~ 11.5) at normal (‘room’) temperature and atmospheric pressure, which determines the high economic efficiency of the cyanidation of gold ores.

Obviously, the processing of the obtained flotation concentrate in order to extract gold from it is much easier and cheaper than the similar processing of the entire mass of ore. If we also take into account that a significant and sometimes most of the gold in the resulting concentrate belongs to the category of refractory and requires special expensive recovery methods, the need to reduce the amount of material subject to such processing becomes quite obvious.

In some cases, flotation beneficiation does not allow concentrating all gold in a gold-bearing concentrate. Nevertheless, in these cases, the use of flotation is expedient, since it allows transferring into concentrate the most refractory part of gold, which is not recovered by conventional cyanidation and gravity concentration methods. The resulting flotation concentrate is subjected to special processing, which is much cheaper than processing the entire mass of ore in this way. Gold from the flotation tailings is recovered by cyanidation.

A long-term not only industrial, but also a social problem in Kazakhstan is the decline in gold mining from placers, while the growth of metal production from ores of primary deposits is rather slow. One of the reasons for the current trend, corresponding to the global trend, is the increase in the structure of gold mineral resources of refractory ores, the processing of which under traditional conditions of cyanide leaching is characterized by insufficient gold recovery [7].

The share of domestic ores containing refractory gold is very significant and currently reaches 30%. The reasons for the low openability of refractory gold-bearing raw materials, first of all, are the fine dispersion of gold in sulfide minerals, most often in pyrite and arsenopyrite, and the presence in some of the ores of “active” carbon “that sorbs gold at the cyanidation stage (this phenomenon is called” preg -robbing ”) [4, 9].

The results of the experiments on ore cyanidation are presented in tables 2 and 3 and show the following. A stable gold content in the sorption tailings of -0.8 gt is achieved in 12 hours of enrichment agitation -0.7 g / t, after 10 hours of mixing with the sorbent. Cyanide consumption was 0.15 kg / t as for ore. The size of grinding of ore material in all experiments was 85% of the class less
than 0.074 mm. Gold recovery in ore solution was 78.95%, for gravity tailings 70.83, from operation. Cyanide consumption did not exceed 0.15 kg / t of product.

**Table 2.** Influence of the duration of agitation on the extraction of gold by cyanidation from the original ore.

| Indicators                        | № of experiments |
|-----------------------------------|------------------|
| Weight, g                         | 300              |
| Grinding size by class -0.074 mm   | 80               |
| Duration of campaigning, hour     | 2                |
| Cyanide concentration, % Initial   | 0.07             |
| The ultimate Cyanide              | 0.065            |
| consumption, kg / t               | 0.075            |
| Lime consumption, kg / t          | 1.0              |
| Pulp density, % solid             | 40               |
| Gold content, g / t               | 9.6              |
| In the original product           | 72.92            |
| In cyanidation tails              | 80.81            |
| Gold recovery, %                  | 72.92            |

**Table 3.** Influence of the duration of agitation on the extraction of gold by cyanidation from the original ore.

| Indicators                        | № of experiments |
|-----------------------------------|------------------|
| Weight, g                         | 300              |
| Grinding size by class -0.074 mm   | 47.              |
| Duration of campaigning, hour     | 24               |
| Cyanide concentration, % Initial   | 0.065            |
| The ultimate Cyanide              | 0.05             |
| consumption, kg / t               | 0.225            |
| Lime consumption, kg / t          | 1.0              |
| Pulp density, % solid             | 40               |
| Gold content, g / t               | 83.              |
| In the original product           | 9.6              |
| In cyanidation tails              | 6.1              |
| Gold recovery, %                  | 1.6              |

**Table 4.** Influence of grinding size on gold recovery by cyanidation.

| Conditions and results            | № of experiments |
|-----------------------------------|------------------|
| Grinding size by class finer than 0.074 m | 55.4             |
|                                  | 65.6             |
|                                  | 74.74            |
|                                  | 82.26            |
|                                  | 90.4             |
|                                  | 97.8             |
The most studied and widely used industrial method of preparing gold sulphide ores for cyanide opening is oxidative roasting. The mode and stages of firing are determined taking into account their specific chemical and phase composition of the feedstock.

For roasting gold-bearing ores and concentrates, multi-hearth furnaces, fluidized bed furnaces, and circulating fluidized bed furnaces are used. During the roasting process, the iron contained in the sulfides is converted to hematite, and sulfur and arsenic pass into the gas phase in the form of arsenic trioxide and sulfur dioxide. From the obtained cinder, which is a porous mass of iron oxide well permeable to solutions, gold is easily extracted by cyanidation.

The roasting method is quite simple, well mastered and is still used in Canada, South Africa, Australia and other countries. The main amount of arsenic is converted into low-toxic compounds for storage in tailings. The gases contain enough sulfur dioxide to produce sulfuric acid; can also be vented or treated with alkali to form calcium sulfate.

Roasting allows you to remove natural coal (which has a "pre-robbing" effect) contained in the fuel due to its oxidation (combustion). However, there are examples where roasting promotes activation of previously inactive carbon (for example, adding coal to increase the temperature in the roasting furnace). Roasting is an economical way to process refractory gold ores, but its efficiency is reduced when tight control of SO2 and As2O3 emissions is required.

Oxidative roasting of the concentrate at temperatures of 600C, 700C and double oxidative roasting reduces the gold content in the cyanidation tailings of cinders to 3.2-3.6 g / t.

Finely dispersed gold, which is in close association with pyrite and arsenopyrite, is practically not recovered by traditional cyanidation. For this reason, a number of gold-extracting factories in the CIS countries and abroad are firing the obtained after enrichment.

One of the important problems in the processing of refractory ores is the removal of arsenic contained in them in forms that are relatively harmless and suitable for storage and disposal. The processing of refractory ores to increase the recovery on cyanidation involves preliminary processing [8-9]. The traditional method of extracting gold from refractory ores is flotation beneficiation, roasting, and subsequent cyanidation of the cinder [3-11].

Since the end of the 1980s, hydrometallurgical technologies have been introduced, including autoclave and bacterial opening of ores and concentrates in an acidic medium, followed by cyanidation of solid residues [7-10]. On a smaller scale, the processes Albion, Leachox, Nitrox, Arseno, etc. are used. Various types of hydrochlorination are among the promising methods of processing refractory gold-bearing raw materials [5-11].

| Table 5. Results of experiments on cyanidation of flotation concentrate and cinders from oxidative roasting. |
|---------------------------------------------------------------|
| Indicators and results | № of experiments | 1 | 2 | 3 | 4 |
| Cyanidation material | cinder | cinder | cinder | concentrate |
| Firing temperature, °C | 600 | 700 | 500+700 | - |
| Cinder yield, %         | 72.95 | 73.0 | 73.0 | -    |
|------------------------|-------|------|------|------|
| Grinding size, % class-0.056mm | -     | -    | -    | 100  |
|                        | 48    | 48   | 48   | 48   |
| Cyanidation duration, hour |       |      |      |      |
| Pulp density, %         | 33    | 33   | 33   | 33   |
| Cyanide concentration, %| 0.08  | 0.08 | 0.08 | 0.08 |
|                        | 0.035 | 0.04 | 0.045| 0.025|
| Cyanide consumption, kg / t | 0.9   | 0.8  | 0.7  | 1.1  |
| Gold content, g / t     |       |      |      |      |
| In flotation concentrate | 77.8  | 77.8 | 77.8 | 77.8 |
| In cinders              | 106.6 | 106.6| 106.6| 106.6|
| In cyanidation tails    | 3.6   | 3.2  | 3.3  | 9.5  |
| Gold recovery, %        | 96.62 | 97.0 | 96.9 | 87.79|

**Table 6.** Influence of the duration of cyanidation of ore gravity tailings on gold recovery by sorption cyanidation.

| Indicators and results | № of experiments |
|------------------------|------------------|
|                        | 1    | 2    | 3    | 4    | 5    | 6    | 7    |
| Grinding size by class finer than 0.074 mm | 85   | 85   | 85   | 85   | 85   | 85   | 85   |
| Duration of campaigning, hour | 2    | 4    | 6    | 8    | 10   | 12   | 15   |
| Pulp density, %         | 40   | 40   | 40   | 40   | 40   | 40   | 40   |
| Cyanide concentration, %|      |      |      |      |      |      |      |
| Initial                 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |
| The ultimate            | 0.035| 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.035|
| Cyanide consumption, kg / t | 0.075| 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.075|
| Lime consumption, kg / t | 1.0  | 1.0  | 1.0  | 1.0  | 1.0  | 1.0  | 1.0  |
| Resin dosage in experiment | 1.5  | 1.5  | 1.5  | 1.5  | 1.5  | 1.5  | 1.5  |
| Gold content, g / t     |      |      |      |      |      |      |      |
| in the original product | 2.4  | 2.4  | 2.4  | 2.4  | 2.4  | 2.4  | 2.4  |
| in sorption tailings     | 1.0  | 0.85 | 0.75 | 0.75 | 0.7  | 0.7  | 0.7  |
| residual in solution    | 0.30 | 0.15 | 0.05 | -    | -    | -    | -    |
| Gold recovery, %        |      |      |      |      |      |      |      |
| into the solution from the operation, % | 58.33| 64.58| 68.75| 68.75| 70.83| 70.83| 70.83|
| from solution to resin, % | 64.64| 85.48| 95.45| 100  | 100  | 100  | 100  |

**Table 7.** Influence of the size of the grinding of gravity tailings enrichment of the experience on gold recovery by cyanide.

| Conditions and results | № of experiments |
|------------------------|------------------|
|                        | 8         | 9         | 10        | 11        | 12        | 13        |
| Grinding size by class finer than 0.074 mm | 55.4 | 65.6 | 74.74 | 82.26 | 90.4 | 97.8 |
| Duration of campaigning, hour | 12    | 12    | 12    | 12    | 12    | 12    |
| Pulp density, %         | 40    | 40    | 40    | 40    | 40    | 40    |
| Cyanide concentration, %|      |      |      |      |      |      |
| Initial                 | 0.06  | 0.06  | 0.06  | 0.06  | 0.06  | 0.06  |
| The ultimate            | 0.05  | 0.05  | 0.05  | 0.05  | 0.05  | 0.05  |
| Cyanide consumption, kg / t | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |
| Lime consumption, kg / t | 1.0   | 1.0   | 1.0   | 1.0   | 1.0   | 1.0   |
| sorbent, g              | 1.5   | 1.5   | 1.5   | 1.5   | 1.5   | 1.5   |
| Gold content, g / t     |      |      |      |      |      |      |
4. Conclusion
It was found that the main processes of gold recovery are cyanidation and flotation. Gravity enrichment plays a secondary role, allowing the gravity concentrate to be separated out part of the refractory associated gold and to reduce its content both in cyanidation tailings (0.6 g / t) and in flotation tailings (0.43-0.42 g / t).

Determined by the method of "steep ascent" (Box-Wilson) regression equations (PFE and TEU), describing the relationship of the main factors affecting the flotation process of gold-bearing ores. Using these equations, the conditions for optimizing flotation are determined.

By flotation of raw ore, tailings with a gold grade of 0.8 g / t were obtained. By flotation of gravity tailings with preliminary separation of 6-7% of gravity concentrate by jigging, a decrease in gold content in flotation tailings to 0.42 g / t was achieved.

The optimal operating parameters of cyanidation and flotation for gravity tailings have been determined.

For cyanidation:

- crushing size up to 97% in class finer than 0.074 mm;
- duration of sorption cyanidation 12 hours.

For flotation:

- flotation circuit - staged;
- the size of grinding in the 1st stage is 65%, in the 2nd stage it is 80% in the finer class 0.074 mm; in the 3rd stage 78% in the class finer than 50 micrometers.
- Consumption of reagents: butyl xanthate 175 g / t, foaming agent T-80-144 g / t.
- It is recommended to carry out flotation without using cleaning operations, maintaining the total yield of flotation concentrates at the level of 14-15%.

To extract gold by cyanidation and gravity and flotation concentrates, their regrinding is required. Under laboratory conditions, the gravity concentrate was regrind to 85.2% of the class finer than 30 micrometers, and the flotation concentrate to 94.75% in the same class. For the gravity concentrate,
the gold content in the sorption tailings was 1.9 g / t, for the flotation concentrate — 0.65 g / t. Cyanide consumption was 1.95 and 1.5 kg / t of product, respectively.

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