Use of Additive Technologies to Optimize Design of Classifying Devices

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Abstract. The article considers perspectives of the use of additive technologies to optimize the design of classifying devices. A brief overview of the solutions developed using 3D printing for mining industry is given. It is stated that creation of models is impossible without knowledge of the laws of distribution of flows and expressions describing them. For this purpose, the influence of the pulp viscosity on classification in a hydrocyclone on an experimental unit has been studied. A modified Plitt model was proposed to predict the separation grain. The proposed model takes into account the pulp viscosity and predicts the size of the boundary grain more accurately.

1. Introduction

The rapid development of technology inevitably affects all areas of the modern world. Historically, there are three disrupting common course of “wave” development of the technological revolution, which arose approximately every 50 years since the beginning of the nineteenth century. The era of steam engine is the first wave. The second wave is associated with emergence of mass production in the early 1900s. The third wave took place in 1970s – 1980s, when the industry began to use process control tools, electronics and robotic equipment to automate routine tasks. The fourth wave is built on the basement of the third one, but it is driven by digital technologies, the number thereof is growing exponentially. In particular, the fourth wave is characterized by the use of advanced intelligent systems, robots, neural systems, and additive technologies in production [1-3].

According to experts, the perspectives for the market of additive technologies in Russia are significant. Additive technologies allowed intensifying technologies in many areas of industry, in particular in mining and metallurgical field. Based on the latest equipment, technologies have been developed for production and fine-tuning of high-quality powder materials for additive technologies and powder metallurgy as an element of Industry 4.0 with the use of combined effects - vibration, magnetic and electrical [2-6].

In the field of mineral processing, additive technologies have found their use in optimizing the design of separation devices. For flotation machines, designs of mixing mechanisms have been developed, which mix the pulp, disperse air and create kinetic turbulence. The use of additive technologies improves technological performance, increases flotation flexibility and makes it possible to reduce the rate of rotation of the mixing mechanism, which, in turn, reduces operating costs. In particular, before launching FLSmidth® nextSTEP™ technology on the market, the company created and tested about 200 rotor/stator combinations using sophisticated software and 3D printing, as well as modeling using computational fluid dynamics (CFD)[3].

Additive technologies play an equally important role in optimizing design parameters of classification in hydrocyclones. For example, the use of small hydrocyclones for separation of particles in microns is of great interest. [4] However, these hydrocyclones are difficult to manufacture because of the need to maintain high precision in manufacturing. Meanwhile, the accuracy and quality of separation largely depends on these parameters, which is confirmed by empirical formulas developed by various researchers. In the case of hydrocycloning as an optimization criterion, it is advisable to use the parameter - boundary grain $d_{50c}$, which is a complex indicator characterizing operation and
performance of the device in general. Using suspensions of pure silica, Plitt [5], Plitt et al. [6] and later Arterburn [7] developed mathematical models linking various factors and $d_{50c}$. Both of these models were obtained experimentally from experimental data on laboratory-sized hydrocyclones. According to the Plitt model:

$$d_{50c} = \frac{k_1 \ D_c^{0.46} \ D_I^{0.6} \ D_U^{1.21} \ \exp\left(0.063 \ \frac{C_{VS(F)}}{Q_{VF}^{0.45}} \ \left(\rho_S - \rho_L\right)^{0.5}\right)}{D_o^{0.71} \ \frac{L_{VF}^{0.38}}{Q_{VF}^{0.45}} \ \left(\rho_S - \rho_L\right)^{0.5}}$$

where $L_{VF}$ - free height of the drain pipe (distance from the end of the drain pipe to the sand hole), m; $D_c$ - cylinder diameter, m; $D_o$, $D_I$, $D_U$ - diameters of drain, input and sand holes, m; $Q_{VF}$ - power volume rate, $m^3/sec$; $C_{VS(F)}$ - % of solid per volume in feed; $d_{50c}$ - corrected separation size, $\mu$m; $\rho_S$, $\rho_L$ - density of solid and liquid phases, respectively, $kg/m^3$; $k_1$ - coefficient depending on the geometric parameters of the hydrocyclone.

Over the years, the Plitt model has undergone many modifications and corrections. Plitt et al. (1980) proposed to add dynamic viscosity of a fluid to the initial model to a power of 0.5, but Austin et al. [8-10] found that the Plitt model gives $d_{50c}$ values that are inconsistent with real data and the model is more suitable for dilute suspensions [11].

In this regard, determination of $d_{50c}$ parameter dependence on the rheological properties of the pulp is an important point for modeling by means of computational fluid dynamics (CFD) and further 3D printing [12-13].

2. Methods

In order to identify dependencies characterizing performance of a hydrocyclone from physical properties of the pulp, a series of experiments were performed in AKW-Laborant ZLF 50ch pilot plant manufactured by AKW Apparate+Verfahren GmbH (Germany). The layout of the installation is shown in Fig.1.

The experimental plant comprised a polyurethane hydrocyclone of AKW A+V type, a reservoir for initial power supply, which is tangentially fed into the hydrocyclone using a centrifugal pump (one may install hydrocyclones with a diameter of 80, 55 and 35 mm with variations in the diameter of the sand nozzle), while pulp moves towards hydrocyclone inlet, its density, temperature, and volume flow are measured in a specially installed monitoring device. The pressure at the inlet to the hydrocyclone is measured with a pressure gauge mounted on the feed pipe [9].

Two samples: a mixture consisting of 65% magnetite and 35% quartz, with a particle size of -1+0 mm and a second sample of crushed quartz (80% of class -71 microns) were prepared for experimental studies. The operating mode of the plant was the following: the pressure of the pulp at the inlet to the hydrocyclone is constant (69 kPa); mass fraction of solids in the samples was 19, 26, 35 and 40%; during the study, and viscosity of the pulp was continuously recorded.

3. Results and discussion

The study of the effect of pulp density in the feeding of a hydrocyclone on classification efficiency was performed with a solid content of 10–40% in 5% increments. With an increase in the solid content in
the diet, respectively, the density of the pulp was increased. In the course of research, it was found that a higher solid content leads to a decrease in the speeds of the radial motion of solid particles, thus the laws of free centrifugal sedimentation change to the laws of constrained sedimentation. Higher and denser bed of large grains of the solid phase is formed near the sand nozzle. As a result, large grains fall into a drain, and the grain size of $d_{50c}$ boundary grain is increased. There was also a slight increase in hydrocyclone performance with an increase in the pulp density, despite the constant pressure at the inlet to the hydrocyclone, while classification efficiency was lower.

For performance of experiments to establish the influence of temperature and solid content on the pulp viscosity, an experiment involving statistical means will improve accuracy and reliability of the results. The results are shown in Fig. 2.

![Figure 2. Dependence of the pulp viscosity on the temperature at various concentration of the solid (%)](image)

The obtained functional dependence allows making a correction for the pulp temperature and solid content in the Plitt equation.

In order to assess the effect of viscosity increase, not related to an increase in the solid content in the feed, a series of experiments was performed with a medium viscosity modifier. The concentration of the modifier ranged from 0 to 50% by weight of pulp. The experiments were performed with a constant solid content in the feed of 10% and temperature with a small range of variation: 20–23°C.

In the course of the experiment, the effect of the pulp viscosity on the size of $d_{50c}$ grain was estimated. The results of the study are shown in Fig. 3.
The dependence of the grain size of the boundary grain on the viscosity of the pulp obtained in the course of experimental studies was subsequently introduced into the Plitt model described above. A new model was formulated, first, by introducing the term of viscosity and then changing the term of solid percentage in the Plitt model [5]. In the original Plitt model, the term is used as a different percentage of solid

The original Plitt model shows this term as \( 0.063C_{V(S/F)} \), and it was replaced with \( C_{V(S/F)}^{0.41} \) in the new equation:

\[
\frac{d_{50c}}{k_2 D_c^{0.46} D_l^{0.6} D_o^{1.21} C_{V(S/F)}^{0.41} \eta^{0.6}} = \frac{k_1 L_{1/F}^{0.38} Q_{V(S/F)}^{0.45} (\rho_s - \rho_L)^{0.5}}{D_c^{0.71} L_{1/F}^{0.38} Q_{V(S/F)}^{0.45} (\rho_s - \rho_L)^{0.5}}
\]

where: \( k_2 \) – coefficient depending on rheological properties of the pulp and geometric parameters of the hydrocyclone; \( \eta \) - pulp viscosity, mPa sec; \( \beta \) - degree of viscosity effect.

Indicator \( \beta \) can be determined graphically and is numerically equal to the slope of the regression prima.

As noted above, the Plitt model is designed to measure the pulp viscosity only from a percentage of solid, and is not designed for any changes in viscosity from other sources (temperature, for example). In fig. 4 shows, how changes in \( d_{50c} \) from both temperature and solid% are accurately predicted using a new model.

This equation uses viscosity data obtained by direct measurement, an increase in \( d_{50c} \) due to changes in viscosity, both from an increase in the solid content (for different % of solids) and temperature changes (from 10°C to 50°C in the individual range of % solids)).
4. Conclusion

Viscosity plays a major role in classification in a hydrocyclone. The viscosity of the pulp may vary under the influence of several factors, e.g.: any changes in the solids content, particle size, temperature, chemical environment, etc. Therefore, the viscosity index should be considered in addition to the solids content in the pulp, when creating models for the hydrocyclone separation grain.

Thus, in the course of experimental studies, dependences were obtained describing the effect of rheological properties on its performance as a classifier. The coefficient that corrected the viscosity in the Plitt model, which allows increasing the accuracy of the calculation, has been determined experimentally. The results are an excellent prerequisite for creating high-precision CFD models. The creation of such models will allow optimizing the design parameters of the hydrocyclone followed by production of the whole structure or its part by means of 3D printing.

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