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PROSPECTS FOR THE DEVELOPMENT OF THE PROCESS OF INTENSIVE CYANIDATION OF GOLD-CONTAINING PRODUCTS IN THE REPUBLIC OF KAZAKHSTAN

Abstract. Data on the raw materials base of the gold mining industry of Kazakhstan, as well as the role of Kazakhstan in gold mining in the world and CIS countries are given. The history and development of the process of intensive cyanidation of gold-containing products in world practice is shown. The prospects of using this method in the Republic of Kazakhstan are shown. Technological schemes of intensive cyanidation are given depending on the material composition of the raw materials.
Key words: intensive cyanidation, gravity concentration, centrifugal concentrator, Acacia, ILRGekko, cyanidation, gold production.

In recent years, there has been a significant increase in the production of precious metals, particularly gold. This is due to the fact that gold is the main banking metal and is a currency reserve of many countries. This issue is especially topical because of the instability of the convertible world currencies, the fall in prices for securities and the consequences of the global financial crisis.

Gold in nature is found mainly in the native state, mainly in the form of small grains interspersed in quartz or contained in quartz sand. In small quantities, gold is found in sulphide ores of iron, lead and copper. Throughout history, mankind produced about 161 thousand tons of gold (estimate for 2011). If you fuse all this gold together, you get a cube with a side of about 20 m [1, 2].

Currently, 50% of gold is used in jewelry, 40% is used as an investment and the remaining 10% is used in industry [3].

The world gold production in 2015, according to Metals Focus, was 3211 tons [4]. The largest countries producing gold are listed in Table 1 and Figure 1.

Table 1 – Twenty leading gold mining countries [4]

Place	Country	Extraction, t	
		2014	2015
1	2	3	4
1	China	462,0	460,3
2	Australia	274,0	273,8
3	Russia	264,7	268,5
4	United States	210,0	214,0
5	Peru	171,1	170,5
6	South Africa	168,6	167,5
7	Canada	151,2	157,2

1	2	3	4
8	Mexico	112,7	133,2
9	Indonesia	93,8	113,0
10	Brazil	91,6	95,0
11	Ghana	106,3	94,7
12	Uzbekistan	83,5	85,5
13	Kazakhstan	49,2	63,7
14	Argentina	60,0	63,5
15	Papua New Guinea	60,7	58,4
16	Tanzania	50,8	51,7
17	Mali	52,8	50,1
18	Colombia	47,0	44,0
19	Philippines	40,4	41,1
20	Chile	44,5	41,1
	Others	558,1	564,4
	Global Total	3153	3211

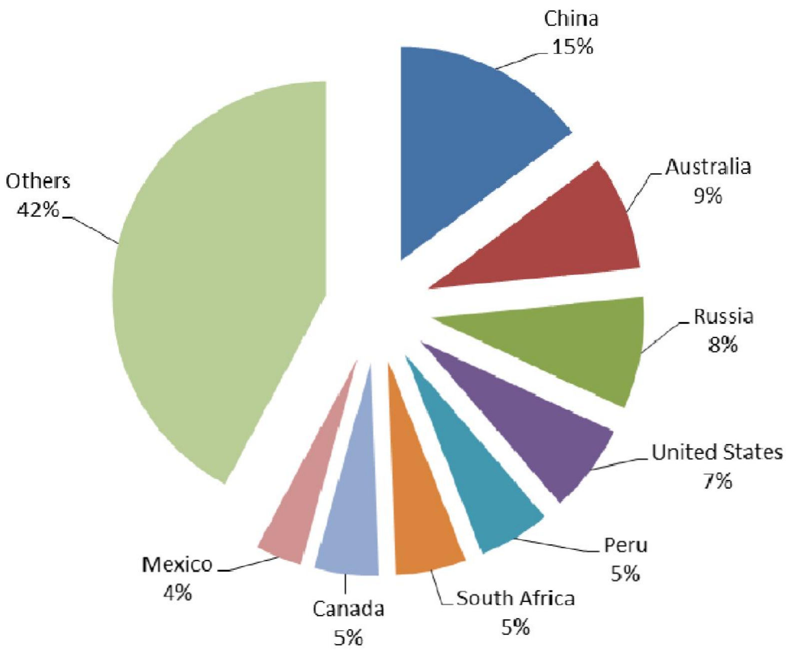

Figure 1 – The largest gold producers in 2015

In 2014 Kazakhstan occupied the sixteenth place in the production of gold (49.2 tons), and in 2015, it took the thirteenth line, increasing gold production by 29% (63.7 tons) [4].

Table 2 shows gold production in the CIS countries in the periods from 2010 to 2015.

Table 2 – Gold mining in the CIS countries [4]

Country	Extraction, t					
	2010	2011	2012	2013	2014	2015
Russia	203,1	211,6	229,3	248,5	264,7	268,5
Uzbekistan	71,0	70,6	80,0	81,0	83,5	85,5
Kazakhstan	30,3	36,8	40,0	42,4	49,2	63,7
Kyrgyzstan	19,0	19,7	11,4	20,2	19,3	18,7
Other	5,7	5,9	5,9	7,1	7,2	8,8
Total	329,0	344,7	366,6	399,2	423,9	445,3

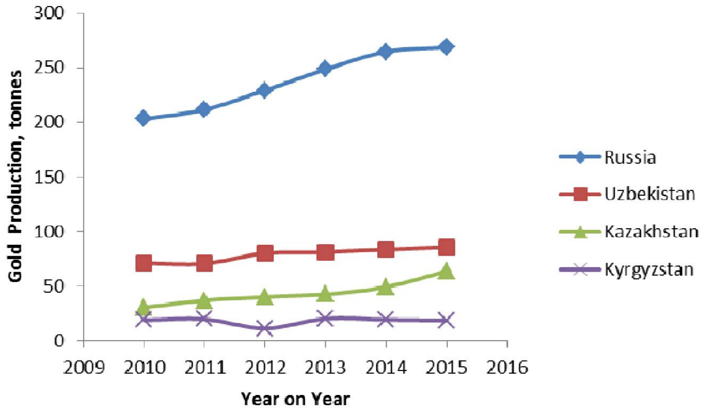

Figure 2 – Graph of gold production in the CIS countries

As can be seen from Figure 2, Kazakhstan is the third largest gold producer among the CIS countries after Russia and Uzbekistan. And recently, the growth of gold production in Kazakhstan continues. The country's resources are estimated at 1.8 thousand tons, gold reserves are ~ 800 tons (according to 2009 data) [5].

Gold ore deposits have been identified in all regions of the republic, East (about 52.2%), North and Central Kazakhstan (30%) occupy the leading positions in terms of reserves, where 16 mining regions are located. The most important of them are: in the east - Kalbinsky and Rudno-Altaisky, in the north - Kokshetausky and Zhetigarinsky, in the south - Shu-Iliysky and Dzungarsky, in the west - Mugodzharsky, in the central part - Maikainsly and North Balkhash.

The raw material base of the gold mining industry in Kazakhstan is represented mainly by small (with reserves of up to 25 tons) and medium (from 25 to 100 tons) deposits. According to some sources, there are 122 indigenous gold ore deposits, 81 integrated and 34 placer mines [6, 7].

Gold ore deposits in Kazakhstan are characterized by low metal content in the ore, as well as the presence of a significant proportion of refractory ore. At the same time, the comparatively favorable mining technical conditions of extraction make it possible to keep its production costs at the level of the world average.

Easy enriched and oxidized ores, which are the main resource of gold mining companies, are already running low and half of all gold reserves are concentrated in the 8 largest complex fields –Bakyrchik, Vasilkovskoye, Mizek, Suzdalskoe, Bolshevik, Akbakay, Bestobe and Zholymbet. In them, gold-bearing ores are generally classified as stubborn [6].

Currently, licenses are issued for about half of the number of deposits, of which about 30 are in service. Some industrial enterprises extract gold as a by-product in the processing of polymetallic ores. The "KAZ Minerals" company (formerly Kazakhmys), the leading copper producer in the country, also simultaneously extracts gold from the ore. In 2012, gold production amounted to 3.6 tons (with a content of 0.66 g/t), in 2013 - 3.2 tons (at a content of 0.61 g/t) [8, 9].

The largest gold mining facility in Kazakhstan is the Vasilkovskoye deposit, located 17 km north-west of Kokshetau. The proven reserves of deposits amount to 370 tons of gold, with an average ore grade of 2.8 g/t. The deposit has been under development since 1979. Since 1991, at the Vasilkovskoe Ore Mining and Processing Enterprise, the processing of oxidized ore was carried out by heap leaching. The capacity of the heap leach plant was 1 million tons of ore per year with an average annual production of 600 to 900 kg of gold. In 2007, the deposit began construction of a large gold recovery plant with modern ore processing technology. At full design capacity, the mine should produce 15 tons of gold per year. Capital investments amounted to about 700 million dollars. The factory was built in two years. In 2010, at the suggestion of the Head of state VasilkovskyGOK was renamed into the "AltyntauKokshetau" company [8, 10].

The second place is occupied by the Bakyrchik deposit located in the northeast of Kazakhstan (about 100 km from Semipalatinsk) [11]. In the second largest gold deposit of Kazakhstan, gold mining is still not conducted due to the high persistence of the ore, high content of arsenic and organic carbon in the ore. Plans for processing such ore by bioleaching have not been implemented, since this technology requires high costs [7, 12, 28].

The following in order of industrial importance can be noted the Aksu, Bestobe, Zholymbet. All of them are worked underground. The ores in the deposits are represented as quartz veined, and in the form of mineralized zones. The mines are located within a radius of 100 km from the central base, located in Stepnogorsk (Akmola region). The richest and easily accessible ores are worked out, in connection with this, in the period of low gold prices there was a decline in production. However, the significant gold reserves of these deposits are more than 100 tons, and the predicted reserves are 400 tons [8, 28].

Despite the fact that Kazakhstan's major and medium size fields are currently mostly exploited, the country has a significant number of small deposits that require additional exploration (Table 3).

Table 3 – Main gold deposits in Kazakhstan [6]

Location	Gold Deposits
North Kazakhstan	Vasilkovskoye, Varvarinskoye, Uzboi, Symbat, Komarovskoye, Elevatornoye, Akkarginskoye, Zhetygorinskoye
Central Kazakhstan	Aksu, Zholymbet, Bestobe, Maikain, Kvartsytovye Gorki, Ushoky, Yenbekshi, Pustynnoye
East Kazakhstan	Bakyrchik, Suzdalskoye, Sekosovskoye, Bolshevik, Vasiliyevskoye, Ridder-Sokolnoye, Zhanan, Akzhal, Kaskabulak
South Kazakhstan	Akbakai, Altyntas, Dalabai, Aksakal-Beskempir, Mynaral, Zharkulak, Karamurun, Arkharly, Kumysty
West Kazakhstan	Yubelienoye

Therefore, the development of technology for the effective enrichment of gold-containing raw materials and the development of research in this direction is timely and important.

Methods of ore dressing consist of the ore pretreatment operation (crushing, screening, sorting, grinding) and methods of beneficiation of prepared ore (gravity, flotation, magnetic separation, etc.). Metallurgical methods for processing ores and concentrates include cyanidation (or other leaching techniques), amalgamation, roasting, sorption methods for extracting gold from pulps and solutions, extractive methods, hydrochlorination, autoclave oxidation [13].

It is known that the most common process of extracting gold from poor ores is cyanidation. This process is based on the selective leaching of gold or other noble metal by aqueous solutions of alkaline cyanides: sodium, potassium or calcium. The resulting solution containing dissolved gold is sent for processing by various methods to obtain a high-quality commodity product in the form of Dore gold in ingots. The resulting alloy is sent to the refinery to produce gold of the required purity [14].

In the practice of gold production for the extraction of large grains of free metal, gravity enrichment is used, which is the oldest method of processing mineral raw materials [15]. For a long period of time this method has undergone changes - from simple washing and separation of grains on the inclined plane to the use of centrifugal concentrators. The method of separation of mineral grains by density in gravity devices is simple and can enrich placer gold in remote areas without the existing infrastructure. In addition, this method does not require the use of chemical reagents and is characterized by low energy intensity [16, 17]. The need to allocate large gold, which is present in almost all ores, is determined by the following reasons [18-20]:

- the duration of dissolution of large particles during cyanidation is increased;
- large particles of gold will accumulate in grinding and classifying equipment;
- particles of large gold in the grinding cycle (mill-classifier) are overwritten.

To prevent the accumulation of gold in the classifier and overwriting in the mill, free gold is continuously withdrawn from the circulating load by the gravitational enrichment method.

New technological schemes for the enrichment of gold-containing products, which include gravity on centrifugal concentrators, allow to obtain concentrates rich in gold content (>100 g/t) with a relatively small yield.

Hydrometallurgical processing of rough gravity concentrates is carried out by cyanidation. The essence of the method lies in the leaching (dissolution) of gold using solutions of cyanide salts in the presence of an oxidizer (oxygen). Factors that affect the cyanidation process can be conditionally divided into two groups: depending on the material composition (gold size, gold form, gold surface and presence of impurities) and technological ones that can be controlled - mixing, temperature, pressure, pH value, viscosity of pulps [21].

Hydrometallurgical processing of these concentrates by traditional methods of cyanidation is difficult due to the lack of equipment of low productivity and significant losses of metal with a cake.

Until recently, the only acceptable method of processing them was considered deep debugging (cleaning), followed by melting the resulting "gold heads" on metal ingots. However, special devices have now been created that permit the leaching of large grains of metallic gold by cyanide solutions.

Since the early 1990s, the introduction of centrifugal concentrators (Knelson, Falcon, etc.) in many plants has significantly increased the extraction of gold into gravity concentrates (by 1-3%), including the processing of ores with a high sulfide content [22-25]. However, standard methods for processing gravity concentrates allow gold recovery at a level of no more than 70% [26]. To solve this problem, intensive cyanidation plants have been tested, which make it possible to achieve a high extraction of gold from gravity concentrates for an acceptable time for the general technological cycle (6-24 h).

In the process of intensive cyanidation, solutions with a higher concentration of cyanide, protective alkali with the addition of soluble compounds of lead (II) and an oxidizer are used.

For the first time in the world, the intensive cyanidation method for the processing of gravity concentrates was applied at the South Africa plant (Western-Holdings) in 1977 and then at the gold-processing plant in East-Gold in 1980. As leach reactors, column type plants with mechanical mixing, equipped with a circulator or revolving arms, were used [27, 28].

But, until recently, interest in the intensive cyanidation process has faded, due to a number of reasons. Firstly, the largest corporations did not consider the gravitational enrichment as a strategic direction for the development of technology for processing South African gold-containing ores. Secondly, the use of agitators with mechanical mixing caused technical problems associated with the rapid deterioration of equipment. Thirdly, there were no opportunities to automate the process, which created the prerequisites for the organization of gold theft [22].

The renewed interest in the process of intensive cyanidation occurred relatively recently in connection with the use of reactors and new type installations. Thus, the Acacia intensive cyanidation reactor was developed by AngloGoldAustralia for the Union-Reef plant (South Africa) in 1999 [25]. In mid-2003, these reactors were used in 27 plants of leading foreign gold mining companies: in Australia – 11; in Zimbabwe – 5;in Canada – 3;inSouth Africa, Papua New Guinea and Mongolia –by 1; in Russia – 5 [29].

Acacia is a complex compact installation, the core of which is a cone-shaped reactor with a suspended layer of concentrate due to the upward flow of the solution. Due to the high concentration of reagents in the solution (2-3% NaCN, 0.2-0.35% NaOH, 0.1-1.0% Leach - accelerator), intensive cyanidation leads to the dissolution of gold both free and rising into the crystal lattice of sulfide minerals. This makes it possible to reduce the number of pieces of equipment in the subsequent processing stages, to reduce the gold content in the tailings, and also to increase the overall gold recovery by 1.0-1.5% [30, 31].

Leaching of gold by alkaline cyanide solutions in the presence of oxygen or air is a widely used process for extracting gold from mineral raw materials. The gold is oxidized and dissolved in the presence of cyanide to form the complex ion $[Au(CN)_2]^-$ according to the Bodlander (1) and (2) and Elsner (3) equations, the latter is the sum of equations (1) and (2)[32-35]:

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

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

$$4Au + 8CN^- + O_2 + 2H_2O \rightarrow 4Au(CN)_2^- + 4OH^-. \quad (3)$$

The behavior of gold during cyanidation depends on a number of factors, of which the main is the relationship of gold to ore and rock-forming minerals. Gold can be as in a free state, and in the form of splices with minerals. Any of these gold conditions can affect its under-extraction during dissolution and cause an increased consumption of reagents [36].

Excessive oxidation of sulphides during gold leaching can also lead to gold passivation due to the formation of gold surface coatings by oxidation products [35].

The presence of sulfides such as marcasite, pyrrhotite or chalcocite in cyanate pulp often inhibits the dissolution of gold, forming a protective film on the surface of gold [21].

To intensify the process of gold leaching, chemical additives are used. Chemical additives, depending on their nature, can be divided into inorganic and organic. Cyanidation accelerators under the trade names LeachAid, LeachWell and others are a mixture of organic and inorganic sodium salts (93-99%), lead nitrate (1-5%) and water (up to 5%). Made in the form of small granules of slightly yellow color, odorless LeachWell or with a weak smell of caramel LeachAid are stable up to a temperature of 300 ºC. The density of these reagents is 1 g/cm^3, the solubility in water is 35-40 g/dm^3[21, 31].

Under the conditions of standard cyanidation, the presence in the solution of the reagent-accelerator makes it possible to increase the dissolution rate of gold and the degree of its extraction from the gravitational concentrate and to shorten the leaching time [31].

In 1997, in Australia (GekkoSystems), an intensive cyanidation unit was developed – InLineLeachReactor (ILR), originally introduced at a number of African factories of AshantiGoldfields, and is currently used in more than 20 foreign factories [31, 37].

The ILR reactor is also a simple apparatus for intensive cyanidation of gravity concentrates. The ILR reacts according to the semi-submerged layer principle and represents a horizontally mounted drum rotating at a low speed, with a set of special partition walls and an aeration system for maximum leaching. In addition to the proven reactors for intensive cyanidation of Acacia and ILRGekko, there are other devices of different design and characteristics.

Many domestic gold mining companies, still using traditional technology of gold enrichment, begin to show interest in the process of intensive cyanidation. Thus, the Acacia (Knelson/ConSep) intensive cyanidation reactors are installed and operate at the fields Pustynnoe and Akbakay for the enrichment of gold-bearing concentrates [38].

Intensive cyanidation, depending on the material composition, can be used in a variety of technological schemes. Figure 3 shows a flow chart of intensive cyanidation for the processing of easily cyanidized raw materials. According to the presented technology, concentrates after gravity concentration are sent to the intensive cyanidation process, in which, productive solutions are processed by electrolysis methods. Thecakeissenttothetailingdump.

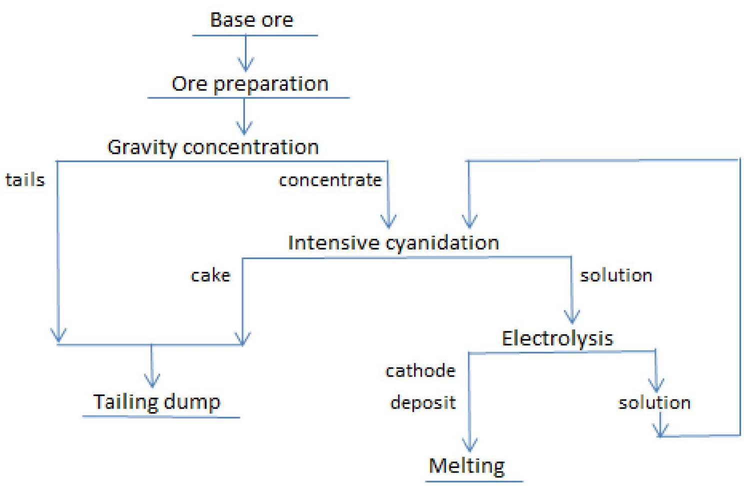

Figure 3 – Technological scheme of intensive cyanidation for the processing of easily cyanidized raw materials

For oxidized ores with a small content of sulphides, a process scheme is used in which the cake after intensive cyanidation is returned to the process for complete gold recovery (Figure 4).

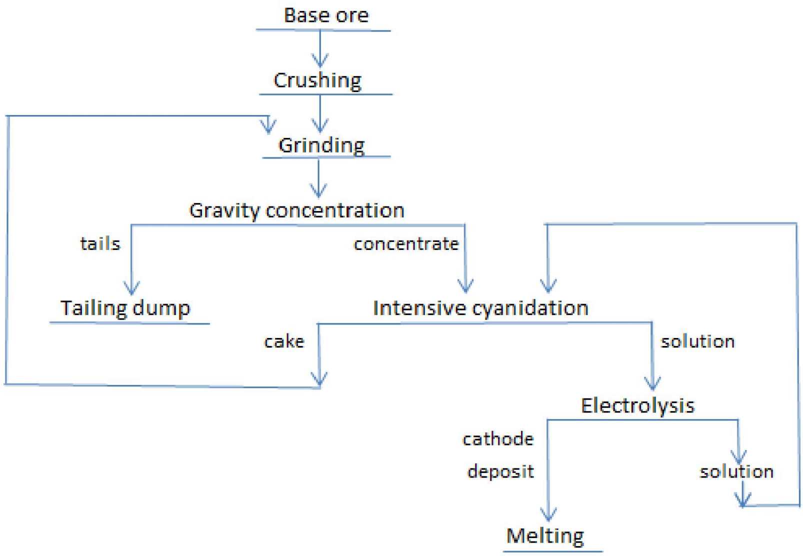

Figure 4 – Technological scheme of intensive cyanidation for oxidized ores

In the scheme for processing sulphide ores, the cake after intensive cyanidation is directed to sorption leaching (Figure 5).

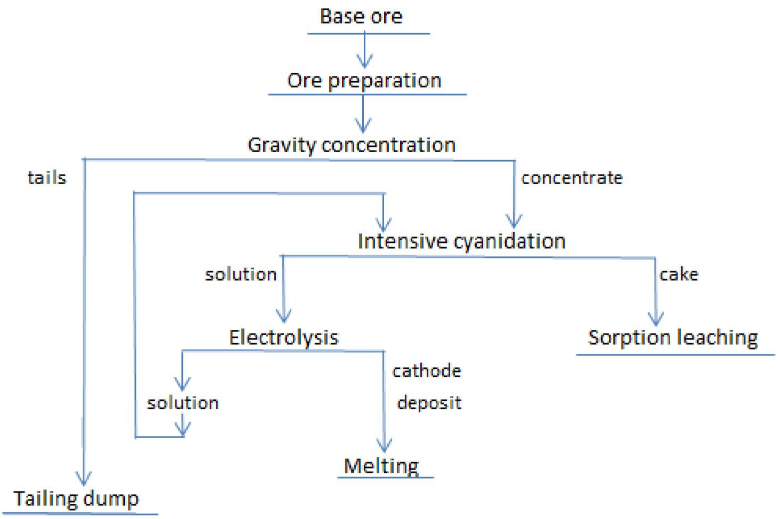

Figure 5 – Technological scheme of intensive cyanidation for sulphide ores

The use of the intensive cyanidation process allows to increase the processing of gold-containing ores by introducing more branched technological schemes.

The data presented in the review show that intensive cyanidation represents a prospect for the processing of gold-containing materials, because it shortens the duration of the cyanidation process and reduces the loss of gold, thereby achieving a high recovery of gold from the gravity concentrate into the solution.

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ПЕРСПЕКТИВЫ РАЗВИТИЯ ПРОЦЕССА ИНТЕНСИВНОГО ЦИАНИРОВАНИЯ ЗОЛОТОСОДЕРЖАЩИХ ПРОДУКТОВ В РЕСПУБЛИКЕ КАЗАХСТАН

Аннотация. Приведены данные по сырьевой базе золотодобывающей промышленности Казахстана, а также роль Казахстана по добыче золота в мире и странах СНГ. Показана история и развитие процесса интенсивного цианирования золотосодержащих продуктов в мировой практике. Показана перспективность использования данного метода в Республике Казахстан. Даны технологические схемы интенсивного цианирования в зависимости от вещественного состава сырья.

Ключевые слова: интенсивное цианирование, гравитационное обогащение, центробежный концентратор, Акация, Гекко, цианирование, добыча золота.

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ҚАЗАҚСТАН РЕСПУБЛИКАСЫНДАҒЫ АЛТЫНҚҰРАМДЫ ӨНІМДЕРДІ ҚАРҚЫНДЫ ЦИАНИРЛЕУ ҮРДІСІНІҢ ДАМУЫНЫҢ БОЛАШАҒЫ

Аннотация. Мақалада Қазақстанда алтын өндіру өнеркәсіп шикізат негізінің көрсеткіштері, сонымен қатар әлемдегі және ТМД елдері арасындағы алтын өндірісі бойынша Қазақстанның рөлі көрсетілген. Әлемдік тәжірибедегі алтынқұрамды өнімдердің қарқынды цианирлеу процесінің тарихы және дамуы көрсетілген. Аталған әдістің Қазақстан Республикасындағы қолдану болашағы көрсетілген. Шикізаттың заттай құрамына тәуелді қарқынды цианирлеу үрдісінің технологиялық схемалары сипатталған.

Түйін сөздер: қарқынды цианирлеу, гравитациялық байыту, ортадан тепкіш концентратор, Акация, Гекко, цианирлеу, алтын өндірісі.

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