Modelling of sediment mixing processes during preparation of conversion of scandium concentrate

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Modelling of sediment mixing processes during preparation of conversion of scandium concentrate

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Abstract. Modern methods of computational fluid dynamics make it possible to evaluate the effectiveness of various design options for chemical devices already at the design stage. This work is devoted to the study of the processes of mixing sediment with a high solids content, in the preparation of the conversion of scandium concentrate, using the methods of computational fluid dynamics, based on a previously developed mathematical model. As a result of the work, the parameters of the distribution of the volume fraction of the solid phase were established, and the velocity field of the suspension in the simulated apparatus was investigated.

1. Introduction
One of the promising areas for improving the environmental safety of mining enterprises is a more comprehensive processing of raw materials [1, 2]. An example of such an approach is the technology for producing scandium oxide from solutions of in situ leaching of uranium. However, the introduction of new redistributions into production is associated, among other things, with the development of non-standard equipment and the determination of the optimal operating modes, both at the design stage and during commissioning. Using the methods of computational fluid dynamics, already at the design stage, it is possible to determine the most effective design options for the devices being developed and the parameters of the technological process.

In this work, the processes of mixing sediment with a high solid phase content during the preparation of the conversion of scandium concentrate are investigated, based on a previously developed mathematical model.

2. Modelling
2.1. Modelling technique
In this work, a method was used to simulate the processes of mixing sediments with a high content of solid particles, based on solving the Navier-Stokes equations by the finite element method. Due to significant differences in the rheological properties of the phases, it is impossible to use the Navier-Stokes equation with simple parameters and rheological properties averaged over the volume fraction of the components to simulate the fluid-solid flow. Therefore, the Euler multiphase model was used, which is usually used to simulate the flow of suspensions with high solids content [3-6]. In this case, the problem of pseudo-viscosity of the solid phase is the most difficult. To refine the pseudo-viscosity of the solid phase, the model of D. Gidaspow [7] is often used. For example, in [3-6], this model is used to simulate flows in technological pipelines. An alternative method for modelling the flow of suspensions
is the use of classical semi-empirical models [8]: Lagrange method, which takes into account the equilibrium of each particle in a continuous flow [9], or a combined use of Euler model and Lagrangian approach [10]. In this work, the Gidaspow model was used to take into account the pseudo-viscosity of the solid phase. Moreover, the Gidaspow equation was supplemented by the Scheffer term to take into account the frictional forces arising in the flow and affecting the pseudo-viscosity of the suspension [11]. To calculate turbulent effects, the standard k-ε turbulence model of Launder and Spalding was used [12]. The rotation of mechanical stirring devices was simulated using the sliding grid method, which reduces the resource consumption of the solution [13].

The simulation is performed by the finite element method in the ANSYS Fluent application suite.

2.2. Design and operating principle of the simulated apparatus

Using the method described above, the mixing process was simulated in an apparatus with a total volume of 100 litres, the main units and elements of which are shown in Figure 1. The apparatus consists of a cylindrical shell of body 1 with a flat bottom 2 and a cover 3. A drive is installed on the cover of the apparatus 4, a mechanical stirrer 5, an inlet of sediment 6, a branch of a strong suspension 7 and an irrigation branch 8 of an inlet 6, a branch of a solution supply 9. To ensure corrosion resistance, the body of the apparatus, the bottom, cover, and blades of the mechanical stirrer are made of polypropylene or polyethylene. The shaft of the mechanical stirrer is lined with polyethylene or polypropylene pipe. The mixing process was simulated for a vessel equipped with a turbine agitator.

The pulping apparatus works as follows. The required amount of a solution of a given concentration is fed into the apparatus through the branch pipe 9. After that, the drive 4 of the mechanical mixing device 5 and the circulation pump are turned on in the operating mode on the line, the outlet branch pipe of the suspension 7 – pump – the branch pipe 8 for irrigation of the inlet pipe.

After the onset of the steady-state circulation mode of the solution, sediment is fed into the pulping apparatus through the branch pipe 6. From this moment, sediment pulping begins. Sediment de-pulping is carried out due to the blades of a mechanical mixing device.

Figure 1. Sketch of the pulping apparatus. 1 – case; 2 - bottom; 3 – cover; 4 – drive of a mechanical mixing device; 5 – mechanical mixing device; 6 – sediment inlet pipe; 7 – suspension outlet branch pipe; 8 – branch pipe for irrigation of the inlet branch pipe; 9 – branch pipe for supplying an alkaline solution.
2.3. Initial data for modelling

Table 1 presents the initial data for modelling the processes of sludge pulping in an apparatus with a total volume of 100 litres. The dimensions of the apparatus and the operating modes of the mixing device of the apparatus are presented in Table 2. Calculations were made for the nominal operating mode of the mixing device with the mixer shaft rotation frequency of 1500 rpm.

Table 1. Initial data for modelling the pulping processes in an apparatus with a total volume of 100 litres.

| Parameter                              | Value             |
|----------------------------------------|-------------------|
| Liquid phase density                   | 1098 kg/m³       |
| Fluid viscosity                        | 0.002 Pa·s        |
| Solid phase density                    | 3000 kg/m³       |
| Particle size of the solid phase       | 100 μm            |
| Volume fraction of solid phase in sediment | 0.67              |
| Volume fraction of solid phase in suspension | 0.20              |
| Maximal volume fraction of solid phase | 0.7               |
| Working volume of the apparatus        | 0.097 m³          |
| Volume of the solid phase in the apparatus | 0.019 m³          |
| Sediment volume from filter press      | 0.029 m³          |
| Internal diameter of the apparatus     | 0.5 m             |
| Area of the radial section of the apparatus | 0.196 m²          |
| Initial height of sediment layer       | 0.147 m           |

Table 2. Agitator characteristics of the apparatus with a total volume of 100 l.

| Parameter                              | Value             |
|----------------------------------------|-------------------|
| Agitator type                          | turbine           |
| Executive agitator diameter            | 0.200 m           |
| Blade width                            | 0.050 m           |
| Blade height                           | 0.040 m           |
| Adopted maximum shaft speed            | 1500 rpm          |

3. Results

As a result of numerical simulation, the following results were obtained.

The distribution of the volume fraction of the solid phase in the apparatus changes for a speed of 1500 rpm when operating from a blockage (Fig. 2). There is a steady-state distribution of suspension velocities in the volume of the apparatus (Fig. 3).

The steady-state distribution of the volume fraction of the solid phase in an apparatus with a volume of 100 litres when pulping from a blockage with a mixer shaft rotation frequency of 1500 rpm is achieved in 30 s. At the same time, the distribution of the volume fraction of the solid phase is practically uniform.

The velocity field in an apparatus with a working volume of 100 litres is formed by local tangential meso-vortices: ascending at the apparatus axis and descending at the apparatus wall. In addition, axial meso vortices are formed in the upper two-thirds of the spacecraft. In the radial direction, the annular flow extends from the mixer blades to a distance of about 1.5 times the mixer diameter.
Figure 2. Change in the distribution of the volume fraction of the solid phase in the apparatus with a volume of 100 litres for a rotation speed of 1500 rpm when operating from a heap: a) before mixing, b) 30 s after the start of mixing and c) 60 s after the start of mixing.

Figure 3. Steady-state field of suspension velocities in an apparatus with a volume of 100 litres for a speed of 1500 rpm: a) in the axial section; b) in a radial section passing through the turbine stirrer disk.
4. Conclusion
The steady-state distribution of the volume fraction of the solid phase in the apparatus with a volume of 100 litres when pulping from a blockage with a rotation frequency of the mixer shaft of 1500 rpm is achieved in 30 s. The distribution of the volume fraction of the solid phase is practically uniform.

The velocity field of the suspension in the apparatus with a working volume of 100 litres is formed by local tangential meso-vortices: ascending at the axis of the apparatus and descending at the wall of the apparatus. In addition, axial meso vortices are formed in the upper two-thirds of the apparatus.

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