REDUCTION OF THE VOLUME OF PUMPING OF LIQUID WASTE FROM THE PRODUCTION OF APATITE CONCENTRATE DUE TO THE TECHNOLOGY OF PARTIALLY CLOSED WATER CIRCULATION

Alexandr V. Artemev[1]
Valentin V. Biryukov[2]
[1, 2] Mining Institute of the Kola Science Centre of the Russian Academy of Sciences, Apatity, Russia

ABSTRACT

The use of recycled water supply technology in mineral dressing plants solves current environmental and economic problems for the mining and processing industry. Usually, water treatment takes a long time and requires constructing large-volume tailing dumps.

The paper proposes a technology of a partially closed water circulation with the purification of watered production waste from suspended particles and water-soluble impurities that negatively affect the flotation process, based on the regularities describing the interaction of flocculants with the phases of a heterogeneous system of process waters.

The authors have determined the most effective reagents providing optimal indicators of recycled water. The proposed technology is implemented in hardware in a radial thickener and eliminates the discharge of process water into an external tailings dumps facility, which will reduce the area occupied by production waste.

Based on the particle size distribution data for various preliminary treatment options, differential and integral particle size distribution curves have been obtained. Analytical expressions of the obtained curves have been used to create discrete functions of volume fractions of particles with different sizes when constructing a model of the initial feed.

The hydrodynamic processes of highly diluted suspension flows in the thickener's body were studied using computational experiments on a model developed in the ANSYS Fluent software package, which is based on the real 3D geometry of a radial thickener. To build the geometry, the authors used a standard module GAMBIT. A computational experiment on cleaning the apatite concentrate discharge was performed on a virtual stand. The distributions of the concentrations of volume fractions of particles and the velocities of their movement in the thickener's volume were obtained.

The results of laboratory studies and computer simulation data allow the authors to tell about the prospect implementation of the technology of intra-plant water circulation, which will reduce by 10% the amount of wastewater discharged into the tailing dump. The use of the most efficient reagents will provide optimal

water parameters for the content of suspended particles and hardness cations and, ultimately, will increase the technological and environmental performance of the Khibiny apatite-nepheline ores processing.

Keywords: *water-preparation process, reagents-flocculants, flotation, apatite-nepheline ores, computer simulation*

INTRODUCTION

Along with the indisputable advantages, the introduction of recycled water supply at the mineral dressing plants has a number of problems affecting on the technological process. The ionic composition of water plays a specific role in using recycled waters for apatite-nepheline ores flotation. It has been found that the main components of recycled water are Ca^{2+}, Mg^{2+}, Fe^{2+}, K^{+}, Na^{+} cations and Cl^{-}, SO_4^{2-}, CO_3^{2-}, HCO_3^{-}, SiO_3^{2-} anions, as well as sludge and organic components [1].

The experience of the mineral dressing plants has revealed that the greatest influence on the change in the surface properties of minerals composing apatite-nepheline ores is exerted by suspended solids and Ca2 + cations. The particle size of suspended solids is usually in the range of 0.1-300 microns, i.e., from course to colloidal particles. The negative effect of sludge on the flotation process is the sorption of the collector on itself, a change in the ionic composition of the pulp and contamination of the apatite concentrate due to the mechanical removal of sludge into the froth. The study of the influence of Ca^{2+} cations on the apatite flotation has shown their interaction with soaps of fatty acids with the formation of sparingly soluble salts as colloidal dispersed formations and reducing the CMC (critical micelle concentration) of collectors. During flotation, cations activate the minerals' surface, violate selectivity, and deteriorate the concentrate quality [2,3]. Earlier works have proved that the ultimate value of calcium cations content in flotation water should not exceed 20 mg/l [4]. According to the experience of the dressing plants processing apatite-nepheline ores, the optimum amount of suspended particles is up to 900 mg/l.

Mining and processing enterprises use tailings ponds to treat process water for its further application. The water is clarified there under the action of gravitational forces. However, it takes considerable time and volumes of the tailings pond to achieve equilibrium of the processes occurring in the tailings dump. At present, the mining enterprises are interested in increasing the technological efficiency and environmental safety of ore processing by involving pre-treated process water of the processing plant without discharging it into the tailings pond.

The most promising source of water, which can be used in in-plant water circulation, is a discharge of the apatite concentrate thickener. The study of the characteristics of this product (Table 1) has shown the excess of the maximum permissible values by several times, which excludes its potential involvement in the technological process without additional purification.

Table 1. *Characteristics of the apatite concentrate thickener discharge*

Content of Ca^{2+}, mg/l	Content of suspended particles, g/l
52.2	27.363

The authors have proposed a technology of intensification of suspended particle separation by means of polyacrylamide flocculants, hardware implemented in the radial thickener [5].

Due to the complexity of industrial tests, the most perspective method to research the influence of technological parameters of the suspension on processes of thickening of the apatite concentrate discharge is a computational model experiment.

MATERIALS AND METHODS

At the first study stage the authors have assessed the efficiency of various organic flocculants differing by molecular weight, origin and quantity of ionogenic groups, in particular, the SNF company reagents, representing polyacrylamides of high molecular mass with various ionicities (Table 2).

Table 2. *Characteristic of reagents-flocculants*

Reagent class	Name	Ionicity	Molecular mass
Anionic flocculants	AN 956 SH	High, 50%	$(13.4\text{-}16.1)*10^6$
	AN 934 SH	High, 30 %	$(13.8\text{-}16.75)*10^6$
	AN 923 SH	Average, 20%	$(12.2\text{-}14.1)*10^6$
	AN 910 SH	Very low, 10%	$(11.6\text{-}13.75)*10^6$
Cationic flocculants	FO 4700 SH	High,70%	$(4.9\text{-}7.25)*10^6$
	FO 4400 SH	Average,30%	$(5.0\text{-}7.55)*10^6$
	FO 4240 SH	Low,16%	$(6.2\text{-}8.25)*10^6$

The flocculation activity of the studied polymeric reagents was determined on model and real disperse systems. As a model system the authors used a suspension of fine dispersed apatite concentrate particles (particle size -0.071 mm, P_2O_5 content - 39.34%) with the content of dispersed phase 2%, prepared on distilled and recycled water.

The hydrodynamic processes of highly diluted suspension flows were studied by means of computational experiments over a model developed in the ANSYSFluent software package. The main research task was to study the influence of technological parameters of the suspension on thickening processes and on the kinetics of the thickening process using polyacrylamide flocculants.

Proceeding from the fact, that the water treatment technology is proposed to be realized by a radial thickener in ANSYSFluent software package (license of Mining Institute KSC RAS), the mathematical model of working space of a 30-meter thickener was developed. The model is based on the real 3D geometry of a radial thickener with a central drive. The standard GAMBIT module was used to build the geometry of the radial thickener. The model is constructed of two main parts: a stationary volume (the thickener's body) and a dynamic volume (a prismatic element - thickener rake). The raking mechanism of the thickener is designed to move the deposited disperse particles to a discharge port and consists of a central axis and four radial rakes with blades. It was modeled using "SlidingMesh" technology. This technology allows the interaction of any rotationally and progressively moving components with multiphase fluid medium and vice versa. In this case, the rotating blades of the thickener's raking mechanism at a controlled speed transmit effort to the medium consisting of dispergating and several dispersed phases of the suspension.

The computational grid of 3D geometry of the virtual stand, as close as possible to the real Outotec thickener with a diameter of 30 meters has 670,000 tetrahedral elements. Feeding of the initial suspension and discharge into the model is performed through the upper and lower nipples of the cylindroconical body. It is possible to control the flow rates of supply and discharge of the suspension. The clarified water is drained through the upper section of the model. The flow of a highly diluted suspension was simulated in the working space of the thickener by multiphase Euler equations for one dispergating and several dispersed phases.

RESULTS AND DISCUSSION

The influence of ionicity on flocculation of fine disperse apatite concentrate particles was studied through concentration and kinetic dependences of the degree of clarification of the model apatite concentrate suspension in recycled water for a number of cationic and anionic flocculants (Fig. 1).

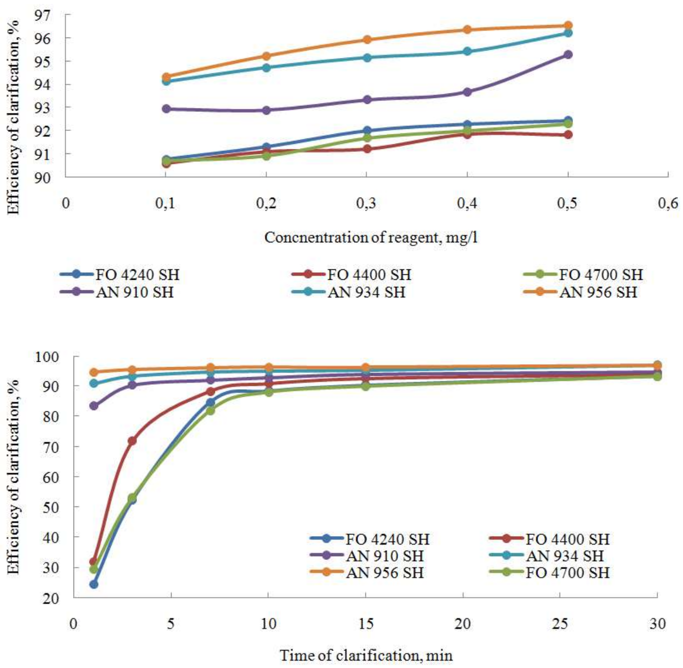

Fig. 1. *Concentration and kinetic dependences of clarification of a model apatite concentrate suspension in recycled water for a number of cationic (FO series) and anionic (AN series) flocculants*

The data show that anionic flocculants are more effective in their action. The advantage of an anionic flocculant is mainly seen in the first minutes of clarification. The anionic reagents-flocculants with a higher degree of ionicity (from 30 %) have a higher efficiency.

Further studies were aimed at creating models of initial feed for different preparation regimes. The real discharge of apatite concentrate's thickener was taken as a basis. As the majority of disperse systems, it contains particles of different sizes, and their content is not equal. Determination of particle sizes of the disperse phase and construction of the curves of particle size distribution is the essence of the sedimentation analysis.

Its use is limited by conditions of the Stokes equation application. To meet these conditions, the industrial thickener discharge with suspended particle content of 109.3 g/l was diluted with distilled water. The concentration of dispersed phase obtained is 1%. The sedimentation analysis was carried out according to known methods [6].

The studies were carried out in two modes:

- sedimentation of the apatite concentrate thickener's discharge without the use of chemical reagents;
- sedimentation of the apatite concentrate thickene's discharge using the developed technology: input of 0.2 mg/l of anionic flocculant AN 934 SH into the initial feed at pH-11.

The relative mass (share) of the sediment of the dispersed phase of the low-concentration suspension of the apatite concentrate thickener's discharge, accumulated during the sedimentation time τ is described by the following empirical functions:

- for a test without chemical reagents:
  $$F(\tau) = 100(1 - e^{-0.25\tau}) - \tau(25e^{-0.25\tau})$$
- for a test with flocculant AN 934 SH at pH-11:
  $$Z(\tau) = 100(1 - e^{-0.68\tau}) - \tau(68e^{-0.68\tau})$$

To characterize the fractional composition of the settling suspensions, the authors have plotted the integral and differential curves of particle size distribution, which show the mass share of each fraction (Fig. 2). The distribution curves were plotted by an analytical method [7].

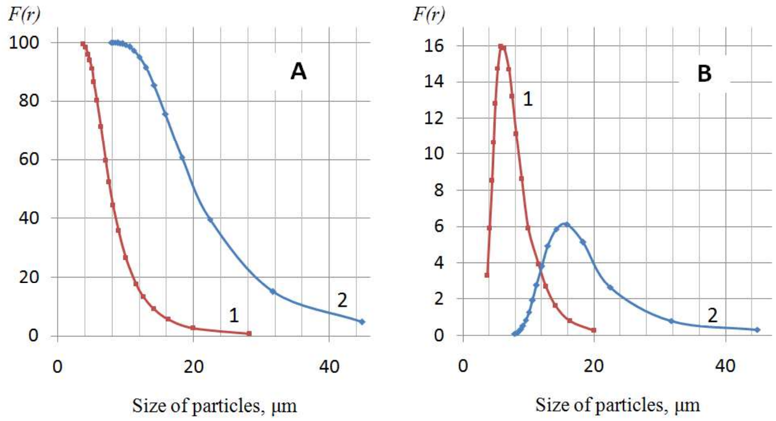

Fig. 2. *The integral (A) and differential (B) curves of particle size distribution form the apatite concentrate's discharge: 1 – without a flocculant, 2 - 0.2 mg/l AN 934 SH at pH-11*

The analytical expressions of the differential curves of particle mass distribution of the suspension by equivalent radius were obtained by differentiating the analytical expression of the integral distribution curves by the variable r. For a test without chemical reagents: $F(r) = -(16.129\tanh(0.323r - 2.226)^2 - 16.129$; for a test with flocculant AN 934 SH at pH-11: $F(r) = -(14{,}706\tanh(0.294r - 2.206)^2 - 14{,}706$

The obtained expressions were used to create discrete functions of volume fractions of particles with different particle sizes when constructing models of initial feed of each water preparation mode.

The computational experiments on the research of sedimentation of the apatite concentrate thickener's discharge under conditions of using a flocculant effectively binding apatite particles (anionic flocculant AN 934 SH with a degree of ionicity 30%) and without reagents (particles sedimentation by gravity) were set on the virtual bench.

The authors have obtained the distributions of concentrations of volume fractions of particles (Table 3, Fig. 3,4) and velocities of their movement in the volume of the thickener (Fig. 5).

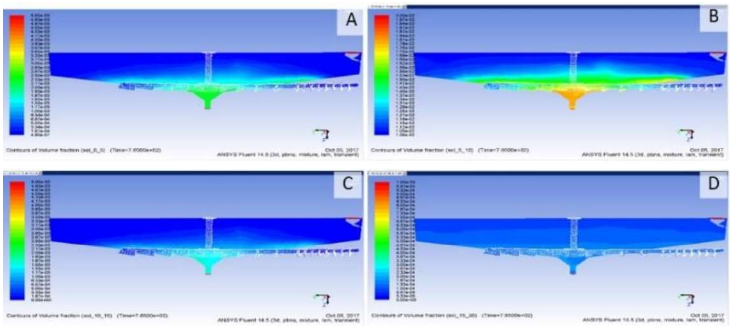

Fig. 3. *Fields of volume concentrations of solid phases of different coarseness of the suspension on the vertical section of the thickener's model (at sedimentation without reagents-flocculants);*

A - coarseness $0 – 5 \cdot 10^{-6}$ m; B – $5 \cdot 10^{-6} – 1 \cdot 10^{-5}$m; C – $1 \cdot 10^{-5}$ - $1.5 \cdot 10^{-5}$m; D - $1.5 \cdot 10^{-5} – 3 \cdot 10^{-5}$m

Table 3. *Distribution of volume fractions of particles*

Fraction of initial suspension, µm	Concentration of volume fractions, kg/s			Fraction of initial suspension, µm	Concentration of volume fractions, kg/s		
	Test without chemical reagents				Test with AN 934 SH at pH-11		
	Initial feed	Sands of thick-ener	Dis-charge of thick-ener		Initial feed	Sands of thicken-er	Dischar-ge of thicken-er
water	60,43	3,91	79,99	water	77,78	3,16	76,80
0-5	0.232	$5.88 \cdot 10^{-5}$	$4.36 \cdot 10^{-10}$	0-20	0.12	0.00168	0.02278
5-10	3.121	0.0039	0.0286	20-70	1.55	0.034	0.208
10-15	0.1032	$2.66 \cdot 10^{-5}$	$1.86 \cdot 10^{-10}$	70-85	0.65	0.034	0.041
15-30	0.000258	$3.48 \cdot 10^{-7}$	$1.93 \cdot 10^{-6}$	85-120	0.82	0.0776	0.0248
				120-170	0.499	0.0965	0.0064
				170-250	0.2699	9.4745	0.2327
				250-500	0.19	7.4389	0.34105
				500-850	0.0699	5.8578	0.1355

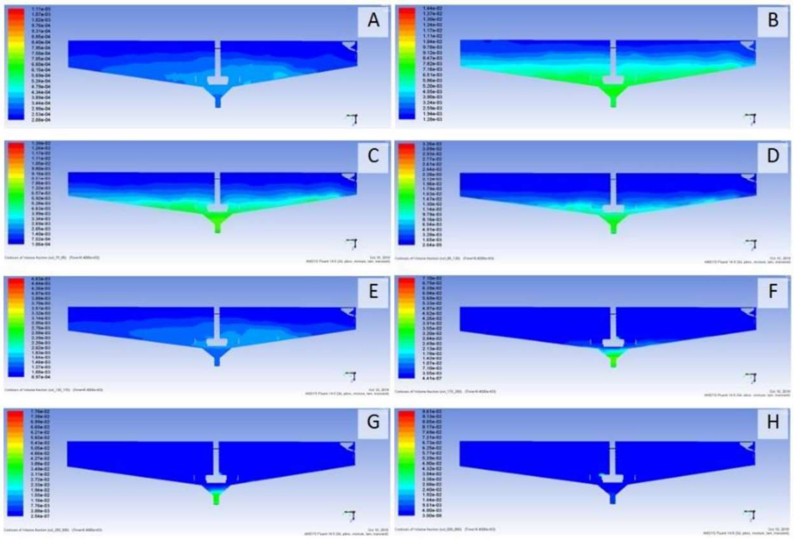

Fig. 4. *Fields of volume concentrations of solid phases of different coarseness of the suspension on the vertical section of the thickener's model (at sedimentation with flocculant AN 934 SH):*

A – coarseness $0 – 2 \cdot 10^{-5}$m; B - $2 \cdot 10^{-5} – 7 \cdot 10^{-5}$m; C - $7 \cdot 10^{-5} – 8.5 \cdot 10^{-5}$m; D – $8.5 \cdot 10^{-5} – 1.2 \cdot 10^{-4}$m; E – coarseness $1.2 \cdot 10^{-4} – 1.7 \cdot 10^{-4}$m; F – $1.7 \cdot 10^{-4} – 2.5 \cdot 10^{-4}$m; G – $2.5 \cdot 10^{-4} – 5 \cdot 10^{-4}$m; H - $5 \cdot 10^{-4} – 8.5 \cdot 10^{-4}$m

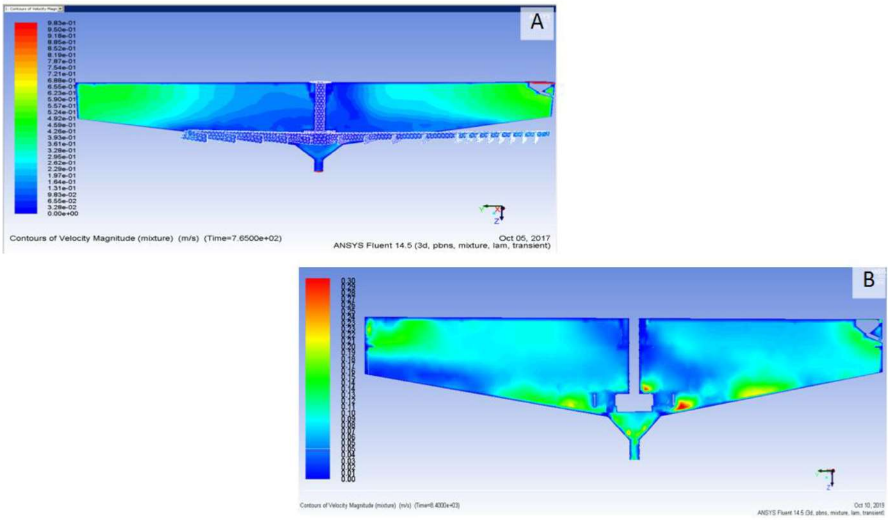

Fig. 5. *The velocity field of the suspension on the vertical section of the thickener's model*

A – at sedimentation without flocculants, B - at sedimentation with flocculant AN 934 SH

CONCLUSION

The authors have analysed the data obtained at this study stage and according to their conclusion, if the reagents-flocculants are not used, the main mass of volume fractions of the initial suspension accumulates on the inclined plane of the thickener's bottom and only a small part comes out through the discharge hole due to transportation with the rakes, but the sands of the thickener are heavily watered.

Thus, water preparation in a radial thickener cannot be carried out without flocculants due to the difficulty of achieving acceptable specific loads on solids. In case of using flocculants, according to the computational experiment results, there is an increase in particle settling velocities, due to enlargement of finely dispersed apatite particles and the density of the resulting thickener's sands. Rotating rotor rakes facilitate the movement of the sedimented suspension to the discharge hole of the thickener, and form the necessary operating mode which can provide mixing and amount of particle collisions necessary for floc formation.

The results of laboratory studies and computer simulation data allow to tell about the prospect implementation of the technology of intra-plant water circulation, which will reduce by 10% the amount of wastewater discharged into the tailing dump.

ACKNOWLEDGEMENTS

This publication has been produced with the assistance of the European Union. The contents of this publication are the sole responsibility of the following authors: A.V.Artemev, V.V. Biryukov and can in no way be taken to reflect the views of the European Union.

Kolarctic CBC
EU FINLAND NORWAY RUSSIA SWEDEN

REFERENCES

[1] Malinskaya I.S., Bacheva E.D. Research of features of selective apatite flotation under recycled water supply conditions. - Processing of oxidized ores. - M: Nauka, 1985. - pp. 205-211

[2] Golovanov G.A. Flotation of the Kola apatite ores. - M: Chemistry, 1976. - 216 p.

[3] Golovanov V.G., Petrovsky A.A., Brylyakov Yu.E., Introduction of recycled water supply at ANOF-2. - Gornyi Zhurnal. - 1999. - № 9. - pp. 48-50.

[4] Gershenkop A.Sh., Mukhina T.N., Artemev A.V. Features of the mineralogical composition of apatite-nepheline ore from the Oleniy Ruchey deposit and their impact on the processing performance. - Ore beneficiation, No. 3, 2014, pp. 33-36.

[5] Mitrofanova, G.V. Ivanova, V.A. Artemev A.V. Use of reagents-flocculants in water-preparation processes during phosphorous-containing ore

processing. - 17th International Multidisciplinary Scientific GeoConference SGEM 2017, SGEM2017 Conference Proceedings , June 29 - July 5, 2017, Issue 11, Vol. 17, 1143-1150 pp.

[6] Practicum on colloidal chemistry, edited by I.S. Lavrov. - M: Higher School, 1983. - 206 p.

[7] Zimon, A.D., Leshchenko N.F. / Colloidal Chemistry. - M: Agar, 2001. - 318 p.