ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ
Satbayev University

# ХАБАРЛАРЫ

# ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН
Satbayev University

# N E W S

OF THE ACADEMY OF SCIENCES
OF THE REPUBLIC OF KAZAKHSTAN
Satbayev University

## SERIES
## OF GEOLOGY AND TECHNICAL SCIENCES

**1 (451)**

**JANUARY – FEBRUARY 2022**

THE JOURNAL WAS FOUNDED IN 1940

PUBLISHED 6 TIMES A YEAR

ALMATY, NAS RK

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**«ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы».**
**ISSN 2518-170X (Online),**
**ISSN 2224-5278 (Print)**
Меншіктеуші: «Қазақстан Республикасының Ұлттық ғылым академиясы» РҚБ (Алматы қ.).
Қазақстан Республикасының Ақпарат және қоғамдық даму министрлігінің Ақпарат комитетінде 29.07.2020 ж. берілген **№ KZ39VPY00025420** мерзімдік басылым тіркеуіне қойылу туралы куәлік.
Тақырыптық бағыты: *геология, мұнай және газды өңдеудің химиялық технологиялары, мұнай химиясы, металдарды алу және олардың қосындыларының технологиясы.*
Мерзімділігі: жылына 6 рет.
Тиражы: 300 дана.
Редакцияның мекен-жайы: 050010, Алматы қ., Шевченко көш., 28, 219 бөл., тел.: 272-13-19
http://www.geolog-technical.kz/index.php/en/



Типографияның мекен-жайы: «Аруна» ЖК, Алматы қ., Мұратбаев көш., 75.

**«Известия НАН РК. Серия геологии и технических наук».**
**ISSN 2518-170X (Online),**
**ISSN 2224-5278 (Print)**
Собственник: Республиканское общественное объединение «Национальная академия наук Республики Казахстан» (г. Алматы).
Свидетельство о постановке на учет периодического печатного издания в Комитете информации Министерства информации и общественного развития Республики Казахстан **№ KZ39VPY00025420,** выданное 29.07.2020 г.
Тематическая направленность: *геология, химические технологии переработки нефти и газа, нефтехимия, технологии извлечения металлов и их соеденений.*
Периодичность: 6 раз в год.
Тираж: 300 экземпляров.
Адрес редакции: 050010, г. Алматы, ул. Шевченко, 28, оф. 219, тел.: 272-13-19
http://www.geolog-technical.kz/index.php/en/



Адрес типографии: ИП «Аруна», г. Алматы, ул. Муратбаева, 75.

**News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences.**
**ISSN 2518-170X (Online),**
**ISSN 2224-5278 (Print)**
Owner: RPA «National Academy of Sciences of the Republic of Kazakhstan» (Almaty).
The certificate of registration of a periodical printed publication in the Committee of information of the Ministry of Information and Social Development of the Republic of Kazakhstan **No. KZ39VPY00025420,** issued 29.07.2020.
Thematic scope: *geology, chemical technologies for oil and gas processing, petrochemistry, technologies for extracting metals and their connections.*
Periodicity: 6 times a year.
Circulation: 300 copies.
Editorial address: 28, Shevchenko str., of. 219, Almaty, 050010, tel. 272-13-19
http://www.geolog-technical.kz/index.php/en/



Address of printing house: ST «Aruna», 75, Muratbayev str, Almaty.

**NEWS**
OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN
**SERIES OF GEOLOGY AND TECHNICAL SCIENCES**
**ISSN 2224-5278**
Volume 1, Number 451 (2022), 69-75 ***https://doi.org/10.32014/2022.2518-170X.142***

**UDC 669.334.3**
**IRSTI 53.37.13**

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# STUDY OF THE FINELY-DISPERSED GOLD RECOVERY PARAMETERS

**Abstract**. This paper provides a study of the parameters of fine gold extraction, using dispersant on a column flotation machine. One of the important problems of gold mining industry is the involvement in the processing of refractory hard-to-enrich gold raw materials, as well as the tailings, which occupy huge areas and worsen the environmental situation. Flotation column machines, which are widespread in the enrichment practice, along with the traditional mechanical and pneumomechanical machines, can radically increase the manageability of the process due to the principle of all sub-processes, which require significantly different hydrodynamic conditions, running in the same volume of the unit. The scientific novelty lies in the use of the cavitation system based on the universal Rayleigh-Plesset (RP) cavitation bubble dynamics equation. As basic reagents were used collector - xanthogenate butyl, foaming agent - T-92, Flotation was carried out on tap water at pH - 7.0. Air pressure in dispersion systems was from 2 to 10 atm. The results of the experiments showed that the most optimal parameter of the pressure generator in terms of pressure fed into the dispersion system, is the figure of 6.0 atm. At pressure of 6,0 atm in dispersal system of the pressure generator the mass yield of a concentrate has reached 9,0% and at the gold content in it 8,12 g/t the recovery has increased to 87,0%. Further pressure increase contributes to intensive transfer of waste rock to the concentrates, which markedly increases the mass yield, but at the same time decreases the gold content in the concentrates. At 6.0 atm, the optimum balance of mass yield and noble metal content in the concentrate is achieved.

**Keywords:** dispersant, finely-dispersed gold, column flotation machine, concentrate, tailings.

**Introduction.** At present, the development of the mineral resource base of Kazakhstan is increasingly associated with the use of refractory finely dispersed mineral raw materials. Increase of the beneficiation product recovery and quality without increase in processing costs remain the most important problems in separation technology.

Since flotation is one of the main methods for beneficiation of finely dispersed mineral raw materials, the development and implementation of highly efficient flotation processes and apparatuses that ensure high selectivity in the separation of minerals without reduction of the recovery of a valuable component is of great practical importance.

At present, the methods of mechanical and pneumomechanical flotation are mainly used in chamber-type apparatuses that do not provide sufficient efficiency for the beneficiation of finely-dispersed components. This disadvantage is exacerbated by the desire to use larger machines with a capacity of up to 100–300 $m^3$ where the flow structure does not contribute to separation selectivity [1, 5].

Selectivity and completeness of recovery are achieved with a pneumatic countercurrent flotation column using finely dispersed bubbles to a greater extent, However, the use of such bubbles due to their entrainment from the device downstream does not enable to achieve a high specific productivity of these devices.

The main problem in increasing the efficiency of the flotation column is to create conditions for the simultaneous production of finely dispersed bubbles and achieve a high specific productivity of the apparatus, as well as a given process selectivity that is usually achieved by spraying the foam layer with water. Development of the pneumatic flotation column method, both in our country and abroad, mainly with the tasks to improve the methods and devices for pulp aeration, improve the hydrodynamic conditions for

the mineralization of bubbles and the separation of mineral components, as well as use various methods of physical impact on the process [6, 10].

One of the new and effective methods created based on physical impact on the flotation process that enables simultaneously achieving high recovery and selectivity of separation of finely dispersed components with an increased specific productivity of the apparatus, is the method developed at "IMB" JSC by a flotation column in a unit with an air aerator [11]-[17].

**Methods and materials.** Modern research and analytical equipment was used during the study: atomic emission spectrometer Optima 2000 DV (USA); X-ray diffractometer D8 ADVANCE; FT-IR Spectrometer Thermo Nicolet Avatar 370 FTIR Spectrometer; X-ray fluorescence spectrometer Venus 200 PA Nalyical BV (Holland) and mineralogical onoptical microscope Axio Scope A1. The following equipment was used during the study: ball mill MSHL - 22k (Russia);

The material composition of the original ore was studied, and the technological modes of their flotation were developed using a dispersant of air microbubbles on a column flotation machine. According to the results of chemical analysis, the industrially valuable component of gold and silver in the test sample is 0.86 and 4.71 g/t, respectively, zinc - 5.61%, lead - 0.29%. X-ray phase analysis was performed with a D8 ADVANCE diffractometer. The analysis results are presented in table 1

Table1 - X-ray phase analysis of the original sample composition

| Name | Formula | Content, % |
|---|---|---|
| Quartz | $SiO_2$ | 82.2 |
| Microcline | $KAlSi_3O_8$ | 15.1 |
| Kaolinite-1A | $Al_2Si_2O_5(OH)_4$ | 1.7 |

The main rock-forming mass of raw materials is represented by quartz (82.2%), as well as aluminosilicates of the microcline type (15.1%) and kaolinite (1.7%) under Table 1. Despite the absence of clear spectra of sulfide minerals, earlier X-ray fluorescence analysis recorded 0.63% sulfur in the sample that can enable to classify this raw material as low-sulfide. X-ray fluorescence analysis is presented in table 2.

Table 2 - Results of X-ray fluorescence analysis of the initial technological sample

| Element | Content, % | Element | Content, % |
|---|---|---|---|
| O | 50.706 | S | 0.63 |
| F | 0.138 | Cu | 0.2 |
| Na | 0.039 | K | 1.237 |
| Mg | 1.573 | Ca | 0.978 |
| Al | 4,860 | Ti | 0.215 |
| Si | 30.8 | Rb | 0.006 |
| P | 0.036 | Sr | 0.004 |
| Mn | 0.07 | Zn | 5.7 |
| Fe | 1.939 | Ba | 0.257 |
| Zr | 0.008 | Pb | 0.077 |

*Mineralogical study.* A mineralogical analysis of a concentrate sample with an initial fineness of 89% class 10 μm (-0.01 mm) was performed to find the gold forms. A polished section (∅ = 25 mm, m of the sample = 10-18 grams), formed from this material was studied under the Axio Scope.A1 optical microscope. As a result, 21 gold particles were found, of which:

• 12 particles in free form - 57.14%, Au dimension from 0.5 to 4.5 μm, i.e. ultrafine, finely dispersed gold (Figure 1, 2).

• 9 particles in intergrowths with waste rock - 42.86%, with parameters - Au from 0.4 to 6.1 μm (Figure 3).

The particle size is as follows: Au (0.4-6. μm), i.e. ultrafine (0.1-1.0 μm) and finely dispersed gold (1.0-10.0 μm) (under Petrovskaya's classification "Native gold").

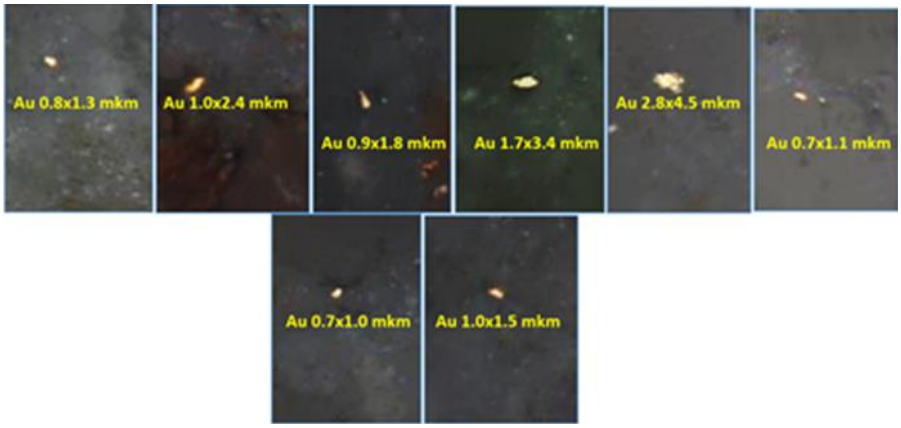


Figure 1. Free gold particles in polystyrene

The found gold particles in the free state, covered with oxidation films, possibly of goethite-limonite composition, are shown below in Fig. 2. Fig. 3 shows gold particles in host waste rock.

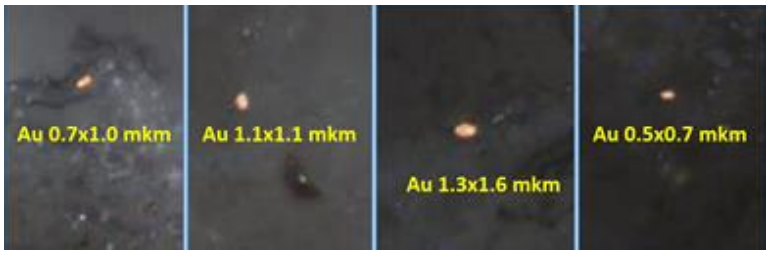


Figure 2. Free gold particles covered with oxidation films

*Characteristics of related components.* Ore components presented in order of their occurrence:

- sulfides: arsenopyrite - Ars (FeAsS), pyrite - Py ($FeS_2$), chalcopyrite - Cp ($CuFeS_2$) and less often bismuthine - $Bi_2S_3$ pyrrhotite - Pirr ($Fe_{1-x}S$);

- iron oxides: goethite - (HFeO2), hydrogoethite - (HFeO2Ч· Ag) - g/g, magnetite - Mgt ($Fe_3O_4$), hematite - Hm ($Fe_2O_3$).

Besides, aggregates of titanomagnetite (Ti-Mgt) with different compositions were found, their decay structures have *ulvospinel* - $TiFe_2O_4$($Fe_2TiO_4$) in the form of the thinnest drop-shaped or dash-dotted inclusions. *Leucoxene* ($TiO_2$·$nH_2O$) develops after titanomagnetite in the form of crusty and penetrating veinlet pseudomorphs.

In turn, there are corroded particles of metal scrap *Fe* (percentage ratio - *7.6%* of the total number of the studied grains, excluding waste rock particles), giving nearby minerals a burgundy-cherry hue of different saturation and, possibly, also being the cause of cover formations on gold particles.

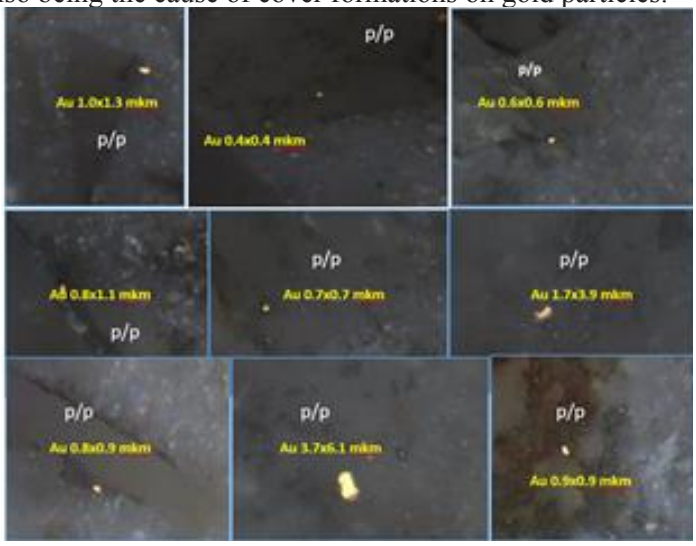


Figure 3. Gold intergrowths with enclosing waste rock

Along with this, there are grains of zircon - ZrSiO4, presented in the form of well-faceted pointed minerals of a long-prismatic and dipyramidal habit, both regular, retaining their contours and shapes, and partially destroyed (marginal remnants).

Non-metallic components are represented by prevailing quartz, mica, feldspars, carbonates, chlorite and sericite (conventionally designated as “p/p” in the figures). Table 3 shows the form of gold particles in the sample.

Table 3. Form of gold particles in a sample

| Form of gold | Free gold | | Gold in intergrowths with waste rock | |
|---|---|---|---|---|
| | Au (surface clean) | Au "in an envelope" | Au edge intergrowths | Au core inclusions |
| Number of particles, pcs. | 8 | 4 | 3 | 6 |
| Percentage, % | 38.09 | 19.05 | 14.29 | 28.57 |
| Total quantity, pcs. | 12 | | 9 | |
| Dimension μm | 0.5-4.5 | | 0.4-6.1 | |
| General percentage, % | 57.14 | | 42.86 | |
| Total: | 100.0 | | | |

So, ultrafine and finely dispersed gold particles were found as a result of microscopic examination of the original sample, both in free form and in intergrowths with waste rock. The size of the encountered Au particles in the product varies within: Au from 0.4 to 6.1 μm. The shape of gold particles is varied - spherical, rounded, hooked, rarely elongated. The surface of Au grains is both smooth with clear contours and rough and embossed. The largest gold grain was found in waste rock with the parameters - Au 3.7x6.1 μm;

In turn, there are corroded particles of metal scrap Fe (the percentage is 7.6% of the total amount of the studied grains, excluding waste rock particles), giving nearby minerals a burgundy-cherry, less often ocher-yellow, shade of different saturation. The main component of the product is ore-bearing veined waste rock (feldspars of various classifications, quartzites, calcium carbonate, micas (sericite, muscovite, biotite), chlorite and, to a lesser extent, mafic minerals such as apatite, olivine, plagioclase), conditionally designated in the figures as “p/p.”. The content of iron oxides/hydroxides is 20.8%.

When the composition was studied, the raw material was sent to the column flotation machine using main reagents. Pulp grinding to a size class minus 0.074 mm was 80%. The reagent mode of flotation beneficiation included the supply of butyl xanthate at a concentration of 120 g/t and blowing agent T92 - 60 g/t. The air pressure in the dispersion systems was from 2 to 10 atm. The results of the experiments are presented in table 4.

Table 4 - Results of experiments on column flotation machine under different pressure regimes

| Pressure generator parameters, pressure, atm | Name of products | Yield, % | Au content, g/t | Recovery of Au,% |
|---|---|---|---|---|
| 2.0 | Concentrate | 7.0 | 8.0 | 66.7 |
| | Tails | 93.0 | 0.3 | 33.2 |
| | Total | 100.0 | 0.84 | 100.0 |
| 4.0 | Concentrate | 8.6 | 7.22 | 73.9 |
| | Tails | 91.4 | 0.24 | 26.1 |
| | Total | 100.0 | 0.84 | 100.0 |
| 6.0 | Concentrate | 9.0 | 8.12 | 87.0 |
| | Tails | 91.0 | 0.12 | 13.0 |
| | Total | 100.0 | 0.84 | 100.0 |
| 8.0 | Concentrate | 12.1 | 5.42 | 78.1 |
| | Tails | 87.9 | 0.21 | 22.0 |
| | Total | 100.0 | 0.84 | 100.0 |
| 10.0 | Concentrate | 14.65 | 4.28 | 74.6 |
| | Tails | 85.35 | 0.25 | 25.4 |
| | Total | 100.0 | 0.84 | 100.0 |

**Results.** As a result of the experiment at a pressure in the pressure generator of 2.0 atm., the concentrate yield was 7.0% with a gold content of 8.0 g/t that gives a recovery of 66.7%. Increase of the pressure to 4.0 atm. contributed to an increase in the concentrate yield up to 8.6%, while the gold content was 7.22 g/t, and already 73.9% was extracted into the concentrate. At a pressure of 6.0 atm. in the dispersion system of the

pressure generator, the mass yield of the concentrate reached 9.0%, and with a gold content of 8.12 g/t, the recovery increased to 87.0%. Subsequent options with an increase in pressure to 8.0 and 10.0 atm., resulted in an increase in the mass yield of concentrates to 12.1-14.65%, while the gold content decreased up to 5.42 and 4.28 g/t, respectively. It also resulted in a decrease in recovery to 78.1% at 8.0 atm. and 74.6% at 10.0 atm.

**Discussion.** The enlarged laboratory tests of the pressure parameters of fine gold extraction, using dispersant on the column flotation machine were carried out. As the base reagents were used collector - butyl xanthogenate, activity according to the certificate of 84.5 %; foaming agent - T-92, activity 100 %, flotation time 15 min. Flotation was carried out with tap water at pH - 7,0. Air pressure in dispersion systems was from 2 to 10 atm.

The foam flotation method plays an important role in the beneficiation of base and precious metals, so it is worth taking a closer look at the basic principles of this technology.

For efficient separation of minerals, they must be sufficiently crushed. It is almost impossible to extract tiny sulfide particles on the concentration table.

During flotation, hydrophobic particles attach to air bubbles (and vice versa) and rise with them to the foam surface. The surface of minerals better interacting with water. In this case the intensification of the process in the apparatus under development can be achieved both by flexible management of processes of fixation and detachment in various hydrodynamic zones and by application of new effective reagents, consumption rates of which in the new apparatus can be significantly reduced due to higher probability of collision, fixation of particles on bubbles and saving the formed flotocomplexes. Wettability features of different minerals are different, so they must be processed in different ways. By adjusting the reagents used, the pH of the slurry, and some other factors, the miner can determine which minerals will be collected by the foam.

With the use of innovative flotation equipment testify to the novelty of the proposed scientific project to improve the gold recovery from 1.6 to 3.7%, and reduction of gold content in the tailings from 0.41 g / t to 0.31 g / t.

**Conclusions.** It was revealed that the content of gold in the test sample is 0.86 g/t, silver - 4.71 g/t. Gold is found in the form of very fine grains in sulfides (arsenopyrite, pyrite), as well as ultrafine and finely dispersed gold particles both in free form. The percentage of free gold in relation to gold in intergrowths is 57.14%: 42.86%, respectively.

Studies have been performed to process the original ore using a dispersant of micro-air bubbles on a flotation machine column. The following main conclusions can be made based on the study results on the flotation concentration of ore on a column flotation machine - the optimal fineness of the initial ore before flotation was 80%0.074 mm; butyl xanthate should be used as a collector reagent; the optimal reagent flotation mode was determined based on the study results - flotation of butyl xanthate - 120 g/t, T-92 - 60 g/t. The yield of gold-containing concentrate was 9% with a gold content of 8.12 g/t and a gold recovery of 87.0%. The study was financially supported by the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan (Grant No. AP 08051925)

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## МАЙДА ДИСПЕРЦИЯЛЫҚ АЛТЫНДЫ АЛУ ПАРАМЕТРЛЕРІН ЗЕРТТЕУ

**Аннотация.** Бұл жұмыста колонна флотомашинасында диспергаторды қолдана отырып, жұқа дисперсті алтынды алу параметрлерін зерттеу ұсынылған. Алтын өндіру саласының маңызды проблемаларының бірі өңдеуге құрамында алтыны бар қиын байытылатын шикізатты, сондай-ақ орасан зор алаңдарды алып жатқан және экологияға залал келтіретін қалдық қоймаларды тарту болып табылады. Байыту тәжірибесінде кең таралған бағаналы флотомашиналар дәстүрлі механикалық және пневмомеханикалық машиналармен қатар, айтарлықтай ерекшеленетін гидродинамикалық жағдайларды қажет ететін барлық қосалқы процестердің аппараттарының бірыңғай көлемінде ағу принципін сақтау нәтижесінде процестің басқарылуын түбегейлі арттыруға мүмкіндік береді. Мақаладағы ғылыми жаңалық – Рэйлей-Плессеттің кавитациялық көпіршігі (RP) динамикасының әмбебап теңдеуіне негізделген кавитация жүйесін қолдану. Базалық реагенттер ретінде бутил

жинағыш – ксантогенаты, көбіктендіргіш – Т-92 қолданылды, флотация pH – 7,0 кезінде ағынды суда жүргізілді. Дисперсия жүйелеріндегі ауа қысымы 2-ден 10 атм-ге дейін болды. Тәжірибелердің нәтижелері көрсетілді, дисперсті жүйеге жеткізілетін қысым тұрғысынан қысым генераторының ең оңтайлы параметрі 6.0 болды. Қысым генераторының дисперсті жүйесінде концентраттың жаппай шығымдылығы 9,0% индикаторға жетті, ал құрамында 8,12 г / т мөлшері 87,0% дейін өсті. Қысымның одан әрі өсуі бос тұқымның концентраттарына қарқынды ауысуға ықпал етеді, бұл бұқаралық шығынды едәуір арттырады, бірақ сонымен бірге олардағы алтын құрамын азайтады 6.0. Жаппай кірістілікке және концентраттағы асыл металдың құрамына оңтайлы тепе-теңдікке қол жеткізуге мүмкіндік береді.

**Түйінді сөздер:** диспергатор, майда дисперсиялық алтын, бағаналы флотациялық машина, концентрат, қалдық.

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## ИССЛЕДОВАНИЕ ПАРАМЕТРОВ ИЗВЛЕЧЕНИЯ ТОНКОДИСПЕРСНОГО ЗОЛОТА

**Аннотация**. В данной работе предоставлено исследование параметров извлечения тонкодисперсного золота с применением диспергатора на колонной флотомашине. Одной из важных проблем золотодобывающей отрасли является вовлечение в переработку упорного труднообогатимого золотосодержащего сырья, а также хвостохранилищ, которые занимают огромные площади и ухудшают экологическое состояние. Получившие широкое распространение в обогатительной практике колонные флотомашины, наряду с традиционными механическими и пневмомеханическими машинами, позволяют радикально повысить управляемость процесса вследствие сохранения принципа протекания в едином объёме аппарата всех субпроцессов, требующих существенно отличающихся гидродинамических условий. Научная новизна заключается в использовании системы кавитации на основе универсального уравнения динамики кавитационного пузырька Рэлея-Плессета (RP). В качестве базовых реагентов применялись собиратель – ксантогенат бутиловый, вспениватель – Т-92, Флотация проводилась на водопроводной воде при pH – 7,0. Давление воздуха в системах диспергации составляло от 2 до 10 атм. Результаты проведенных экспериментов показали, что наиболее оптимальным параметром напорного генератора в плане давления подаваемого в диспергационную систему является показатель в 6,0 атм. При давлении 6,0 атм. в системе диспергации напорного генератора массовый выход концентрата достиг показателя 9,0 % и при содержании в нем золота 8,12 г/т извлечение увеличилось до 87,0 %. Дальнейшее повышение давления способствует интенсивному переносу в концентраты пустой породы, что заметно увеличивает массовый выход, но в то же время снижает содержание золота в них. Показатель в 6,0 атм. позволяет достичь оптимального баланса по массовому выходу и содержанию благородного металла в концентрате.

**Ключевые слова:** диспергатор, тонкодисперсного золота, колонная флотомашина, концентрат, хвосты.

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**CONTENTS**

**Absametov M.K., Itemen N.M., Murtazin Ye.Zh., Zhexembayev E.Sh., Toktaganov T.Sh.**
FEATURES OF THE ISOTOPIC COMPOSITION OF GROUNDWATER IN THE MANGYSTAU REGION....6

**Akimbek G.A., Aliyarov B.K., Badaker V.C., Akimbekova Sh.A.**
METHODOLOGY AND EXPERIMENTAL SETUP FOR THE STUDY OF RELATIVE ABRASIVENESS OF BULK SOLIDS....14

**Baibolov K., Artykbaev D., Aldiyarov Zh., Karshyga G.**
EXPERIMENTAL INVESTIGATIONS OF THE COARSE-GRAINED SOIL IN THE DAM OF THE PSKEM HEP....21

**Bolatova A., Kuttybayev A., Kainazarov A., Hryhoriev Yu., Lutsenko S.**
USE OF MINING AND METALLURGICAL WASTE AS A BACKFILL OF WORKED-OUT SPACES....33

**Hajiyeva G.N., Hajiyeva A.Z., Dadashova Kh.D.**
IMPACT OF URBAN LANDSCAPE POLLUTION ON HUMAN HEALTH....39

**Hayitov O.G., Zokirov R.T., Agzamov O.O., Gafurov Sh.O., Umirzoqov A.A.**
CLASSIFICATION OF HYDROCARBON DEPOSITS IN THE SOUTH-EASTERN PART OF THE BUKHARA-KHIVA REGION, JUSTIFICATION OF ITS METHODOLOGY AND ANALYSIS OF THE RESULTS....46

**Kabylbekov K.A., Abdrakhmanova Kh.K., Kuatbekova R.A., Makhanov T.S., Urmashev B.**
COMPUTER SIMULATION OF RADIONUCLIDE ISOTOPE SEPARATION USED IN NUCLEAR ENERGY AND MEDICINE....53

**Kassenov A.Zh., Abishev K.K., Absadykov B.N., Yessaulkov V.S., Bolatova A.B.**
ANALYSIS AND JUSTIFICATION OF THE LAYOUT OF A MULTIPURPOSE MACHINE FOR THE DEVELOPMENT OF MINERAL DEPOSITS....63

**Kaumetova D.S., Koizhanova A.K., Toktar.G., Magomedov D.R., Abdyldaev N.N.**
STUDY OF THE FINELY-DISPERSED GOLD RECOVERY PARAMETERS....69

**Rakhmanova S.N., Umirova G.K., Ablessenova Z.N.**
STUDY OF THE GREATER KARATAU'S SOUTH-WEST BY RANGE OF GEOPHYSICAL SURVEYS IN SEARCH OF THE CRUST-KARST TYPE POLYMETALLIC MINERALISATION....76

**Oitseva T.A., D′yachkov B.A., Kuzmina O.N., Bissatova A.Y., Ageyeva O.V.**
LI-BEARING PEGMATITES OF THE KALBA-NARYM METALLOGENIC ZONE (EAST KAZAKHSTAN): MINERAL POTENTIAL AND EXPLORATION CRITERIA....83

**Sarmurzina R.G., Boiko G.I., Lyubchenko N.P., Karabalin U.S., Demeubayeva N.S.**
ALLOYS FOR THE PRODUCTION OF HYDROGEN AND ACTIVE ALUMINUM OXIDE....91

**Suleyev D.K., Uzbekov N.B., Sadykova A.B.**
MODERN APPROACHES TO SEISMIC HAZARD ASSESSMENT OF THE TERRITORY OF KAZAKHSTAN....99

**Temirbekova M.N., Temirbekov N.M., Wojcik W., Aliyarova M.B., Elemanova A.A.**
THE USE OF ORGANIC FRACTION OF SOLID HOUSEHOLD WASTE TO GENERATE ETHANOL AND BIOGAS USING A SIMULATION MODEL....105

**Tulegulov A.D., Yergaliyev D.S., Bazhaev N.A., Keribayeva T.B., Akishev K.M.**
METHODS FOR IMPROVING PROCESS AUTOMATION IN THE MINING INDUSTRY.....115

**Tulemisova G., Abdinov R., Amangosova A., Batyrbaeva G.**
STUDY OF THE BOTTOM SEDIMENTS OF RESERVOIRS OF URAL-CASPIAN BASIN.....126

**Turgazinov I.K. Mukanov D.B.**
ANALYSIS OF FLUID FILTRATION MECHANISMS IN FRACTURED RESERVOIRS.....135

**Uakhitova B., Ramatullaeva L.I., Imangazin M.K., Taizhigitova M.M., Uakhitov R.U.**
ANALYSIS OF THE LEVEL OF OCCUPATIONAL INJURIES ON THE EXAMPLE
OF AN INDUSTRIAL ENTERPRISE OF A METALLURGICAL CLUSTER.....145

**Yurii Feshchuk, Vadym Nizhnyk, Valeriia Nekora, Oleksandr Teslenko**
IMPROVING THE SYSTEM FOR RESPONDING TO FIRE IN AREAS CONTAMINATED
BY THE CHERNOBYL DISASTER.....152

**Sherov A.K., Myrzakhmet B., Sherov K.T., Absadykov B.N., Sikhimbayev M.R.**
METHOD FOR SELECTING THE LOCATION OF THE CLEARANCE FIELDS OF THE LANDING
SURFACES OF GEAR PUMP PARTS WITH A BIAXIAL CONNECTION.....159

**Khamroyev J.Kh., Akmalaiuly K., Fayzullayev N.**
MECHANICAL ACTIVATION OF NAVBAHORSK BENTONITE AND ITS TEXTURAL
AND ADSORPTION CHARACTERISTICS.....167

**Zhurinov M.Zh., Teltayev B.B., Aitbayev K.A., Loprencipe G., Tileu K.B.**
MODELING OF NON-STATIONARY TEMPERATURE MODE OF A MULTI-LAYER
ROAD STRUCTURE.....175

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**ISSN 2518-170X (Online),**
**ISSN 2224-5278 (Print)**

Редакторы: *М.С. Ахметова, А. Ботанқызы, Д.С. Аленов, Р.Ж. Мрзабаева*
Верстка на компьютере *Г.Д.Жадыранова*

Подписано в печать 14.02.2022.
Формат 60x881/8. Бумага офсетная. Печать – ризограф.
11,5 п.л. Тираж 300. Заказ 1.

*Национальная академия наук РК*
*050010, Алматы, ул. Шевченко, 28, т. 272-13-19*