Problematics and perspectives of the development of automatic control systems for concentration tables using computer simulation

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Abstract. The Concentration tables are widely used for the enrichment of various materials due to a number of reasons, which include the low cost of the process and aggregates, high recovery of concentrate; environmental friendliness of the process. However, there are a number of problems associated with both the specific capacity of a single apparatus and the need to adjust the parameters of the process mode in accordance with the characteristics of the used raw materials. Currently, there are no automatic control systems for concentration tables, which is associated both with the lack of a mathematical apparatus for assessing the ore behavior during the process and with the complexity of using computer simulations for various types of materials consisting of liquid and solid systems. This article presents the prospects for the development of automatic control systems for concentration tables with regard to industry development trends.

1. Introduction

Concentration tables are widely used in mineral processing. These units are commonly used in the processing of gold, coal, silver, platinum group metals and other materials [1]. Their distribution is caused by a number of factors, which include the low cost characteristics of the units in terms of their operation, simplicity of the process and pre-commissioning activities, the absence of toxic reagents and, consequently, the ecological purity of the process.

The significant disadvantage of concentration tables is their low specific productivity, as a result of which there is a need to introduce a large number of units of this type into the production process [2]. The above mentioned aspect is the main reason for the spread of concentration tables as laboratory equipment, as well as for processes characterized by low specific productivity (including the enrichment of rare-earth and precious metals).

The enrichment on concentration tables is realized due to the gravitational / inertial forces acting on the wet material, realized due to the asymmetric reciprocating motion of the deck. In addition, flushing by a stream of water in the direction perpendicular to the direction of movement of the material is realized on the units. It allows minimizing friction of the particles, as well as effective separating them in a turbulent mode of fluid flow [3].

Material characteristics (density, particle size and shape), as well as the operation mode of the concentration table (including the parameters of the reciprocating motion of the deck, the angle of
inclination of the table, the flow of water and granular material) most affect the specific performance of the concentration tables. Consequently, in order to increase in efficiency, there is a need to calibrate the mode of operation of the unit depending on the characteristics of the incoming material.

2. **Prospects for the development of automated control systems for concentration tables**

At present, the selection of the parameters of the operating regime of the concentration table is carried out manually on the basis of laboratory studies conducted for the average composition of particles, as well as taking into account the experience of the staff of the workshop.

One of the main problems in determining the optimal parameters of the concentration tables is related to the transfer of data due to the lack of a sufficient theoretical basis that allows making additional corrections to the process. Whereas laboratory-scale experiments examine only average ore compositions, as a result of which constant adjustment of concentration tables is necessary during their work at specific time intervals.

The correction of the operating mode of the concentration table is made manually by the staff of the workshop. The discreteness of the adjustment is often not associated with changes in the input parameters of bulk materials, but with the employment of staff, which greatly affects the unit capacity and the extraction of the target component.

The low degree of automation of the process at concentration tables is often associated with high costs for automation equipment, low efficiency of these systems due to the lack of a mathematical apparatus for characterizing the process, as well as the lack of the necessary flexibility and predictability of automated control systems that would eliminate the human factor from managing these units.

Nowadays, there are trends in the implementation of mathematical modeling of concentration tables [4-8]. There are two fundamentally different approaches in the study of concentration tables using the method of mathematical modeling. The first method explores the dependencies formed on the basis of empirical output data for the material depending on the concentration table operation mode. The data obtained is often applicable in a particular production, taking into account the use of identical concentration tables and ores similar in composition. The derived formulas frequently do not allow obtaining fundamental information in the course of the process, as a result of which the data obtained are not universal and do not allow predicting the optimal operation of the concentration table in the case of using fundamentally different ores by physicochemical properties.

Moreover, the construction of mathematical models based on experimental data is characterized by the restriction on the number of experiments. The use of a full factorial experiment to optimize the course of research introduces a complementary error in the data obtained. Concentration tables are characterized by a study that includes no more than two or three joint parameters, which ultimately affect the extraction of a valuable component, as a result of which there is no generalized view of the process of separation into this equipment.

Consequently, the similar method of mathematical modeling is reduced to the need for continuous adjustment of mathematical dependencies according to the properties of the ore used and the characteristics of the concentration table, furthermore the resulting equations are selected depending on the behavior of the pulp and do not have a physical basis.

The second approach is the use of principles of physics to describe the behavior of particles on a concentration table. In this case, there are difficulties associated with choosing the mathematical apparatus that most characterizes the work of the concentration table. Furthermore, the unit is characterized by a complex physical base due to the presence of vibration and two phases (liquid and solid). The development of additional software is impractical due to the high complexity of the described processes and the need to use powerful computing equipment. However, this approach allows estimating the trajectory of the particles, which is virtually impossible to implement on industrial and laboratory scale units in consideration of the small size of particles.

Consequently, the modeling methods of concentration tables used at the current moment do not provide a rough idea of the nature of the process. The data obtained depends either on the experiment
plan drawn up by the researchers, or on the physical dependencies chosen to describe the process. Based on the above mentioned aspects, it can be concluded that it is necessary to use a fundamentally different approach for modeling concentration tables.

Currently, computer modeling of technological processes and equipment is being actively used [9-15], including these methods are beginning to be applied with respect to mineral-processing equipment. Bundled software for computer modeling is distinguished by high functionality and complexity of the principles of physics included in the program, as a result of which the results obtained are highly convergent with respect to real processes.

3. Prospects and problems of sharing methods DEM and CFD

To evaluate the pulp behavior, it is advisable to use DEM and CFD modeling methods together [16-20].

DEM-modeling (discrete element method) allows simulating bulk materials, where each element is considered separately. There are a number of problems associated with the use of DEM modeling for ore modeling. These include: the complexity of the shapes of particles and the variability of their size, the inconstancy of the composition and properties of ores, the difficulty of determining the main characteristics of materials (including dynamic and static friction, rheological properties and others) [21-25].

The problem of determining the parameters of bulk materials for further computer modeling is typical for the entire mining processing industry. The most frequently, reference data or laboratory scale experiments are used to assess the behavior of bulk materials. To achieve convergence of the results obtained on the physical and computer models, the parameters of bulk materials are selected iteratively. The foregoing significantly affects the accuracy of the measurement method.

Currently, methods for determining the parameters of bulk materials are being developed [17-21], however, there are difficulties in assessing the adequacy, predictability and scalability of models implemented using these methods, which is caused by the need to reconcile models in kind.

The use of DEM-modeling allows estimating the behavior of exclusively bulk materials, which introduces a number of measure of inaccuracies in the resulting model, namely: the lack of consideration of the influence of the regime of fluid motion on the ore behavior; the absence of segregation of particles by gravity and other.

For leveling these factors, it seems appropriate to further use the CFD method (computational fluid dynamics). The introduction of computational fluid dynamics (CFD) is necessary to assess the behavior of the liquid phase and the influence on it of the process parameters (parameters of the reciprocating motion of the deck, the angles of the table, the flow of water and bulk material) and the behavior of the granular medium environment (the so-called two-direction integration).

It should be pointed out that the joint use of the DEM and CFD methods is quite resource-consuming and time-consuming to implement, as a result of which there is no possibility to promptly use computer simulations for adjustments to the operating mode. It is possible to use supercomputers to solve these problems. However, their implementation on the basis of enterprises is impractical from an economic point of view. As a possible option is to attract outside companies to carry out the necessary calculations, but it will also have a negative economic effect, furthermore the results obtained will characterize some averaged over the charge, which will significantly reduce their applicability to the enterprise.

Consequently, it conceivable to develop a digital twin based on the resulting model, which will greatly simplify the automation of concentration tables, as well as reduce resource costs for evaluating the behavior of the pulp depending on the variation of process parameters.

The creation of digital twins (a computer model that describes the product or process as accurately and completely as possible) is one of the main trends in engineering manufactory, automotive industry and other similar industries [26-30]. However, in consideration of the complexity of the enrichment processes, this method was not widely used. The cumulative introduction of a digital twin and a digital shadow (a computer model operating on a database obtained from inbuilt tool of the process
automation) is proposed to refine the mathematical dependencies. Digital shadow will allow clarifying the results of computer modeling by means of obtaining relevant industrial data. The introduction of a digital twin and a digital shadow will solve the problem associated with varying the characteristics of the incoming charging material, which will greatly increase productivity and simplify the process of managing concentration tables.

4. Conclusion
At present, concentration tables are characterized by a low degree of automation, and they are often managed manually by the workshop staff.

The complexity of the implementation of automation systems for concentration tables is associated with a number of reasons, which include the lack of a mathematical apparatus for evaluating the behavior of the material / pulp in the enrichment conditions, and high time expenditure in terms of modeling the totality of liquid and solids.

The use of computer simulation, namely the combination of DEM and CFD methods seems to be the most promising. It will clarify the existing mathematical dependencies, greatly simplify them, which in turn will reduce the time expenditure on subsequent iterations of computer modeling, as well as develop automatic control systems with low cost estimate and high accuracy. In the time following, it is proposed to build a digital twin based on the developed computer model. The digital twin will be adjusted by using data from a digital shadow, which will optimize the process of selecting the parameters of concentration tables depending on the characteristics of the incoming charging material.

References
[1] Isaev I N 1962 Concentrations tables (Moscow: Gosgortekhizda)
[2] Sokur A K 2012 Overview of gravitational technologies of enrichment of coal slimes of non-flotation size Zagagachennya korisnyh kopalyn 92(51)
[3] Lenev L A, Kuskov V B, Vasil’ev A M 2007 Different methods of enrichment from hematite ore Obogashchenie Rud 1 6-8.
[4] Bukin S L, Komarov V F and Shold R A 2013 Mathematical model of fluid motion in inter-column space of a concentration table deck Scientific works of the Donetsk Nat. Technical University. Sir: Mining and electromechanical 1 47-56
[5] Yuryevich B V., Borisovich K V 2016 Production of fuel briquettes from carbon containing materials XVIII International Coal Preparation Congress Springer, Cham 701-705
[6] Evdokimov S I 2013 Improving the technological schemes of jigging and concentration on the tables during the enrichment of gold-bearing raw materials Mountain Journal 12 59-62
[7] Zvonarev I E, Shishlyannikov D I 2017 Information and diagnostic tools of objective control as means to improve performance of mining machines IOP Conf. Series: Materials Science and Engineering 177
[8] Koptev V Yu and Kopteva A V 2018 Improving Pit Vehicle Ecology Safety 1015(5) Journal of Physics: Conf. Series
[9] Coetzee C J 2017 Calibration of the discrete element method Powder Technology 310 104-142
[10] Vasilyeva N V, Koteleva N I and Fedorova E R 2018 Real-time control data wrangling for development of mathematical control models of technological processes Journal of Physics: Conference Series 1015(3)
[11] Sizyakov V M, Brichkin V N 2018 About the role of hydrafed calcium carboaluminates in improving the technology of complex processing of nephelines Journal of Mining Institute 231 292-298
[12] Jovanović A et al. 2014 DEM/CFD analysis of granular flow in static mixers Powder technology 266 240-248
[13] Fries L et al. 2011 DEM–CFD modeling of a fluidized bed spray granulator Chemical Engineering Science 66(11) 2340-55
[14] Mishra B K and Tripathy A A 2010 Preliminary study of particle separation in spiral
concentrators using DEM Int. Journal of Mineral Processing 94(3-4) 192-195
[15] Kopteva A V and Koptev V Yu 2018 Automatic Measuring System for oil stream paraffin deposits parameters IOP Conf. Series: Materials Science and Engineering 327
[16] Boikov A V, Payor V A, Savelev R V 2018 Technical vision system for analysing the mechanical characteristics of bulk materials Journal of Physics Conference Series 944
[17] Boikov A V, Savelev R V and Payor V A 2018 DEM Calibration Approach: Random Forest Journal of Physics Conf. Series 1118
[18] Boikov A V, Savelev R V and Payor V A 2018 DEM Calibration Approach: Implementing Contact Model Journal of Physics Conf. Series 1050
[19] Boikov A V, Savelev R V, Payor V A 2018 DEM Calibration Approach: design of experiment Journal of Physics: Conference Series 1015(3)
[20] Beloglazov I I 2018 Automation experimental studies of grinding process in jaw crusher using DEM simulation Journal of Physics: Conference Series 1118 (10)
[21] Rackl M and Hanley K J 2017 A methodical calibration procedure for discrete element models Powder technology 307 73-83
[22] Boschert S and Rosen R 2016 Digital twin – the simulation aspect Mechatronic Futures 59-74
[23] Kruk M N, Semenov A S 2017 Project Risk Analysis and Management Decision-Making in Determining the Parameters of Ore Quarries Journal of industrial pollution control 33(1) 1024-1028
[24] Siziakova E V, Ivanov P V, Boikov A V 2019 Application of calcium hydrocarboaluminate for the production of coarse-graded alumina Journal of Chemical Technology and Metallurgy 54(1) 200-203
[25] Xiang F, Zhi Z and Jiang G 2018 Digital Twins technology and its data fusion in iron and steel product life cycle IEEE 15th Int. Conf. on Networking, Sensing and Control (ICNSC) pp 1-5
[26] Kovalski E R, Karpov G N, Leisle A V 2018 Geomechanic models of jointed rock mass International journal of civil engineering and technology 9(13), 440-448
[27] Bazhin V Y, Kuchitskiy A A, Kadrov D N 2018 Complex control of the state of steel pins in soderberg electrolytic cells by using computer vision systems Tsvetnye Metally (3) 27-32
[28] Koptev V Yu and Kopteva A V 2016 Mining business transportation system structure optimization 11
[29] Siziakova E V, Ivanov P V, Boikov A V 2019 Application of calcium hydrocarboaluminate for the production of coarse-graded alumina Journal of Chemical Technology and Metallurgy 54(1) 200-203
[30] Xiang F, Zhi Z and Jiang G 2018 Digital Twins technology and its data fusion in iron and steel product life cycle IEEE 15th Int. Conf. on Networking, Sensing and Control (ICNSC) 1-5