Modeling separation of mineral particles in the upward flow

IA Matveev¹*, BV Yakovlev²**, NG Eremeeva¹ and TP Kulichkina²

¹Chersky Institute of Mining of the North, Siberian Branch, Russian Academy of Sciences, Yakutsk, Republic of Sakha (Yakutia), Russia
²Institute of Physics and Technologies, Ammosov North-Eastern Federal University, Yakutsk, Russia

E-mail: *igor.andr.matveev@gmail.com; **b-yakovlev@mail.rucom

Abstract. The paper presents a new tested and approved physico-mathematical model which sufficiently accurately and reliably describes the path of mineral particles in the upward flow along the inclined surface. The Mineral Dressing Laboratory at the Institute of Mining of the North has developed the separation method in the upward flow of hydraulic fluid and the high-angle concentrator design. The modeling results can be used to control separation in the working zone of the high-angle concentrator.

1. Introduction

Gravity concentration is one of the most popular and inexpensive methods of mineral separation. Principles of gravity concentration are widely used both in dressing of different ore and minerals, and during classification and dewatering in the pretreatment circuits.

The Mineral Dressing Laboratory at the Institute of Mining of the North has developed the separation method in the upward flow of hydraulic fluid and the high-angle concentrator design [1].

Separation in slurry in the concentrator runs in accord with the principles of equal fall or hydraulic classification. Settling of particles on settling surfaces of plates in the concentrator occurs by the mechanism of gravity separation on the inclined plane. Owing to combination of these two types of separation in the concentrator, two tasks are fulfilled simultaneously, namely: hydraulic classification of material into size grades by equal fall and subsequent fractional dressing of particles of different hydraulic size by density [2, 3].

Efficient design of the high-angle concentrator and operating condition of gravity separation are determined on physico-mathematical models of particle flow in the working zone of the concentrator.

Figure 1. Pattern of particle flow in model.
2. Experimental test results

Figure 1 shows the pattern of particle flow in the lab-scale model of the high-angle concentrator. Water flow comes out of angle 1 (dashed line 2). Nearby point 1, a particle gets into the flow and moves under the action of the forces of water, inclined plane (angle \( \beta \)), as well as friction and gravity along a certain path (solid line 3) depending on the initial velocity.

Physical modeling of collective motion of particles is associated with additional mathematical problems connected with determination of position probability of a particle in the concentrator. The final modeling result is the determined position probability of the particle on the inclined plane by the time of displacement at the preset initial conditions.

The particle position probability is determined using the Gibbs ensemble method \([4, 5]\). In this method, all possible positions of a particle are determined at random times and at different initial positions and velocities of the particle. The initial parameters depend on the initial distribution of probabilities. The set of possible positions is a problem space. The distribution function is a proportional value of distribution density of possible positions of the particle in the assigned domain. The possible positions of the particle on the working surface of the concentrator are governed by the law of motion derived by integrating of the motion equation.

In the problem in Figure 1, at the initial time, the velocity of the particle has an arbitrary direction. Let the particle velocity direction at the initial time be equally probable in terms of all directions. Therefore, we consider an isotropic flow coming from point 1 at the initial time. Then, we determine the equation of motion:

\[
m\ddot{R} = F_v + mg + F_f + N
\]

where \( \dot{R} \) is the radius-vector of the particle; \( m \) is the mass of the particle; \( F_v = a(u - v) \) is the water flow force; \( a \) is the particle resistance coefficient dependent on the characteristics of the medium, and on the shape and properties of the particle; \( u \) is the water flow velocity; \( v \) is the particle velocity; \( g = ge_z \) is the acceleration of gravity; \( F_f = Nf \) is the friction force on the working surface; \( N = -mg \sin \beta \cos \beta \mathbf{e}_y + mg \cos^2 \beta \mathbf{e}_z \) is the reaction force of the surface.

The developed physico-mathematical model is tested and approved on the dedicated laboratory model of the high-angle concentrator. The test particles—markers were shots with diameters of 3.0, 3.1, 3.5 and 4.1 mm, and a flat particle with diameter of 4.6 mm and thickness of 1.5 mm. Water was fed at different velocities (1.77, 2.03, 2.58, 3.47 and 4.83 m/s). Also, the angle of the model incline was varied from 40 to 90 deg. The test particles (60 shots) were fed via a tube, captured by water and spread between cells. After that, shots were counted in each cell. Each test was repeated 10 times for the improved reliability.

![Figure 2. Experimental distribution of markers depending on water flow velocity at model angle of 60 deg.](image-url)
Figure 3. Theoretical distribution of markers depending on water flow velocity at model angle of 60 deg.

3. Conclusions
The experimental results and theoretical data were compared using the distribution charts of markers in the laboratory model at the angle of 60 deg and different velocities of water flow (Figures 2 and 3). For plotting, the peak of particle distribution per cells is calculated as an average value in the range of probability distribution of a finite domain of particle fall.

The mathematical model of particle motion in the upward water flow has been developed and experimentally tested. It can help optimize and improve the high-angle concentrator designed at the Institute of Mining of the North.

The modeling results on the paths of different shape particles in the upward water flow on the inclined surface, with regard to the set of forces affecting the particle, can be used to control separation of mineral particles in the working zone of the high-angle concentrator.

References
[1] Filippov VE, Ereemea NG, Sleptsova ES and Salomatova SI 2003 RF Patent No 2196005 High-Angle Concentrator Izobreteniya No 1
[2] Ereemea NG, Matveev AI and Monastyrev AM 2010 Gravity separation of minerals on high-angle concentrator GIAB No 2 pp 36–37
[3] Matveev IA, Matveev IA and Ereemea NG 2015 Pre-studies into gold recovery from dimaond-bearing sand talings GIAB Special Issue 30 pp 251–259
[4] Landau LD and Lifshots EM 1976 Theoretical Physics Moscow: Fizmatlit
[5] Krylatova SR, Matveev AI, Lebedev IF and Yakovlev BV 2018 Modeling particle motion in a spiral separator by statistical methods Matematich Zametki SVFU Vol 25 No 1 pp 90–97