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Substantiation of the hydrodynamic disintegration of hydraulic fluid's mineral component of high-clay sand in precious metals placers

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Abstract. General regularities and theoretical approaches determining hydroimpulsive effects on the mineral component of the hydraulic fluid are analyzed, with reference to the disintegration of high-clay sands of gold-bearing placers. Theoretical conclusions on the hydrodynamic effect on the solid component of the hydraulic fluid give insight into emerging processes in multicomponent media under hydrodynamic influences initiated by various sources of physical and mechanical influence. It is noted that the theoretical justification of the structurally complex hydrodynamic effect on the hydraulic fluid with the formation of phenomena arising from the collision of solid components with each other and obstacles includes the consideration of changes in such force characteristics as speed, pressure, flow power, and also changes in design parameters and characteristics of the environment.

A conceptual approach is given to the theoretical substantiation of the disintegration of the hydraulic fluid's mineral component using the example of the proposed installation. Calculation of economic indicators for the use of a hydrodynamic generator in comparison with processes based on known technologies has shown significant advantages of using the proposed installation, which can increase productivity and quality production indicators.

Keywords: hydraulic fluid, mineral component, disintegration, jet separation, cavitation

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At present, new types of placers are being commissioned in the Far East region, previously not related to industrial facilities for the content of valuable components. A considerable number of placers discovered in the Amur region are characterized by small gold and an increased content of clay fractions. According to the data of geological studies of gold-bearing placers in the Far East of Russia, more than 60% of them are clayey. Analysis of placer fields in the Amur region showed that many of them can be classified as complex for processing because of the significant volume of fine gold (fractions less than 0.5 mm make up more than 90%, and gold sizes less than 0.1 mm – up to 26%). An example is the Kutum field, a sieve analysis of the gold bearing stratum of which showed a 93% of gold content of 0.16-0.63 mm in size (Figure 1) (Khrunina et al., 2011).

The Kutum field is located in the Sutar gold-bearing area, in the zone of the right-bank inflow of the River Sutara. The length of the placer is 4 km; the average width is 62.1 m; the thickness of loose deposits is 5.4 m; peat thickness – 3.1 m; the thickness of the sands is 2.3 m. The composition of the loose sediments: the soil-vegetation layer is 0-0.3 m; Peat with silt – 0,3-1,2 m; quartz-feldspar sand, fine-medium-grained with silt, rare fragments of granites, in the lower layers peat and brown clay interlayers (0.5-1.0 m) – 1.2-3.0 m; quartz-feldspar sand coarse-grained with gravel, rubble and a small amount of pebbles – 3-5 m. The granulometric composition of the loose deposits of the Kutum field is presented in Table 1, the sieve analysis of gold in Table 2. The lower parts of the gold-bearing strata enter the destroyed granites . On the terraces there is more clay fraction.

The high energy intensity of the mining machines and technological equipment used, the poor quality of the disintegration process of high-clay sands of placers, the significant losses of valuable components exceeding 50%, caused not only by deviations in technological regimes from optimal values, but also by imperfect machine designs, reduces the efficiency of processing gold-bearing sands (Mamaev et al., 2015).

One of the fundamental tasks of the destruction

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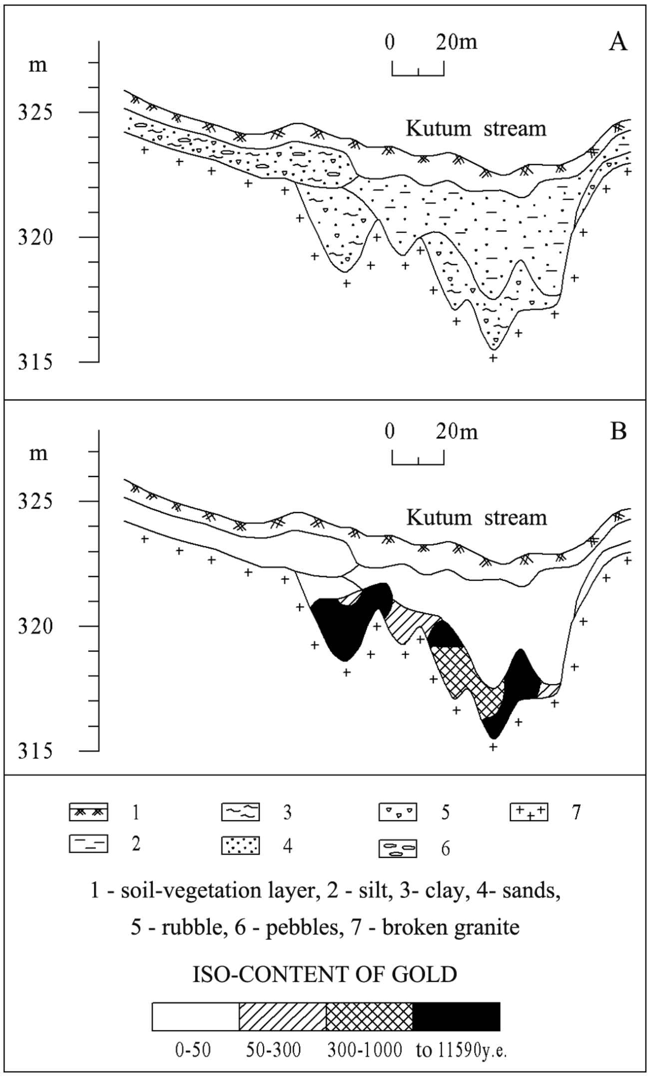

Figure 1. Cross sections of the Kutum placer: A – lithological section; B – section of gold content

Fraction, mm	-2	2-10	10-200	200-300
Composition, %	46,9	43,3	11,3	0,5

Table 1. The granulometric composition of the loose deposits of the Kutum field

Grain-size category, mm	-0,16	0,16-0,63	0,63-2,5
Composition, %	3	93	4

Table 2. Sieve analysis of gold from the Kutum field

processes in liquid media is to elucidate the nature of the appearance and propagation of waves interacting with deformable bodies (Ganiev, Ukrainskiy, 2011; Kulagin, 2000; Rudenko, 1993; Fedotkin, Nemchin, 1984). The processes of energy conversion between vibrational and translational forms of motion can cause both amplification of oscillations and the appearance of unidirectional flows.

Statement of the problem and analysis of approaches to its solution

Understanding the complex mechanisms of wave interaction, the dynamics of their propagation and cavitation can allow controlling these processes. (Khrunina, 2014). Consideration (Kizevalter, 1979) of the equilibrium is given, acting on a particle of forces in the case of gravitational separation of a solid in hydraulic fluid, which is expressed by the dependence:

$$V\rho_{\text{т}}g - Vg\left[(1-m)\int_{\rho_{\text{т}1}}^{\rho_{\text{т}2}}\gamma d\rho_{\text{т}} + m\rho_{\text{ср}}\right] - - V\text{К}_{\text{м}}\frac{1}{\gamma(\rho_{\text{т}})}grad\,\gamma(\rho_{\text{т}}) - av = 0, \qquad (1)$$

where V – the volume of the particle; $\rho_{\text{т}}$ – the particle density; m – content of the medium (water) per unit volume of suspended matter; g – the acceleration vector of gravity; γ – the density distribution function of particles, $\int_{\rho_{\text{т}1}}^{\rho_{\text{т}2}}\gamma d\rho_{\text{т}}$ – fraction share in the range of density change from $\rho_{\text{т}1}$ to $\rho_{\text{т}2}$; $\rho_{\text{ср}}$ – the average density of the medium; v is the vector of the average particle velocity; $K_{\text{м}}$, a – the coefficients.

Theoretical conclusions on the gravitational separation of solid in hydraulic fluids give general ideas about emerging processes in multicomponent media under hydrodynamic influences initiated by various sources of physical and mechanical influence.

The aim of the research is to develop an approach to the substantiation of the disintegration process of high-clay sand under the conditions of changing the pressure of the flow, with the formation of vortices, shock waves, and dilution of the hydraulic fluid, on the basis of an analysis of the aspects of hydrodynamic phenomena and interactions.

The results of the study and their discussion

To substantiate the disintegration processes of the mineral component of the hydraulic fluid under conditions of resonant acoustic phenomena in the hydro-flow and to determine the technological and design parameters of the systems simulating the cavitation and hydrodynamic effects, it is necessary to identify factors influencing the nature of the process from all the diversity of approaches to the solution of the problem posed. The hydraulic fluid at disintegration is a liquid with solid inclusions. It is known that the strength of a liquid is sharply reduced when it contents solid particles or gas inclusions. Proceeding from the molecular theory, the tensile pressure necessary for the occurrence of ruptures in water at 20°C is 3200 kg/cm^2. However, the phenomenon of cavitation is observed in the liquid long before reaching the value of the tensile force. This indicates that during the cavitation process a rupture of the cavitation pocket occurs in the places of thermal fluctuations of the liquid. The rupture of the liquid occurs at the boundary with the solid surface of the suspended particles. In addition, microcracks of solid suspended particles may initiate the appearance of cavitation effects, as well as a different degree of wetting of the particles may contribute to the formation of cavitational discontinuities (Kruglitskiy, 1971).

To study the process of disintegration by means of cavitation, samples of high-clay sands from one of the sections of the Besheny field of Primorsky Krai were selected. Samples of 150 g were placed in water and were cavitated by IMAHASHI (model USD150B) unit. The disintegration was estimated by the change in the mass of mineral particles separated from the sample. The separated part of the mineral particles separated with water was drained, dried in an oven and after cooling it was weighed on a laboratory electronic scale OHAUS Scout Pro SPU202 (Mettler Toledo, China) with a systematic error of ± 0.001. Based on the results of studies, the dependence of the intensity of cavitation on the mass of the disintegrated clay component of the slurry is established (Figure 2).

The process of disintegration initiated by ultrasonic action and mechanical stirring of smaller samples and the clay component of the hydraulic fluid were also compared. To do this, samples of 35-40 g, with average initial moisture content of 12%, were weighed on laboratory electronic weighbridges OHAUS Scout Pro SPU202 (Mettler Toledo, China) with a systematic error of ± 0.001, then placed in water purified by filtration using the REVERSE OSMOSIS SYSTEM system “ATOLL 560”. The time of action on the mineral mixture with pieces of samples was 5, 10 and 15 min. The average value of the specific interfacial surface of the particles (fractions less than 0.5 mm) was determined by the sandy-clay composition of the mineral hydraulic fluid after mechanical and cavitation effects (Figure 3). The dispersion of the fraction less than 0.5 mm was established using a Fourier spectrum in a mineral slurry medium by means of an “Analysette 22 MicroTec Plus” laser diffractive microanalyzer (Fritsch GmbH, Germany) operating on the basis of a converging laser beam and using the physical principle of electromagnetic wave scattering to determine the particle size distribution. The estimation of random errors was performed on the basis of the Student’s method with a reliability value of 0.95 and the number of measurements n=5, and the elimination of gross errors in the statistical series by the rule of three sigma.

Considering the theoretical plan proposed for the practical use of the installation (Khrunina, 2014), it is possible to distinguish simulated hydrodynamic effects in a number of zones of its working space that are initiated by cavitation, including due to the configuration of the hull that creates changes in the pressure of the hydraulic fluid at the inlet – in the diffuser, which turns into a confuser (Figure 4). Material processing will be carried out under conditions of active hydrodynamic influences by means hydrodynamic generator placed inside coaxially and in series connected stationary cavitation elements. There are no moving parts in the installation. Energy costs go only to the supply of pulp under pressure.

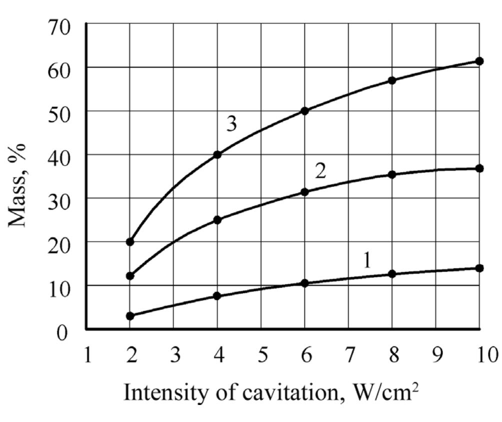

Figure 2. Dependence of the disintegration degree of the sandy-clay component of the mineral hydraulic fluid on the intensity of cavitation, with the time of action (min): 5 (1); 10 (2); 15 (3)

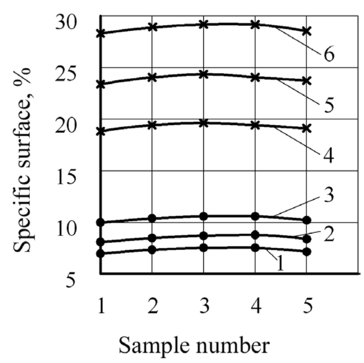

Figure 3. Dependence of the disintegration intensity at 5, 10 and 15 minutes, respectively: 1-3 – with mechanical stirring; 4-6 – with ultrasonic cavitation

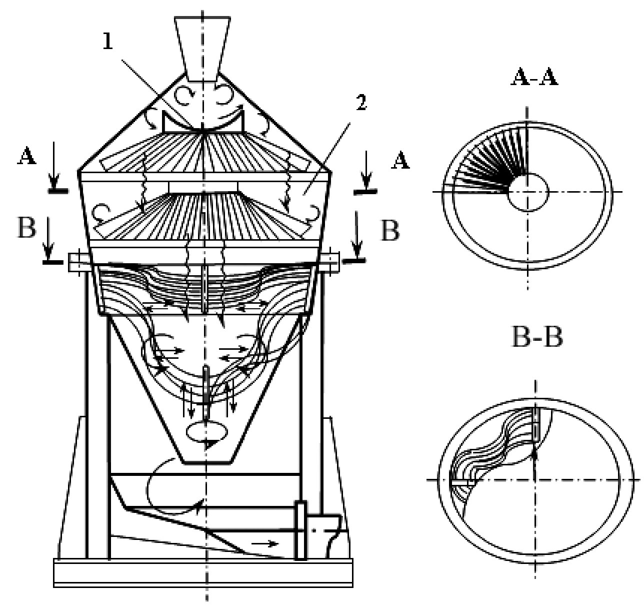

Figure 4. Hydrodynamic generator of jet-acoustic disintegration of the mineral component of the hydraulic fluid

The initial stage of disintegration is carried out by means of a high-speed jet supply through the inlet hole directly to the reflective spherical surface 1 located in the upper part of the housing and mating at the base of its lower part with successively installed cone-shaped cavitational surfaces. A reflective spherical surface 1 with diffuser walls forms a shock wave that transforms into a toroidal cavitation zone with an increase in the shock oscillations and the appearance of fields of primary hydrodynamic and secondary acoustic cavitation in the hydraulic fluid. With a high pressure gradient, the hydraulic fluid successively falls on the tapered cavitational surfaces with slot-like openings and blades. The blades play the role of additional cavitators. The slurry is cavitated and divided into thin streams, passing through the slit-shaped openings. Then the hydraulic fluid enters the zone of the stepped confuser. With the help of packages of movable elastic plate-like cavitation elements made with bends and sagging relative to the fastening, additional jet separation is performed with increasing cavitation-acoustic influence on the mineral component of the hydrosphere and obtaining a given average value of the volumetric power density of the hydrodynamic disturbance to provide a pressure gradient, exceeding the strength limit of microparticles. At the output, it is possible to obtain mineral components of a hydraulic fluid with a particle size within 1-2 μm. The arrangement of the intermediate fastenings of the lower pack of elastic plateau cavitation elements with a significant displacement in the vertical plane provides a significant vortexing both in the flow direction of the hydraulic fluid and perpendicular to it. The frequency range of the radiation obtained during cavitation in the disintegration process can be in the range 0.4-40 kHz (Mamaev, Khrunina, 2008), and the velocity of the jet from the inlet controls the maximum of the sound pressure.

In the pressure zone of the jet of the mineral hydraulic fluid to the enclosing surface 1, without taking into account the recessed jet in the upper region of the expansion-diffuser, the pressure of the jet is determined by the formula (Idelchik, 1975):

$$\mathrm{P} = \frac{\gamma}{g} Qv(1 + cos\beta) = \rho Qv(1 + cos\beta) = \\ = \rho Qv\big(1 + (-0{,}5)\big) = 0{,}5\rho Qv, \quad (4)$$

where γ – the volumetric weight of the liquid; g – acceleration of free fall; Q is the flow rate; v – the velocity of the liquid jet; β – the angle between the tangent to the enclosing surface and the axis of the jet; ρ – the density of the hydraulic fluid.

In the narrowing-confusion zone 2, the loss of pressure is determined by the formula (Idelchik, 1975):

$$h = \zeta_{суж} \frac{v_2^2}{2g}, \quad (5)$$

where the coefficient of contraction resistance is determined by the semiempirical formula:

$$\zeta_{суж} = 0{,}5\left(1 - \frac{S_2}{S_1}\right) = 0{,}5\left(1 - \frac{1}{n}\right), \quad (6)$$

in which $n = S_1/S_2$ is the degree of restriction. Hydrodynamic effects should also be considered in the following zones of the installation, which are below. The intensity of hydrodynamic cavitation, which ensures the destruction of the mineral component of the hydraulic fluid at the final stage, will be proportional to the change in the speed of the water flow (Promtov, 2001)

$$\mathrm{I} = (V - V_{кр})^n, \quad (7)$$

where V – the initial flow velocity at the entrance to the confuser; V_{cr} – the critical velocity corresponding to the instant of the beginning of cavitation destruction; n – the exponent, determined from the experimental data.

An analysis of the phenomena occurring in the conditions under consideration requires further development. In addition, the main factor of interest to us is the result of the destruction, disintegration of the solid mineral component of the slurry. The investigated process of vortex and pulsed hydrodynamic action on the solid component includes elastoplastic deformation and fracture with the formation of new surfaces of small particles S, which will depend on the intensity of hydrodynamic cavitation

$$S = f(\mathrm{I}) = f\,[(V - V_{кр})^n]. \quad (8)$$

The efficiency of disintegration depends on the physico-mechanical features of high-silt sands, including the effect of the medium, and various types of hydrodynamic effects. In the hydrodynamic generator, the main forces of action are the hydrodynamic forces of the flow, as well as the mechanical forces of interaction of the particles with each other, with the walls and other elements of the generator. One of the factors that should be taken into account in justifying disintegration at the microlevel is the study of the effect of water saturation on high-clay sands of placers. The application of new approaches to the assessment of the influence of water saturation on the disintegration processes of high-clay sands and the expansion of the investigation objects, with a more detailed study of the effect of water saturation on the elastic characteristics of clay sands in placers, broadens the possibilities for the development of theoretical studies of hydrodynamic phenomena.

The economic efficiency is given of the processing high-clay sand (clay content above 30%), with an increased content of small and fine particles of valuable components, based on the use of a developed cavitation plant (Khrunina, 2014), compared to two basic options based on the physico-chemical method of selective exposure to polyelectrolyte complexes (Myazin, 1996) and using the widely applied PGSh-50 complex. The economic advantage of disintegration through cavitation initiation in comparison with the physicochemical method of selective action of polyelectrolyte complexes, according to the methodology (Bogatin, 1999), is the reduction of the transferred costs for the new technology. Calculations have shown that the use of two cavitation generators in a standard enrichment scheme, including a deep filling gateway, a washout and classification system, and thin-layer screw sluices, can reduce the present costs by 38%.

Comparison of the disintegration process through the proposed installation with the process based on the PGSh-50 complex according to the methodology (Bogatin, 1999) was carried out on the calculation basis of the resulted effect, since these processes differ in the volume of production and in the quality of the products (i.e., with functional solutions tasks). Compared with the disintegration process based on the PGS-50 complex, a system with the use of hydrodynamic cavitators is most preferable, since its reduced effect is 4 times higher, i.e. productivity and quality indicators of production significantly exceed not only by economic, but also by technological indicators.

Conclusion

More than 350 fields and occurrences of gold and gold with silver have been taken into account on the territory of the Khabarovsk Territory. Of the 180 gold fields, most of which are placers, including with increased clay content – up to 80% and more, a significant part of them is not ready for development due to the lack of environmentally and technologically efficient technologies. This includes the Amur Region, in which about 630 placers are also found with considerable clay content and a high content of fractions with small and fine gold particles and other valuable components. The use of the proposed installation based on hydrodynamic cavitation will solve the problem posed. The theoretical justification for a structurally complex hydrodynamic effect on a hydraulic fluid includes accounting for changes in such power characteristics as speed, pressure, flow power, and also changes in the design parameters and characteristics of the medium. The development of studies of hydrodynamic impact on multicomponent media of hydraulic mixtures will provide information that will ensure the implementation of technology for the disintegration of high-silt sands of precious metals with a number of significant advantages, including ensuring low energy costs. This will provide new knowledge about the processes and phenomena under study and solve the rather acute problem of complex processing of mineral raw materials by effective and environmentally safe physico-mechanical methods.

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