Analysis of the processing mechanism in a centrifugal concentrator with a horizontal axis of rotation

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Abstract. This scientific work presents the results of comparative tests of centrifugal concentrators with a vertical and horizontal axis of rotor spinning. The article also describes a qualitative analysis of the behavior of mineral particles in a centrifugal field with fluidization for concentrators with a horizontal axis. The experiment demonstrated that concentrators with a horizontal axis are not inferior in terms of the qualitative recovery indicators to concentrators with a vertical axis. The researches also provided facts about the wide practical application of concentrators with a horizontal rotor arrangement.

1. The revival of gravity concentration methods
Gravity concentration methods, attractive because of their ecological purity, meet their revival. First of all, this is due to the invention of centrifugal concentrators with the fluidization of the layer of mineral particles.

The creation of a new generation of gravitational centrifugal concentrators made it possible to achieve a tangible breakthrough toward the direction of reducing the grain size of mineral particles effectively divided by density, up to 10 µm, at a high production capacity of the vessels reaching 500÷600 tons per hour. Such separators enable dressing a crushed ore of flotation grade and in some cases replace the flotation process, especially in primary operations, in joint cycles. In the long term, this method of concentration should significantly expand the scope of application, replace partial flotation processing and ensure the introduction of environmentally friendly energy-saving technologies at ore-processing plants.

Summarizing the international experience of the last 30 years, it can be confidently asserted that centrifugal methods of concentration have become widely used in processing schemes to separate finely dispersed products in the mining industry.

An interest in the creation of installations using centrifugal acceleration for the separation of mineral particles by density has particularly grown.

Various centrifugal concentrator constructions have been created and continue to improve. Centrifugal concentrators have a number of obvious advantages, which are especially relevant today.

Losses of fine gold during the process of mining are well known. Gold washers crews, spiral separators, jigging machines and sluices traditionally used in the production processes do not solve the problem of fine gold recovery.

Attempts to capture small particle and fine gold have been undertaken for quite a long time [1–5]. The effect of ”pseudo-coarsening” of particles achieved in the centrifugal field makes
it possible to reach the highest rates of recovery of fine particles and to efficiently separate products with a minor difference in specific gravity.

Centrifugal concentrators with fluidization, in which the action of centrifugal forces is compensated by the action of hydrodynamic forces created by water injection into concentrator cone grooves, are the most widespread and recognized in the world. Knelson (FLSmith), Falcon and Itomak.

Pugachev's centrifugal-vibrating concentrator of CKPP Polymetal with Running Wave elastic rotors and many others are well-known in Russia.

The main distinguishing feature of the ITOMAK concentrators is the location of the spinning axis of the bowl (rotor) in the horizontal plane.

This arrangement of the spinning axis, at first glance, does not give any advantage, except for ease of maintenance. From the detailed analysis of the behavior of a mineral particle in a horizontal rotor performed in the [4, 7, 9] works, one can obtain the equation of the resultant force $F$ acting on an individual particle:

$$F = F_0 - F_{hd} = \omega^2 V_s r (\rho_s - \rho) - \psi \rho d^2 v_s^2$$

where $F_0$ is a total centrifugal force; $F$ is a centrifugal force; $\rho_s$ is the density of solid particles; $\omega$ is the angular velocity of rotation of the liquid flow in a rotor; $V_s$ is the mineral particle volume; $r$ is the radius of rotation; $F_{cp}$ is a centripetal force - Archimede’s force in a centrifugal field; $\rho$ is the density of the liquid; $F_{hd}$ is a hydrodynamic force - Stokes force acting on a particle during flowing around; $\psi$ is a resistance factor; $d$ is the particle diameter; $v_s$ is the velocity of the particle moving in relation to the liquid; $G'$ is Archimede’s buoyant force; $g$ is the acceleration of gravity; $G$ is the force of gravity.

The condition for the precipitation of particles of the heavy fraction is the excess of $F_0$ over $F_{hd}$, directed from the wall to the spinning axis, that is $F > 0$. When accumulating specific heavy particles in the depressions of the bowl, the action of $F_{hd}$ weakens, this leads to a deterioration of the fragmentation of the mineral bed and the cessation of the penetration of the particles into the settling zone. The operating mode of such vessels is selected in such a way for the heavy fraction to comply with the above condition of $F > 0$, and $F < 0$ for the light fraction, when it is removed throughout the inner surface of the bowl.

Let’s consider the effect of forces on the example of the horizontal position of the rotor with a bowl (Figure 1).

Considering that the action of the hydrodynamic force $F_{hd}$ at all points is directed from the wall into the bowl, that is, to squeeze the particle out of the depression, the resultant force $F$ in this case will be:

$$F = F_0 - F_{hd} + G \sin(\omega t),$$

where $t$ is the time.
Figure 1. The balance of forces acting on a particle with the spinning axis in a horizontal position (a – at the top point, b – at the lowest point).

It is obvious that $\sin(\omega t)$ with the bowl rotation frequency will gain values from $+1$ to $-1$, and then the resultant force $F$ will change periodically in time.

Thus, the resultant force $F$, acting on the particle and ensuring its penetration into the heavy fraction precipitation zone, is supplemented by the action of a periodic force due to the horizontal position of the axis, with the rotational frequency of the rotor together with the bowl.

In the depressions, the compacted material is exposed to water jets fed through holes in the bottom of the depressions. Water brings the material in the depressions to a "boiling" state, when the Stokes force $F_{hd}$ action compensates for the effect of the centrifugal force $F_c$ and brings the particles to some unstable "suspended" condition of "levitation". For a certain fraction of particles (of corresponding sizes and specific gravity), the resulting centrifugal and the centripetal forces $F_{cp}$ and the hydrodynamic force $F_{hd}$ will be equal to 0, and the effect of $G$ will make the particles vibrate (vibration), which will contribute to the further fragmentation of the mineral "bed". In this case, the change in the direction (vector) of the periodic force action due to $G$ becomes significant for the separation of particles with different specific gravity.

The change in the direction of action of the periodic force due to the gravity $G$, depending on the design dimensions and capacity of the vessel occurs at a frequency of 8 to 50 Hz (the
rotor spinning with the bowl). The effect of additional fragmentation of the mineral bed is the most obvious with the horizontal position of the axis of the rotor spinning with the bowl and weakens as it deviates from the horizontal.

Given the design parameters of the vessel with the vertical arrangement of the rotation axis, the only controlling parameter is the fluidization water pressure, which determines the value of the Stokes force.

The conducted analysis shows that, with the horizontal position of the spinning axis, the force of gravity, which direction vector rotates at an angular velocity coinciding with the rate speed of the rotor, actively affect the particle.

The principle of operation of similar devices is that the separation of the material by density occurs as a result of the interaction of the flow of washing water, centrifugal forces and gravity, which all affect the particle in a horizontally spinning rotor. The intensity of the density separation process increases due to the vibrations of the mineral layer, which occur due to the horizontal position of the rotor. At the same time, due to gravity, the vibrations of the mineral layer, in the radial and axial direction, occur with the rotor speed rate. Theoretical analysis is presented in more detail in [7] and [9].

The use of centrifugal concentrators with a horizontal spinning axis at gold mining enterprises has proved their high efficiency in fine gold particles collection [2,6,8,10].

It should be noted that to date, dozens of articles have been published, in which an attempt is made to analyze the processes of separation of mineral particles in an aqueous medium in centrifugal concentrators, but all of them are of an evaluating nature. Actually there are no works published with detailed development of the model of a two-phase medium flow in a centrifugal concentrator rotor.

One can hope that modern methods of continuous medium mechanics, and in particular, numerical methods of the mechanics of multiphase flows, make it possible to find solutions that will substantially optimize the processes of centrifugal concentration.

The main distinguishing feature of the ITOMAK concentrators is the location of the rotation axis of the concentrator cone in the horizontal plane.

In this regard, the question arises. How will the recovery parameters differ with the horizontal position of the spinning axis of a concentrator’s rotor?

Table 1 presents the results of comparative experiments on the concentration of an artificial mixture of minerals - quartz sand and magnetite, quartz sand and ferrosilicon in centrifugal concentrators with fluidization with the vertical and horizontal positions of the spinning axis of the rotor.

ITOMAK-KN-0.1 centrifugal concentrators (with a vertical rotation axis) and ITOMAK-KG-0.1 (with a horizontal rotation axis) were used in the experiments. The same conical bowl was used for the experiments. A frequency converter was used to change the speed.

A SMS-20 magnetic separator was used to assess the recovery of magnetite of different sizes; the separator was used to recover magnetite from the precipitate and tailings, and thus the recovery was calculated. Before each experiment, magnetite and ferrosilicon were demagnetized.

As a result of the studies conducted one can see that recovery with a horizontal position of the rotor spinning axis is not less than at its vertical position, with all other similar initial parameters.

It should be noted that to date, dozens of articles have been published in which an attempt is made to analyze the processes of separation of gold-containing products in centrifugal concentrators, but they are all evaluative in nature. Almost no work has been published with a detailed development of a model for the flow of a two-phase medium in a rotor of a centrifugal concentrator.

It can be hoped that modern methods of mechanics of continuous media, and in particular numerical methods of mechanics of multiphase flows, make it possible to obtain solutions that
Table 1. Data on the magnetite recovery into a precipitate in vessels with a vertical and horizontal rotation axis.

Weighed quantity-model mixture: quartz sand 980 g (250 microns) + 20 g magnetite (70 µm).

| Test No. | Pressure, bar | Recovery, % | Rotation speed rpm | Separation factor Fr/g |
|---------|--------------|-------------|--------------------|------------------------|
|         | 0.1          | Vertical    | 1250               |                        |
|         |              | 0.2         |                    |                        |
|         |              | 0.3         |                    |                        |
|         |              | 0.4         |                    |                        |
|         | 0.5          | Horizontal  |                    |                        |
|         |              | 0.2         |                    |                        |
|         |              | 0.3         |                    |                        |
|         |              | 0.4         |                    |                        |
|         |              | 0.5         |                    |                        |

will significantly optimize centrifugal enrichment processes.

Centrifugal concentrators with a horizontal rotor are not inferior to devices with a vertical axis such as Falcon or Knelson and have been widely used in enterprises in more than 50 countries for more than 25 years and continue to.

2. Conclusions

It is shown that, with the horizontal position of the spinning axis, the gravity force, which direction vector rotates at an angular velocity coinciding with the rate speed of the rotor, actively affect the particle.

The recovery indicators in the vertical and horizontal vessels are similar in values for different separation factors.

The horizontal position of the bowl rotation axis does not change the main regularities of enrichment in centrifugal concentrators.

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