Simulation of Three Hardware Potassium Flotation Control Facilities Based on System Thinking

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Abstract: This article discusses the issues of modeling three hardware units for controlling the flotation of potash ore based on systems thinking. On the basis of system analysis, it was determined that a flotation apparatus having a number of input and output parameters is characterized by control and controlled variables. Determination of the input, output, and internal parameters of both the system and the process allows one to define and carry out a preliminary analysis. Subsequently, the relationships between the parameters are determined. In most cases, determining the relationship between the output and input parameters provides a more complete analysis of the research object. After that, it is possible to proceed to determining optimal solutions. The improvement of technological processes and flotation devices is demonstrated on the basis of systems thinking and modern trends in the development of ore processing plants. Multistage methods, computer models, and algorithms for more accurate calculation of the dynamics of technological apparatuses are proposed; the coefficients of technological processes and operating modes of three-vessel flotation units are determined.

1 INTRODUCTION

In global production, research and development in the field of manufacturing, as well as modeling and optimization of technological processes in the context of modern scientific and technological progress, have enabled industry to increase productivity by reducing energy consumption and improving product quality through the widespread use of modern technologies in the development of high-performance, reliable, and cost-effective technological equipment. At the same time, the search for optimal solutions for technological processes in practice remains one of the main areas of technical development aimed at increasing productivity, improving product quality, reducing costs, facilitating working conditions, and protecting the environment.

The main direction in the technology of mineral processing and automation of processes at a modern potash flotation plant is the production of high-quality fertilizers with minimal losses of valuable components and high technical and economic performance indicators.

The production of fertilizers with improved physical and chemical properties is driven by the needs of agriculture, production economics, and increasing demand in the global market. Therefore, improving potash ore beneficiation technology through the development and implementation of more advanced technological schemes, new high-performance and efficient equipment, optimized reagent regimes, and full automation of production processes is currently highly relevant and in demand [1]. The urgency of improving beneficiation technology is also associated with the need to develop new potash deposits in Uzbekistan, Kazakhstan, and Turkmenistan in order to produce competitive potash fertilizers for domestic and global markets [2]. For this purpose, an approximate model of a modern potash flotation plant has been developed and proposed, integrating advanced directions in beneficiation technology and process automation.

The methodology of systems thinking [3], [4], building on existing methods, makes it possible to analyze complex systems effectively. In this study, system analysis is considered a more comprehensive stage of analysis and the search for optimal solutions.

This involves a thorough investigation of the object of research, representing it both as a system and as a set of processes occurring within the system and its subsystems (quasi-devices). The determination of input, output, and internal parameters of both the system and the process enables a preliminary analysis to be performed. Subsequently, the relationships between the parameters are identified. In most cases, establishing the relationships between output and input parameters provides a more complete analysis of the object under study. This then allows the determination of optimal solutions.

In general, systems thinking and analysis, as well as system synthesis, are carried out in the following sequence:

- First stage (systems thinking and analysis): the selected object, element, system, and process are preliminarily studied; system requirements are formulated; and the input and output parameters of both the system and the process under study are determined.
- Second stage: determination of relationships between parameters. In most cases, this requires deeper investigation of the system, after which the elements and subsystems are identified.
- Third stage (selection of the optimal solution).

2 SYSTEM MODELING

2.1 Flotation Equipment and Process Description

In general, passing into systems thinking and analysis, the apparatus for flotation of potash ore is considered:

In the first stage of systems thinking:

- the selected object of potash ore flotation is preliminarily studied - element - system and process. System requirements are formed;
- the input and output parameters of both the system and the studied process of potash ore flotation are determined.

Flotation is a process of separation of finely ground minerals, carried out in an aqueous medium and based on the difference in their ability (natural or artificial) to be wetted with water, which determines the selective adhesion of mineral particles to the interface of two phases.

The flotation process is carried out most often in a three-phase system that includes solid (S), liquid (L) and gaseous (G) phases. Of all the varieties of the flotation method of beneficiation, the most widespread is froth flotation, which is based on the ability of non-wet table (hydrophobic) minerals to adhere to air bubbles formed as a result of aeration of the pulp and float with them to the surface of the pulp, forming a foam product, while wet table (hydrophilic) minerals - to remain suspended in the pulp, forming a chamber product. Mineral particles fixed on the surface of air bubbles are called floating, not fixed - non-floating. The size of the floated particles during froth flotation usually does not exceed 0.15 mm for ores containing heavy minerals [5].

To increase the natural difference in the surface wettability of minerals or to artificially create such a difference, the mineral surface is treated with special substances called flotation reagents [6]. By selecting flotation reagents, conditions can be achieved under which some minerals will float and others will not, i.e. create conditions for their selective separation. The essence of the froth flotation process is as follows. The initial pulp, after processing it with flotation reagents, enters the flotation machine, where it is saturated with air in the form of small air bubbles. Nonwettable (hydrophobic) particles when colliding with bubbles adhere to the latter, creating aggregates consisting of air bubbles with solid particles fixed on them. Aggregates with a density lower than the density of the pulp float to its surface, forming a layer of mineralized foam that is removed from the surface. Wettable (hydrophilic) particles do not adhere to air bubbles and remain in the pulp volume, forming a chamber product [7].

Usually, a useful mineral is extracted into the frothy flotation product and the waste rock minerals are extracted into the chamber product. This process is called direct flotation. In some cases, it is more expedient to extract the minerals of the waste rock into the foam product and concentrate the useful minerals in the chamber product. This process is called reverse flotation. If a concentrate containing two or more valuable components is obtained in the flotation process, such flotation is called collective flotation. If several concentrates are successively obtained in the flotation process, with only one valuable component in each individual concentrate, such flotation is called selective. If, in the process of flotation, a collective concentrate is first obtained and then successively valuable components are isolated from it into independent concentrates, such flotation is called collectively selective [6].

The flotation machine provides pulp aeration and mineralization of individual particles with a more hydrophobic surface, alignment and removal of mineralized foam.

For example, it is designed to separate sylvite and halite minerals using flotation, which utilizes the different adhesion properties of these minerals to the interfacial surface. The chamber volume is 6.3 cubic meters, the motor power is 30 kW and the throughput is 12.6 cubic meters/min. The key parameters for this model are listed in Table 1.

Table 1: Technical specifications of the LMZ Universal FM-6.3 KSM flotation machine.

Chamber capacity	6.3 cubic meters (m)
Throughput 0.21 cu. m / sec	12.6 cc m / min
Two-chamber section weight	7350 kg
Average total life of impeller and stator	8500 h

2.2 Computer Modeling of a Three-Unit Flotation Plant

The second stage (building a computer model), where several sub steps take place [8], [9].

The construction of the model is intended for the calculation of a three-device installation with ten cas-layer structures of potash salt flotation in each device (Fig. 1).

On the basis of system analysis, it was determined that a flotation apparatus having a number of input and output parameters is characterized by control and controlled parameters. Among the output parameters, we can talk about two controlled variables. This is the amount (or concentration) of the valuable component in the gas phase and the amount (or concentration) of the valuable component in the liquid phase. These output parameters are influenced by the input parameters, these are the slurry flow rate and gas flow rate in the flotation apparatus. It was determined that the main control parameter for the flotation apparatus is the gas flow rate. The identification of the apparatus is carried out on the basis of typical models. The flotation apparatus is considered as a stable object with lumped parameters. When solving control problems for these devices, a typical model of an inertial link (or aperiodic link of the first order) is used, which, from the point of view of processes and devices of chemical technology, can be attributed to a link of ideal mixing.

Let us now turn to inter-element influences, i.e. interfacial action, in which the useful component from the liquid layer will pass into the gas phase. This phenomenon is characterized by the coefficient of mass transfer.

Here, the concept of the equilibrium concentration of valuable components can be introduced. The actual concentration of valuable components in the liquid phase is determined by the equilibrium concentration, which depends on the properties of the binding agents and the nature of the gas phase. The transient process, i.e., mass transfer between the liquid and gas phases, is then described by the mass transfer (1):

$$\frac{dY_i}{d\tau} = Q_y k(y_i - y_{i-1}) + A_v V_a (x - y_i) \quad (1)$$

Here: y_i – is the concentration of the incoming gas, y_{i-1} – outlet gas concentration, Q– gas consumption, k – gas condition coefficient, A_v –coefficient of mass transfer from liquid to gas, V_a – quasi-layer volume, x – concentration of a valuable component in a liquid. Now you can compose the material balance equation in this form:

$$((Qg*u(3)*(u(2)-u(4)))+(Av*Va*(u(1)-u(2))))/(Va*rog*u(3)) \quad (2)$$

The process in the gas phase in the selected quasi-layer has a computer model in the form shown in Figure 2. The liquid phase in each quasi-acid has common characteristics. In the cube of the flotation apparatus, almost ideal mixing of the liquid occurs, at which the concentration of the valuable component at all points of the apparatus will be the same. Therefore, for the liquid phase, one mass transfer equation is constructed (or a block that calculates the concentration in the bubble cube) (Fig. 3).

This model receives signals about the parameters: air flow rate in the apparatus, concentration of valuable components in the incoming air, flow rate of suspension or pulp in the bubble cube, initial concentration of valuable components of the liquid phase. The model determines the values of the input concentration of the components in the liquid phase. Blocks of the computer model show changes in the input concentration of valuable components, both in the liquid and in the gas phases. A computer model of the process in a bubble cube is formalized.

Based on the models of the gas phase and the liquid phase of the bubbling cube, a computer model of the process in the bubbling cube of the flotation apparatus was obtained (Fig. 4). Input parameters - equilibrium concentration of the material in the gas phase, the concentration of the material in the liquid phase, the initial values of the concentration in the liquid phase.

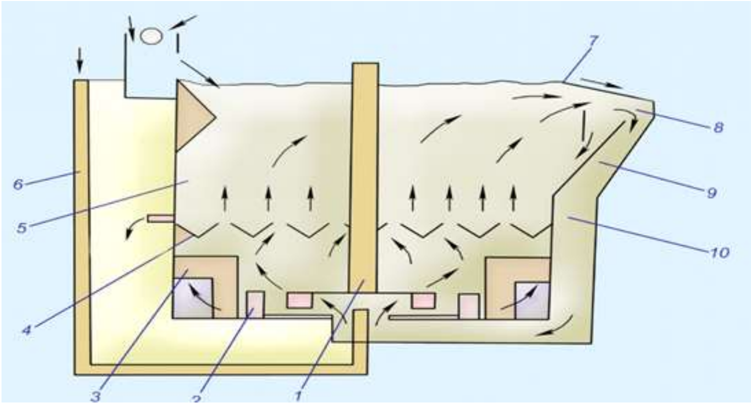


Figure 1: Flotation machine for fluidized boiling of pulp, in particular, in an apparatus for sylvite flotation of potassium salts: 1 - central pipe of the aerator block; 2 - shaft; 3 - impeller; 4 - supra-impeller glass; 5 - supra-impeller disk; 6 - guide vanes; 7 - pipe; 8 - split grille; 9 - circulation pocket.

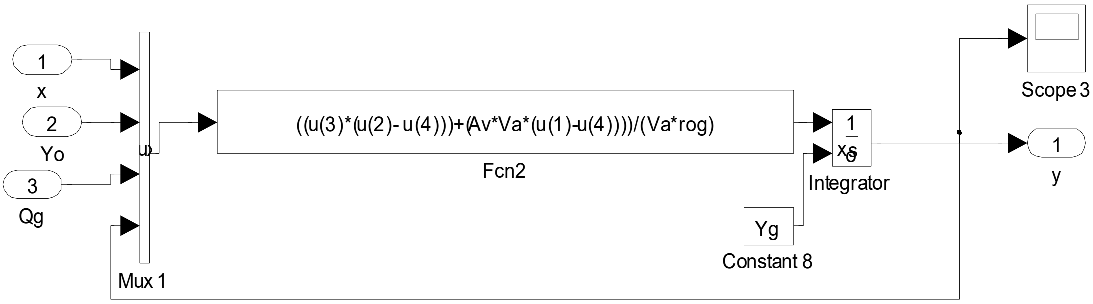


Figure 2: Computer model of the process in the quasi-acid gas phase of the object of one-stage flotation.

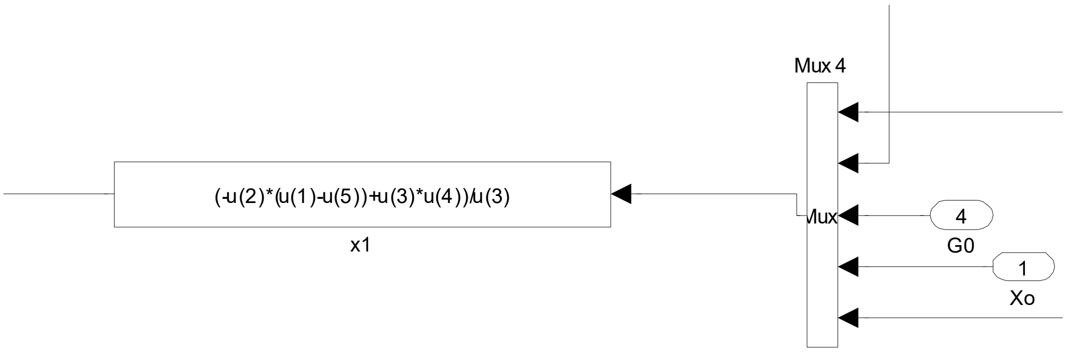


Figure 3: Block for calculating the equation of mass transfer in a bubbling cube.

This computer model receives signals about the input parameters: the air flow rate in the apparatus, the concentration of valuable components in the incoming air, the pulp flow rate in the bubble cube and the initial concentration of valuable components in the liquid phase.

According to the model, the values of the concentration of components in the liquid phase are determined by calculation.

2.3 Analysis of the Flotation Process Simulation

The functionality of the proposed software product consists in the fact that when inputting the initial data into a computer model of a three-device plant with a ten-layer structure, the computer will automatically calculate the necessary process parameters for a three-device plant with a ten-layer flotation structure

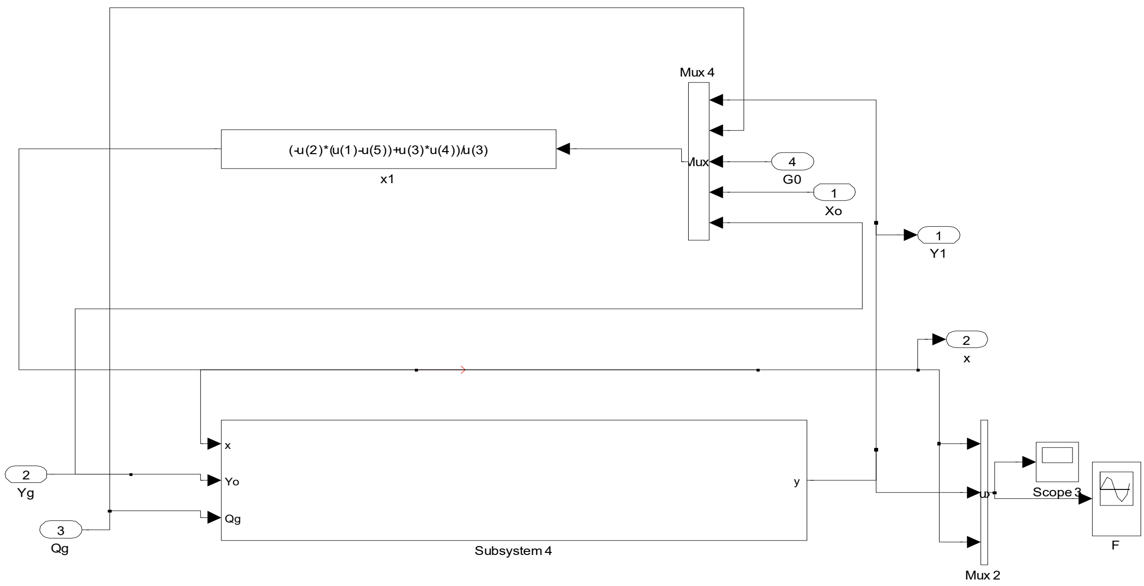


Figure 4: Computer model of the bubbling zone based on the MATLAB application program.

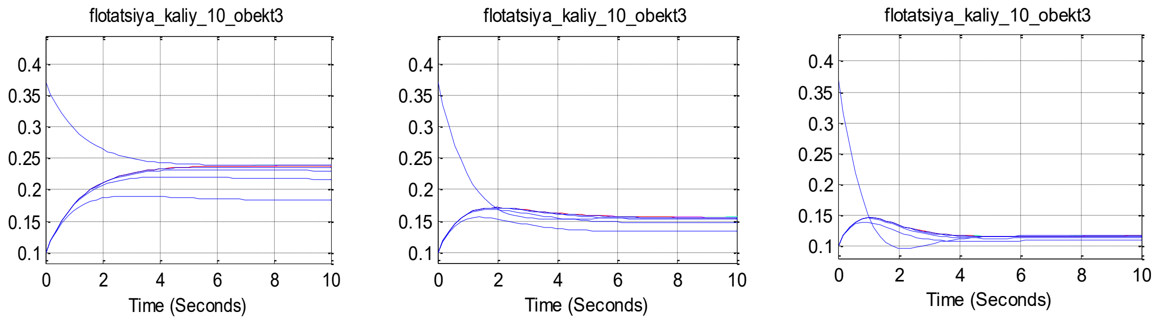


Figure 5: Results of a three-device plant with ten cas-layer structure of potash salt flotation.

in each device. The expediency of using each apparatus and the possibility of obtaining the maximum recovery of valuable components when using a three-apparatus installation of ten causal flotation structure in each apparatus is revealed.

The program can be used in the tasks of determining the optimal values of the apparatus and the parameters of the technological process of flotation of precious metal ores in a three-apparatus installation with a ten-layer flotation structure in each apparatus

The determination of the coefficient of mass transfer from the pulp to the bubbles of the gas phase in the working zone of the flotation apparatus is essential [10]. The mass transfer coefficient is determined by the methods of the Kolmogorov criterion by considering the probability distribution. The consistency of the change in the output parameter in the working area of the flotation apparatus in time when the disturbing effect is applied by changing the input parameter.

In this intelligent control in the flotation apparatus, the control parameter is the air flow rate and the output-controlled parameter is the concentration of the valuable component in the outgoing slurry. By abruptly changing the air flow rate, it is possible to trace the change in concentration in the outgoing pulp flow. For this, two variants of determining the change in the output parameter were used.

Object identification, based on the analytical method with perturbation, by determining the change in the output parameter in the form of a transient curve. This graph shows that from its maximum value, the parameter will decrease to a certain value. The nature of this change is due to the laws of probability distribution. The nature of the change in probability can be reflected by determining the maximum value of the change in the output parameter (Δy). Dividing each value of the output parameter increment by the difference of the change Δy, the distribution of the probability of the output parameter change from the input parameter over time is determined. At the beginning of the transient process, the probability is zero and at the end of the transition period, when the object comes to a steady state, has a maximum value, equal to one. As a result, we obtained the nature of the change in probability over time [P = f (τ)].

Exactly the same nature of the probability distribution takes place in cases when the analytical model is used. Thus, based on the identification of the object, the curves of the transient process are transformed in the coordinates of the probability of changing the output parameter due to the introduction of a disturbing effect. Any form of disturbance can be translated into a similar probability distribution apparatus in time. We compiled a mathematical model, then it took the form of a computer model based on an analytical and experimental approach. The acceleration curve obtained by the analytical and experimental model is shown in Figure 5.

As a result, we got the probability distributions for two cases. The first case is an identified object, the coefficients of which were selected according to the size of the existing installation and the equations were determined according to the indicators of a real installation and the identification was carried out carefully. The second option is an analytical model.

The adequacy and consistency of the results can be determined by comparing the two curves of the probability distribution. For each moment in time (5-10-15-20 seconds), we compare the values of the points of the curves, we obtain the difference in the probability distribution. As a result, discrepancies in the probability distribution were obtained: the smaller the area of the obtained curve, the better the match. If this difference is too large, then it is necessary to correct the computer model obtained analytically. The model includes the mass transfer coefficient, which characterizes the transition of a valuable component from a liquid to a gas phase. By changing the value of this coefficient, you can reduce the analyzed area, but in this particular case the coincidence is acceptable, so you can use the standard deviation criterion:

$$\sigma = \frac{1}{n}\sqrt{\sum \left(P_{u_i} - P_{м_i}\right)^2} \,.> \min.$$

Obtaining the root-mean-square deviation of the probability distribution over the values of the output parameter, the correspondence of the two methods was found; in the case under consideration, the degree of coincidence entered the zone of 0.95.

As a result of the study, it became possible to create an analytical and experimental model of a flotation object, as well as to perform mathematical calculations that are suitable for the implementation of analytical identification of the flotation process. By comparing the two models, the potential for adequacy can be seen.

It should be noted that the method for calculating the mass transfer of the flotation process, the most important components are gas bubbles passing through the fluidized liquid. The work made it possible to create a computer model using practical applied software packages based on a mathematical model of the flotation process.

In accordance with Kolmogorov's criteria for assessing the adequacy of mathematical models, the probability of transition of the flotation process from one state was determined by the transition line. The analytically obtained computer model reflects the probability of the object transition from the initial state to the final stable one. The corresponding probabilities of its transition from one state to another and the probability distribution in time are determined experimentally on the physical model of the object. The probability distribution can be compared to the actual probability distribution (Fig. 6).

The experiments were carried out on different values of the mass transfer coefficients. The results were compared with the calculated values of the parameters of the identified model (Fig. 7).

Figure 7 shows the results of comparison by the standard deviation criterion of the calculations of the distribution of the probabilities of dynamic changes in the parameters of the output product, performed using an analytical computer model, with experimental data obtained on a real physical model of the ore flotation process in the bubble cube of the flotation machine. Figure 8 shows the standard deviations of the probability distribution of dynamic changes in the parameters of the outgoing product depending on the mass transfer coefficient in the flotation apparatus.

The results showed that the most acceptable degree of adequacy is provided if, we simulate a computer model with a mass transfer coefficient of 0.03.

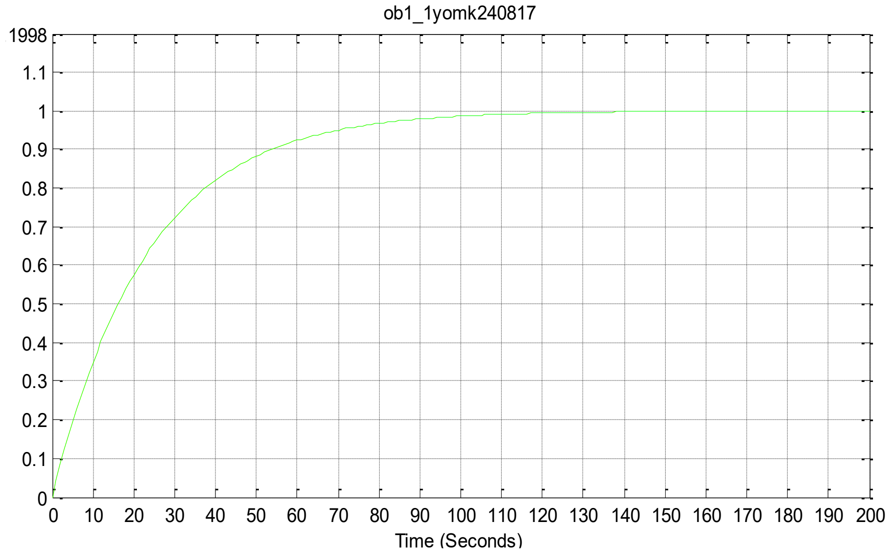
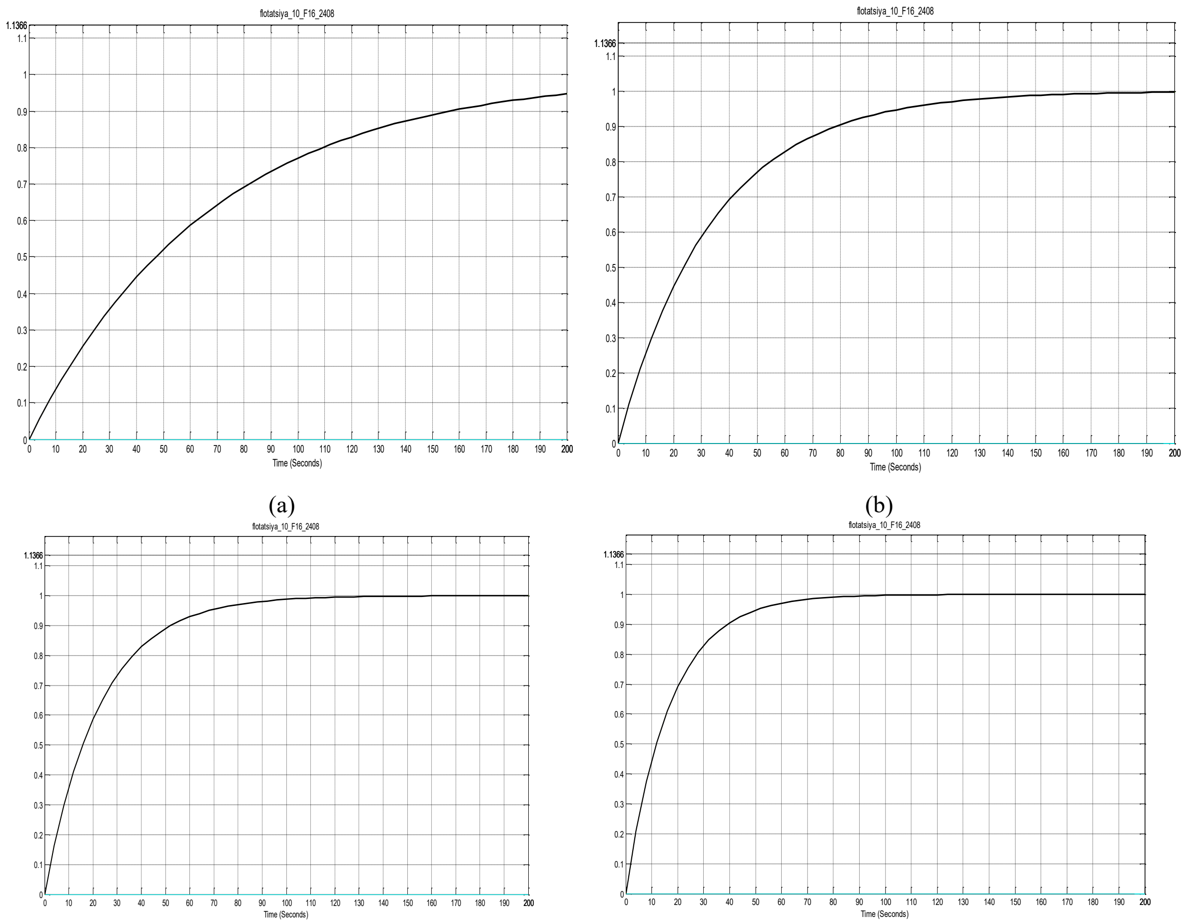


Figure 6: Transient process of ore flotation.



(a) (b) (c) (d)

Figure 7: Transient processes according to the analytical model at search values of the mass transfer coefficient: a) k=0.01; b) k=0.02; c) k=0.03; d) k=0.04.

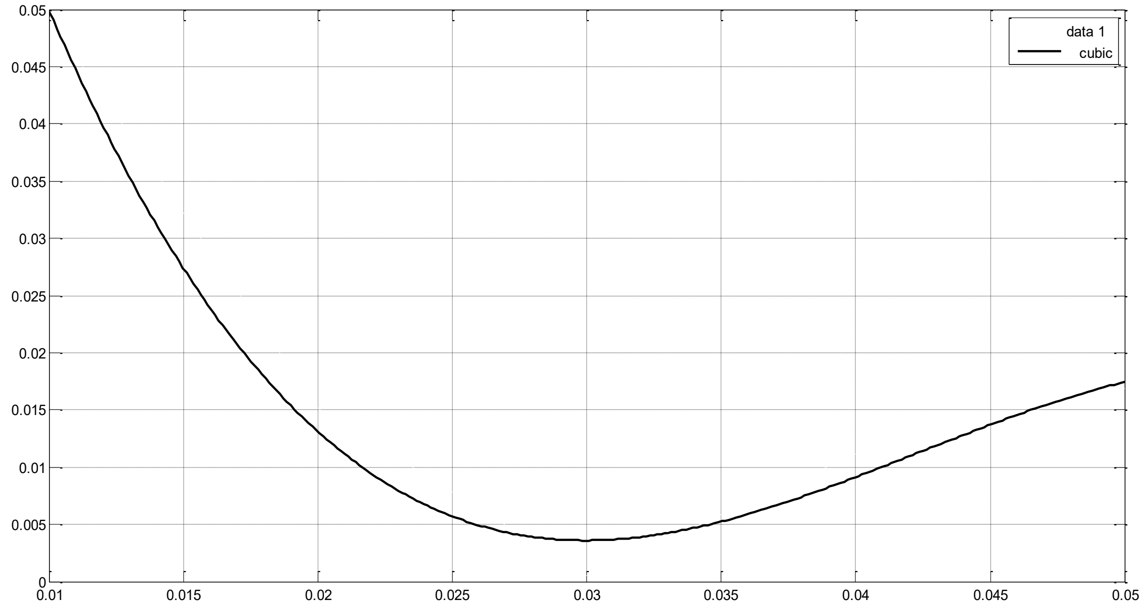


Figure 8: Standard deviations of the distribution of the probabilities of dynamic changes in the parameters of the outgoing product depending on the coefficient of mass transfer in the flotation apparatus.

3 CONCLUSIONS

The developed mathematical model of the process provides designers with effective solutions for equipment design problems and the selection of optimal operating modes. On the basis of systems thinking and modern trends in ore processing plants, the improvement of technological processes and flotation devices has been substantiated. The planned experiments and the obtained dependencies of potassium chloride concentration on input parameters of the flotation unit in potash fertilizer production were analyzed. Multistage methods, computer models and algorithms for more precise calculation of the technological apparatus dynamics are proposed, while the coefficients of technological processes and operating modes for one-, two-, five- and ten-shell flotation plants are determined. In particular, the coefficient of mass transfer of valuable components (0.03) from the liquid phase to the gas phase was experimentally established. These research results contribute to sustainable development by enhancing the efficiency of mineral processing and ensuring rational resource use, while also supporting ecological safety through the optimization of operating modes and reduction of negative environmental impacts. A method for determining the value of the action coefficients for optimal control of the dynamic process in the apparatus is recommended.

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