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FLOTATION DEVICE WITH A HIGH FREQUENCY ROTARY PULSATION AERATOR (HFRPA) FOR ENRICHMENT OF FINE-GRADE GOLD-CONTAINING ORES

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Abstract: *On the manufactured enlarged version of the flotation device with a high-pressure rotary pulsating aerator (HFRPA), investigations and tests were conducted on refractory finely minified gold-bearing ore samples. The experiment and practice of flotation with the developed by the authors HFRPA showed that the pressure fluctuations created by the aerator ensure the efficiency of the functional use of the two periods. Which is the dissolution of additional gases in the high-pressure compression period, which ensures the aeration process with the required amount of dissolved gases and pseudo cavitation emission of gases in the medium rarefaction period, and this provides aeration with gas separation from the aqueous phase directly on hydrophobic mineral micro particles, i.e. micro dispersions selective flotation.*

KEYWORDS: *PULSATING FLOTATION DEVICE, VIBRATIONS, AERATOR, HIGH-PRESSURE COMPRESSION, PSEUDO CAVITATION, MATERIAL COMPOSITION, INDICATORS.*

1 Introduction

When flotation of finely divided ores that require fine grinding, most of the mineral particles have dimensions not exceeding 10 μm, which cannot be selectively separated by modern technologies. As the size of the mineral particles decreases, their behavior in hydrodynamic flows changes: in flotation, they lose mass and a boundary limit sets in, below which the micro particle cannot accumulate kinetic energy in motion, which allows it to overcome the water-structural energy barrier when it meets bubbles.

Previously, a number of researchers addressed issues of flotation of fine particles [1-8], and it was found that the most effective method is aerating gases released from the aqueous phase of flotation systems. However, neither in theory nor in practice, significant progress was achieved in this area, since the issue of increasing the amount of gases soluble in the water phase to the level that ensures the flow of flotation processes was not resolved.

When studying the methods of aeration with the release of gases from the aqueous phase by lowering the pressure and using acoustic cavitation [9], an unknown phenomenon of "inexhaustible" gases in pulsating fields was discovered - in the absence of a pulsating field at a temperature of no more than 25 °C, emission of gas from water is no more than 25 mg/l, but in the pulsation field in the presence of hydrophobic dispersions this restriction disappears and the process of aeration, and hence of flotation, continues, at least, as long as hydrophobic dispersion is still present in the water phase of the system.

When considering the degassing action of acoustic oscillations, we highlight three physical aspects:

the first – is a qualitative one, which consists in the fact that when acoustic oscillations are imposed on an aqueous system containing dissolved gases, under the influence of systemically changing pressure, alternating cavitation dissolution occurs (in the high-pressure phase) and release (in the low-pressure phase) of gases;

the second – in the presence of hydrophobic macro- and micro surfaces in the water system, cavitation cavities formed on them in the phase of gas evolution do not completely collapse (pseudo cavitation), but grow like gas bubbles up to a certain resonance size corresponding to the frequency of oscillations and other physicochemical parameters;

the third – and the main one, revealed by us and consisting in the fact that in the absence of pulsation oscillations from the water system it is possible to isolate not more than 25 mg of gases from one liter of water (the generally accepted physical restriction of the solubility of *air gases* in water), while when superimposed on a water-dispersed system of pulsating oscillations, gas bubbles are pseudocavitatively released on hydrophobic surfaces in amounts that are multiples of the above limitations in 25 mg/l of water - until all bubbles cover hydrophobic surfaces and the particles.

When the possibility of efficient flotation of micro dispersions with pulsation aeration of the process was in principle established, technological and methodological issues came to the fore, the main one of which was the choice of the frequency range. The study of the pseudo cavitation aeration method has already shown good results when using an ultrahigh frequency (300 kHz) pulsating field for the flotation of micro dispersions [9]. Experimentally, it was found that:

– the presence in the aqueous system of hydrophobic surfaces (both macro- and micro-dispersions) initiates the selective release of gases from their aqueous solution;

– when applied to an aqueous system containing hydrophobic dispersions, pulsations, the quantitative restriction (25 mg/l) for providing the water system with the amount of gases dissolved in the water phase, necessary and sufficient for flotation of all hydrophobic mineral particles in the flotation system, disappears.

During the research it became clear that the electronic method of creating a pulsating field in the flotation of roads and for widespread use was difficult, and it was decided to study the possibility of efficient pulsation flotation at infrasound frequencies of 2.4-3.4 kHz.

In the study, the authors discovered the effect of the lack of limited quantity of hydrophobic dispersions (including micro- or nanosized) or surfaces that are released in the pulsating field in the presence of water in the water system. That is, the possibility has been found of effective selective flotation by Klassen method without restriction in ensuring the necessary quantity of process gases.

A device with a high-frequency rotational pulsating aerator (HFRPA) has been designed for this pulsation-pseudo cavitation method.

In this article, we study the possibility and efficiency of aeration with the use of pulsations of much lower frequencies excited by the mechanic-hydraulic method using the developed *high-pressure rotary pulsating aerator - HFRPA*, whose stator and rotor have a rod structure. The excitation of the pulsating field in the HFRPA makes it fundamentally different from the existing rod apparatuses, for example, "Fagergren", "Adzhtejr", "Float Force" and others [11], in which the interstator-rotor gap is large, measured in centimeters and therefore before the active mixing of the sucked gases with water is carried out in it and in the near-stator zone the flotation with the release of gases from the solution is not preferential and conditions for flotation of micro dispersions are not created.

The purpose of this work is to study the technological properties of a pilot sample of a flotation device with a high-frequency rotational pulsating aerator (HFRPA) for the enrichment of fine-grained gold-bearing ores. The principal difference is the aeration of the apparatus in a field of elastic vibrations of sonic and ultrasonic frequency range. The process embodied in the apparatus is a combination of a number of elementary physicochemical processes and their stages, carried out in the rhythm of the pulp oscillations given by the HFRPA. Flotation in the apparatus with

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HFRPA will significantly improve the selection of particles with a particle size from 44 μm to 10 μm.

2 Results and discussion

The HFRPA is a group of two hollow coaxially located cylinders with rods separated by parallel slots (Figure 1). The number of rods and slots in the stator and rotor can be equal, and then on the periphery of the stator a constant pulsating field is formed, or their number can be different, and then the generated pulsating field will be running - relative to the stator. When the rotor rotates, its rods overlap, and then the stator slots open.

The stator and rotor rods have the same width and are located at the same distance from each other. The alternation of alignment and misalignment of the slots occurring when the rotor rotates relative to the stator causes pulsation of the flotation slurry passing through the slots. The frequency of pulsations depends on the number of slots and rods and on the speed of rotation of the rotor and can be adjusted within wide limits.

The pulsations caused by rotation of the rotor are accompanied by the phenomena of dispersion and cavitation in the pulp sucked into the inner cylinder and successively passing in the radial direction first through the slots of the rotor and then the stator. During the rotation of the rotor, a vacuum arises in its cavity, so that pulp from the chamber and air from the environment are continuously sucked through the hole in the stator connected by the tube to the air duct.

A mixture of pulp and air, ejected from the rotor slots with a large centrifugal and circumferential velocity, hits the edge of the stator rods. Air and pulp are actively mixed. In the stator slots and when the front face of the rod is being pushed, the flow to some extent remains laminar, although the general direction of the flow varies. In proportion to approach the edge of the stator core, the fluxes coming out of the slots of the rotor decay. At this point, the pulp undergoes the greatest pressure, the magnitude of which depends on the rate of onset and on the density of the pulp. Due to the increased pressure in the high-pressure zone, favorable conditions are created for dissolving the gases (Figure 1).

The most favorable conditions for dissolving the gases in the pulp are created when passing through the HFRPA, where, due to the high head and active mixing of pulp and air, a large bubble surface is formed, and in interstitial sections of the stator the air-rich pulp passes through the zone of increased pressure (Figure 1). At high speeds of rotation of the rotor in the stern area of the stator rods, behind the separation line, vortices are separated from the faces of these rods and the motion of the pulp streams is swirled (Fig. 1).

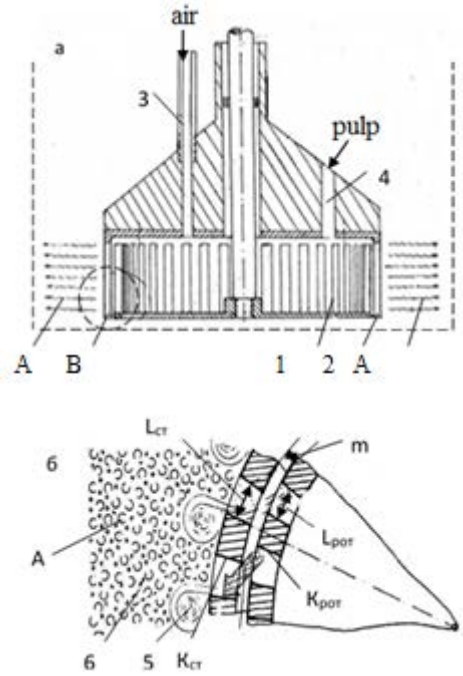

Figure 1- Scheme of the HFRPA (a) and the pulsation mechanism for the formation of high and low pressure zones (b):
1 - rotor, 2 - stator, 3 - adjustable air intake, 4 - pulp-channel, 5 - primary large-scale eddies, 6 - zone of developed turbulence.
A - pulsation zone, $K_{ст}$ and $K_{рот}$ - thickness of stator and rotor shaft, $L_{ст}$ and $L_{рот}$ - width of stator and rotor rods, m - gap between stator and rotor.

In this paper, the influence of the frequency factor on the efficiency of enrichment of micro dispersions on the flotation device with HFRPA on three grades of ore samples from the Arkharly, Komarovskoe and Bakyrchik deposits was studied.

All selected samples of ores refer to hard-enriched thin-grained ores, when enrichment of which on the standard flotation device gives low values. Flotation in the apparatus with HFRPA will significantly improve the performance due to the full disclosure of minerals and their involvement in the process.

Four samples weighing 1 kg were sampled on the ore samples of each deposit, alternately they were ground in a ball mill MSHR-12 to obtain a 100% class - 0.044 mm and loaded into an experimental flotation device with a high-pressure rotational pulsating aerator (HFRPA). After feeding the reagents and setting the optimum pulsation frequency of the HFRPA, flotation was carried out. The products obtained during the analysis were analyzed for gold content.

To determine the influence of the frequency factor on the enrichment efficiency, flotation experiments were carried out at a different frequency of the aerator pulsations. An ultrahigh frequency apparatus controlled the pulsation frequency.

For the convenience of carrying out the experiments, the pulsation frequency (F, kHz) was calculated in advance, depending on the rotor speed:

$$F=\frac{Vn}{60}k,$$

Where n = 60 - number of teeth on the rotor; V-rotor speed of revolutions per minute; k = diameter of the engine pulley/rotor pulley diameter, mm = 235/128 = 1.83.

The data obtained are presented in Table 1.

Table 1 - Results of calculating the ripple frequency

V, revolutions per minute	Frequency, kHz
1	
1000	1.830
1100	2.013
1200	2.196
1300	2.379
1400	2.562
1500	2.745
1600	2.928
1700	3.111

The optimum degree of grinding of the ores studied before flotation at the HFRPA was: at the Arkharli deposit, the optimum grade minus 10 microns was 50%; on the Komarovskoe ore deposit and the Bakyrchik deposit, it is necessary to crush the ore to 40% of the minus 10 micron grade.

In all three grades of ores, experiments were performed at a rotor speed of 1200 to 1700 revolutions per minute, which corresponds to frequencies from 2.196 kHz to 3.111 kHz, since at revolutions of 1000 and 1100 there was a zero yield of the foam product.

During the tests, the amount of air released from the solution was determined.

Figures 2, 3, 4 present the graphs of the influence of the rotational speed of the HFRPA on the extraction rate and the quality of the concentrates in the flotation of ore samples.

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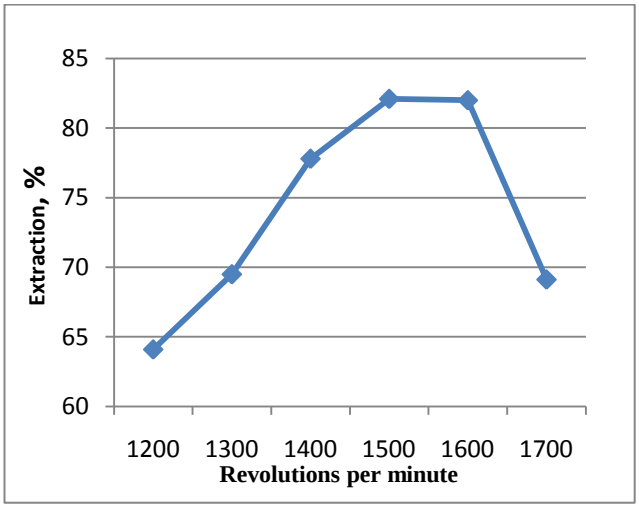
On the graph of Arkharli ore, it can be seen (Fig. 2) that at the HFRPA rotation speed of 1200 rpm (2.1196 kHz ripple frequency), the highest gold content in the concentrate was 233.7 g/gold extraction 64.1%. As the frequency of pulsations increases, the gold content decreases slightly, but the extraction increases. The best results are obtained at a rotation speed of the pulsating aerator of 1500-1600 rpm, which corresponds to the ripple frequencies of 2.745 and 2.928 kHz, at these frequencies the gold content in the concentrates was 181.5 - 176.64 g/works, with extraction into concentrates of 82%. The amount of air released from the solution was 50.0 dm3/s.

On the Komarovskoe deposit, the graph also shows (Fig. 3) that as the frequency of pulsations increases, the gold content of the concentrates decreases from 139.7 to 66.6 g/ton of ore with an increase in extraction from 64.1 to 92.7%. The best indications were obtained at a rotation speed of the pulsating aerator of 1500 - 1600 rpm, which corresponds to a ripple frequency of 2.745 and 2.928 kHz, at these frequencies the gold content in the concentrates was 76.13-75.3 g/works, with 93.2-92.7% recovery.

At the trial of the Bakyrchik deposit, the results of the studies show (Fig. 4) that the best indicators were obtained at a rotation speed of the pulsating aerator of 1600 rpm, which corresponds to the pulsation frequency and 2.928 kHz, at a given frequency, the gold content in the concentrates was 90.5 g/works, with extraction into concentrate 82.4%.

The amount of air released from the solution in all three grades of ores was 50.0-55 dm3/s.



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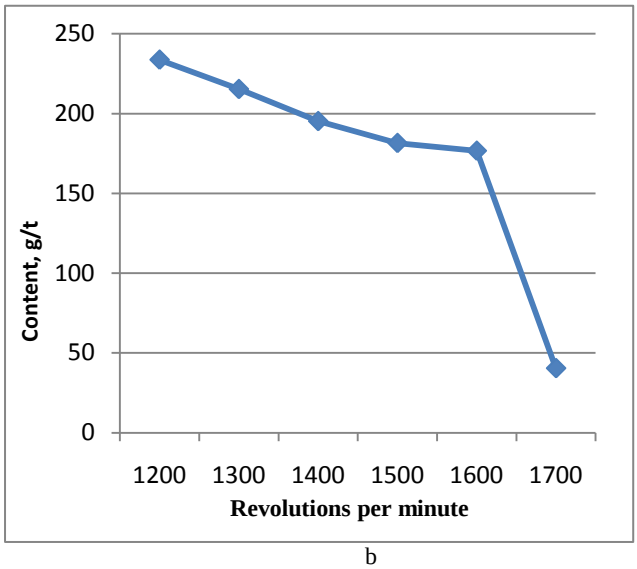

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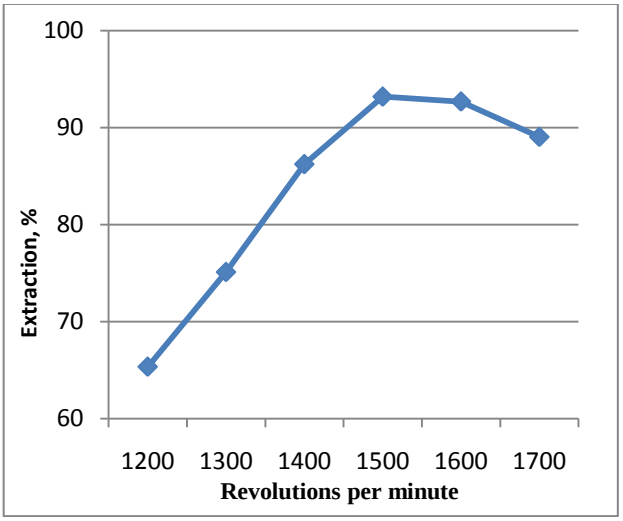
Fig. 2 Influence of the HFRPA rate on the gold recovery rate (**a**) and the quality of the concentrates (**b**) during the flotation of the ore sample of the Arkharli deposit



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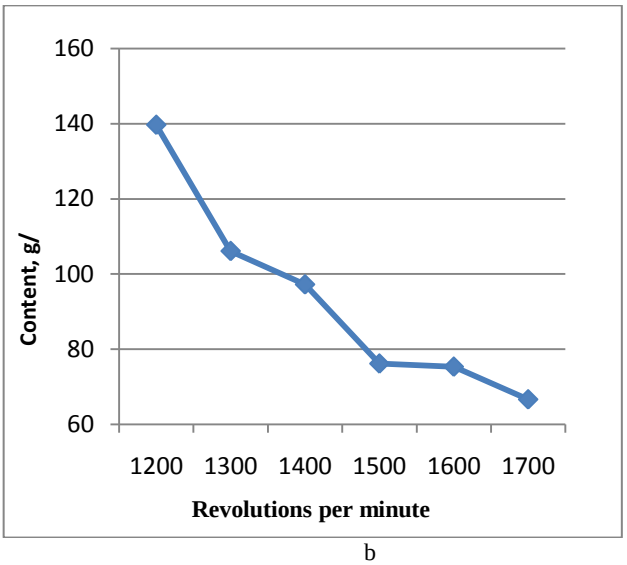

b

Fig. 3 Influence of the HFRPA rate on the gold recovery rate (**a**) and the quality of the concentrates (**b**) during the flotation of the ore sample of the Komarovskoe deposit

Table 2 presents the comparative test results for flotation on a standard flotation device and on a pilot sample of a flotation device with HFRPA.

The results of comparative tests show that when flotation of the investigated samples of ores on an experimental sample of a flotation device with HFRPA, an increase was obtained both in the quality and extraction of gold into concentrates:

– on the ore of the Arkharli deposit, the gold content in the concentrate amounted to 180.5 g/t on a standard flotilla of 60.7 g/t with an increase in gold recovery to concentrate by 11.78%;

– on the Komarovskoe ore deposit, the gold content in the concentrate was 75.4 g/t on a standard flotilla of 64.3 g/t with an increase in gold recovery to concentrate by 7.3%;

– on the Bakyrchik deposit ore, the gold content in the concentrate was 90.0 g/t on a standard flotilla 43.46 g/t with an increase in gold extraction in concentrate by 5.79%;

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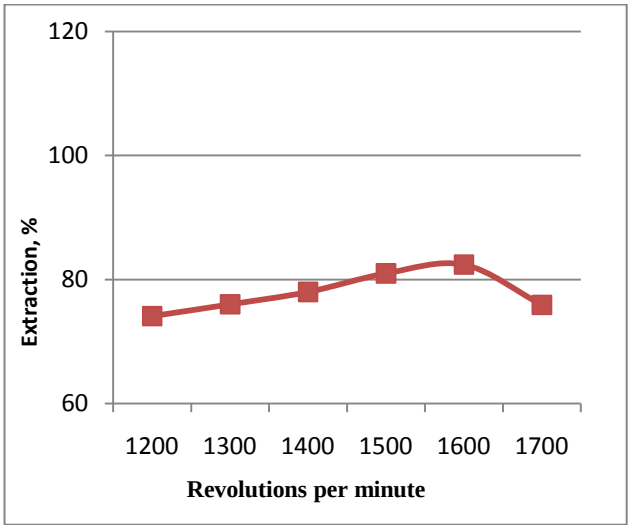

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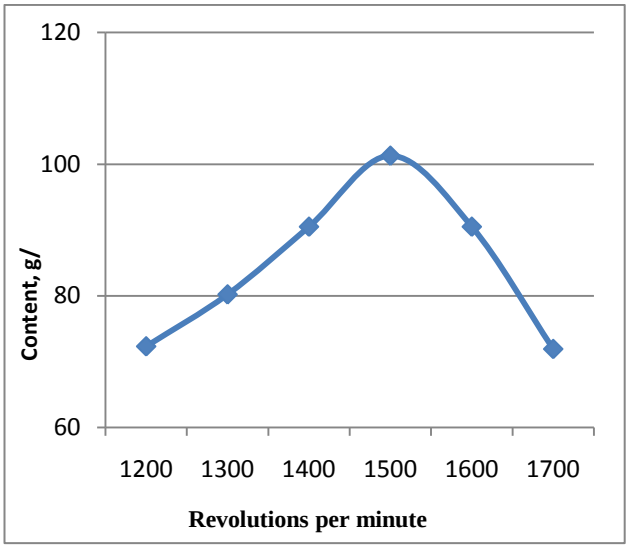

b

Fig. 4 Influence of the HFRPA rate on the gold recovery rate (**a**) and the quality of the concentrates (**b**) during the flotation of the ore sample of the Bakyrchik deposit

Table 2 The results of comparative tests on a standard flotation machine and on a pilot sample of a flotation device with HFRPA

Description of parameters	Standard flotation device	Flotation device with HFRPA
1	2	3
Arkharly ore deposit		
Gold content in ore, g/t	2.62	2.62
Gold content in concentrate, g/t	60.7	180.5
Gold extraction into concentrate, %	70.0	81.78
Ore deposit of Bakyrchik		
Gold content in ore, g/t	6.86	6.87
Gold content in concentrate, g/t	43.46	79.0
Gold extraction into concentrate, %	81.49	87.28

Table 3 (*Continued*)

Komarovskoe ore deposit		
Gold content in ore, g/t	1.99	1.87
Gold content in concentrate, g/t	64.3	75.4
Gold extraction into concentrate, %	85.38	92.68

Conclusion

In the study, the authors discovered the effect of the lack of limited quantity of hydrophobic dispersions (including micro- or nanosized) or surfaces that are released in the pulsating field in the presence of water in the water system. That is, the possibility has been found for effective selective flotation with Klassen method without restriction in ensuring the necessary quantity of process gases.

With pulsation pseudo cavitation method was created flotation device with high-frequency rotational pulsating aerator (HFRPA).

The results of tests of flotation of three thin-grained gold-bearing ores on a flotation device with a high-frequency rotational pulsating aerator showed that at a pulsation frequency of 2.745-2.928 kHz (1500-1600 rpm):

– dissolution of additional gases in the high-pressure compression period, which ensures the aeration process with the necessary amount of dissolved gases;

– pseudo cavitation emission of gases in the medium rarefaction period, which causes aeration with the release of gases from the aqueous phase directly on the hydrophobic mineral micro particles, i.e. selective flotation of micro dispersions.

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