INTTELICHTIZATION OF THE PROCESSES OF MONITORING THE STATE OF THE MOBILE TECHNOLOGICAL COMPLEX OF MINE WATER TREATMENT

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Abstract. The research is aimed at solving some problems of controlling the processes of monitoring the process of mine water purification by mobile technological complexes with variations in its costs and physical and chemical characteristics. The initial data are the results of discrete and continuous monitoring of the characteristics of the treated water and the technological mode of reagent-free water treatment by a mobile technological complex. The analysis of the problems that arise when choosing the observation procedures necessary to solve the problem of predicting a non-stationary random process with varying mathematical expectation, variance, and the type of distribution laws itself is performed. To ensure the stability of the water treatment process in the statistical sense, a procedure for parametric identification of the predictive model from a limited sample is proposed. The requirements for monitoring the quality of process management at the upper hierarchical level of the mine water treatment management system are formulated.

Keywords: "wet" mine conservation, intellectualization of observation processes, prediction of a non-stationary random process, identification of a predictive model, monitoring of the mine water treatment process.

Introduction

The completion of the development of a large number of fields in recent years has led to the need to manage the processes occurring at the post-operational stage of the operation of these fields, disrupted by long-term mining operations. One of these processes is the self-discharge of mine water. In 1998, the International Network for Acid Prevention (INAP) was established as an association of leading mining companies (Anglo American, Barrick Gold Corporation, Rio Tinto, etc.). The goal of INAP is to make significant improvements in the management of sulfide ore materials during mining and after completion, to reduce the consequences associated with acid drainage, by consolidating information and experience in the field of acid drainage, sharing knowledge and research, and developing technologies. However, it has not yet been possible to solve the problem of purification of acidic mine waters from heavy metals and their neutralization using reagent-free methods on an industrial scale. The increased interest in reagent-free methods of treatment of liquid media is explained by the fact that these methods of cleaning and disinfection do not pollute the natural environment with chemicals, do not have a harmful or irritating effect on the human body. For the treatment and disposal of mine water, it is proposed to use a mobile technological complex developed by our team, which provides water purification and extraction of heavy metal ions from acidic mine water [1]. Mines that are wet-conserved are poorly structured objects with unstable functioning and data uncertainty. One of the promising commercial products that can be obtained during the processing and utilization of man-made waters of mining enterprises is highly dispersed metal powder (VMP). In the process of functioning of a complex technical system, defects arise that can be detected when an observed failure occurs.

When operating mobile technological complexes, the task of managing the processes of monitoring compliance with the technological regime of water treatment with variations in its costs and physical and chemical characteristics arises. An important control element of the observation process is the solution of the problem of parametric identification of the predictive model from a limited sample.

Materials and methods

The object of observation is the process of cleaning mine waters, the self-discharge of which occurs from copper-pyrite mines that are on "wet" conservation. Currently, their neutralization is carried out with lime. Mine waters are complex multicomponent systems, which, in addition to dissolved substances, include colloids, solid suspended substances of inorganic and organic origin. The main pollutants of waste water of mining enterprises are heavy metals, high acidity (acid mine drainage) or alkalinity, salts, oxides, suspended solids, etc. The planned infrastructure of the automated mine water treatment complex includes: pumping stations that pump water out of mines; mobile technological complexes for mine water treatment; a storage pond that receives treated water, and a system for collecting highly dispersed metal powders extracted from treated water. A control structure in the form of a fuzzy cognitive model is proposed. The required efficiency of the acid mine water treatment complex is impossible without the creation of appropriate mechanisms for monitoring technological processes, which ensure that the prerequisites for the occurrence of abnormal and emergency situations are minimized. These include, in particular, procedures for parametric identification of a predictive model based on a limited sample. Numerical results were obtained for the mines belonging to the Levikhinsky ore field located in the Kirovograd district of the Sverdlovsk region.
In the Tagil River valley there are several spent copper-ore mines, these are Ezhovsky, Lomovsky, Karpushikhinsky, Belorechensky and Levikhinsky. The treated mine water is discharged into the Tagil River, where the Lenevskoye reservoir is located, which is one of the sources of water supply for the city of Nizhny Tagil (population 350 thousand people).

Currently, the method of neutralizing acidic water with lime milk (or lime solution) is used, which is the most common method of treating large volumes of wastewater both in our country and abroad. The degree of purification of the mine waters of the flooded Levikhinsky mine reaches 94 % for iron and copper. However, below the discharge of treated mine water in the Tagil River water, the maximum permissible concentrations of MPC for reservoirs of fishery significance are exceeded for copper and zinc (80 times), manganese (12 times), iron (8 times), and sulfates (4 times) [2].

![Fig. 1 Overview of the location of water bodies and observation points in the area of the Levikhi spent copper-pyrite mine. (Rybnikova, 2019).](image)

When choosing observation procedures, the following problems arise [3]
* The approach to environmental and economic risk assessment is currently not strictly defined [4]. In the present conflict situation, the economic efficiency of a specific project is proposed to evaluate a sales volume of the PMF extracted from the EOC, as well as reduction in operating costs to offset the EOC. This approach is consistent with the probabilistic safety assessment (PSA) approach currently adopted by the International Atomic Energy Agency (IAEA).

* The justification of the complex of controlled parameters for the primary processing of acidic mine water by the reagent-free method was carried out on the basis of laboratory experiments [5]. It is shown that the control should cover the conditions for the occurrence of the required technological regime (developed cavitation and ionization of hydrogen atoms of water molecules), as well as the values of control actions on the technological process and output variables. When selecting a set of controlled parameters for the reagent-free process of primary processing of CRV, an approach based on the methodology of multiscale modeling and prototyping of processes and structures should be used [6]. Solving the problem of predicting a non-stationary random process with varying mathematical expectation, variance, and the type of distribution laws itself is very complex. Already for the simplest case - a stationary random process and a linear trend, there is a need to estimate several densities of conditional and joint probabilities [7]. To solve this problem, we assume that the properties of perturbations that manifest themselves over short time intervals have a wave character and are described, for example, by a weighted linear combination of known basis functions \( f_i(t) \) having unknown coefficients \( c_i \), which can change in a jump in a previously unknown piecewise constant manner [8]:

\[
w(t) = \sum c_i f_i(t)
\]

The nature of the change in the hydrochemical parameters of the mine water, which allows us to build a predictive model, is studied by the results, examples of which are summarized in Tables 1, 2, 3.

<p>| Concentrations of contaminants in the untreated mine water Levai. |
|---------------------------|----------------|----------------|----------------|----------------|----------------|----------------|</p>
<table>
<thead>
<tr>
<th>pH</th>
<th>Copper</th>
<th>Zinc</th>
<th>Iron</th>
<th>Dry residue</th>
<th>Chlorides</th>
<th>Sulfates</th>
<th>Manganese</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.8</td>
<td>21.5</td>
<td>249</td>
<td>1224</td>
<td>37.8</td>
<td>14394</td>
<td>6662</td>
<td>65.7</td>
</tr>
</tbody>
</table>

Fig. 1 Overview of the location of water bodies and observation points in the area of the Levikhi spent copper-pyrite mine. (Rybnikova, 2019).
Table 2.
Results of measurements of mine water samples from the Levikhinsky mine (March–June 2018 (element content, mg/dm$^3$)).

<table>
<thead>
<tr>
<th>Element</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mg</td>
<td>1138</td>
<td>1124</td>
<td>955</td>
<td>539</td>
</tr>
<tr>
<td>Mn</td>
<td>169,5</td>
<td>146,5</td>
<td>156,4</td>
<td>146,4</td>
</tr>
<tr>
<td>Fe</td>
<td>2918</td>
<td>2952</td>
<td>2902</td>
<td>2722</td>
</tr>
<tr>
<td>Cu</td>
<td>17,9</td>
<td>13,7</td>
<td>12,7</td>
<td>16,4</td>
</tr>
<tr>
<td>Zn</td>
<td>746,9</td>
<td>708</td>
<td>717</td>
<td>6713,48</td>
</tr>
</tbody>
</table>

Table 3.
Data of regime observations of the volume of water from the Levikhinsky mine self-discharge.

<table>
<thead>
<tr>
<th>Month</th>
<th>Volume of mine water, m$^3$/day</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
<td>4199,8</td>
<td>5,17</td>
</tr>
<tr>
<td>May</td>
<td>6333,1</td>
<td>4,6</td>
</tr>
<tr>
<td>Yune</td>
<td>3054,2</td>
<td>3,92</td>
</tr>
<tr>
<td>Yuly</td>
<td>3054,1</td>
<td>3,49</td>
</tr>
<tr>
<td>August</td>
<td>3054,1</td>
<td>3,5</td>
</tr>
<tr>
<td>September</td>
<td>4730,3</td>
<td>3,49</td>
</tr>
<tr>
<td>Oktober</td>
<td>5002,3</td>
<td>3,71</td>
</tr>
<tr>
<td>November</td>
<td>2674,4</td>
<td>4,21</td>
</tr>
</tbody>
</table>

The non-stationary nature of changes in hydrochemical parameters is recorded in many closed mines and is called "first flush" or the first flush, the duration of which is tens of years. It defines a large environmental risk (P. L. Younger, 1997; C. Wolkersdorfer, 2008). Thus, the mine at the post-operational stage is a source of disturbing influences, including: a trend caused by a decrease in the content of the useful component in the water; seasonal fluctuations in mine water consumption, metal content in the water, and pH values, as well as fluctuations due to the condition of the equipment. To prevent discord control systems, occurring in random time, it is necessary to control the quality of its operation, forming a corrective actions that determines the choice of the process approach, the relevant standards of series ISO 9000 (GOST R ISO 9000) According to the latest international requirements in the field of Metrology and standardization of the basic assessment of the quality of measurement result it is recommended to consider its uncertainty [10]. Based on the process quality criterion formulated by Shuhart [11], in accordance with which the process must be stable (stable) in the statistical sense, we formulate the problem of process management of the effectiveness of an automated system for monitoring technological parameters. The task is to maintain a stable random process of variations of the measured parameters at the output of the process and to ensure the constancy in time of the distribution functions of the parameters by forming corrective measures.

The stability of the random process of variations of the measured parameters is ensured by monitoring the quality of the process at the upper hierarchical level of the mine water treatment management system, which should provide for the control of the following information fields:
- initial settings of the quality control process (sample size; sampling frequency; upper and lower control limits; date; time);
- types of control charts (X-R chart; MX-MR chart; X-MR chart; X-S chart; median chart);
- statistical interpretation of control maps (mean for each sample X; span for each sample R; singular points; trend);
- corrective actions performed (replacement/repair of equipment; changes in technology; changes in the quality of the extracted VMP);
- monitoring the calculation of control charts (risk of mine water treatment processes; operational quality forecast; recommended measures).

The technology for improving the reliability of monitoring the state of the process includes:
- detection of abnormal results of monitoring of technological parameters in conditions where mutual verification of the readings of different sensors is impossible;
- correction of measured values on a separate thread, given that deviations of calculated values from the true would be minimal given the accuracy of cost control for each stream;
- determination and elimination of anomalous values of the results of discrete control (the algorithm is designed to process a limited number of observations for which statistical processing methods cannot be used due to the insufficient representativeness of the number of observations and the lack of information about the probabilistic characteristics of the observation errors) [12].

The quasi-stationarity of the projected mobile technological complex for the processing of SRW
makes it necessary to solve the problem of parametric identification of the predictive model based on a limited sample. The sample size is determined from the conditions of a compromise between the need to have numerically stable estimates of the model coefficients and the desire to minimize the averaging of the time-varying signal.

Output variables of the designed mobile technological complex of processing EOC

\[
Y_j(n) = \sum_{i=1}^{K} a_i * Y_j(n-i) + \sum_{r=1}^{l} \sum_{i=0}^{m} b_{ri}(\mu) * u_r(n-i) + \varphi(n) + \xi(n)
\]  

\( n \) - where is the moment of discrete time;  
\( Y_j \) - quality characteristics of purified water;  
\( U_r \) - input variable, \( r = 1, ..., l \)  
\( M \{ \xi(n) \} = 0, M \{ \xi^2(n) \} = \sigma_\xi^2 \)  
\( m, K \) - the depth of the object's memory by controls and by perturbation;  
\( \varphi(n) \) - disturbance caused by the condition of the equipment;  
\( \mu \) - parametric perturbation that changes the transmission coefficients of the control actions.

The first term in equation (1) is the autoregressive (AR) component. The coefficients of the AR component are found by the least squares method (OLS) from the Yule-Walker equation for known values of the autocorrelation functions of the qualitative characteristics of treated water.

Identification of parameters that predict the model includes the following sets of procedures:

- calculation by deterministic models using the characteristics of the treated water of the values of the transmission coefficients for the control action;  
- calculation of the OLS coefficients of the AR component;  
- calculation based on a deterministic model of perturbation caused by a change in the state of the equipment over time;  
- adjustment of the model coefficients according to the deviation of the actual values of the agglomerate quality characteristics from the predicted values.

Quasi-stationarity makes it necessary to solve the problem of parametric identification of the predictive model based on a limited sample. The sample size is determined from the conditions of a compromise between the need to have numerically stable estimates of the model coefficients and the desire to minimize the averaging of the time-varying signal. Limiting ourselves to the case of a scalar output variable for ease of writing, we present equation (1) for moments of time in the form

\[
Y(k + 1) = \sum_{i=1}^{k} a_i * Y(k + 1 - i) + \sum_{i=1}^{l} b_i * U(k + 1 - i) + \xi(k + 1)
\]

\[
Y(k + 2) = \sum_{i=1}^{k} a_i * Y(k + 2 - i) + \sum_{i=1}^{l} b_i * U(k + 2 - i) + \xi(k + 2)
\]

\[
Y(k + m) = \sum_{i=1}^{k} a_i * Y(k + m - i) + \sum_{i=1}^{l} b_i * U(k + m - i) + \xi(k + m)
\]  

or in vector form

\[
\vec{Y}_{k+m} = \vec{Y} * \vec{a} + \vec{U} * \vec{b} + \vec{\xi}_{k+m}
\]

where

\[
\vec{a} = (a_1, ..., a_k)^T, \quad \vec{b} = (b_1, ..., b_r)^T, \quad \vec{y}_{i+j} = (y(i), y(i+1), ..., y(i+j))^T
\]

\[
\begin{align*}
Y &= [y_{k+m-1}^{1}, y_{k+m-2}^{1}, ..., y_1^{1}] - m \times k \\
U &= [U_{k+m-1}^{1}, U_{k+m-2}^{1}, ..., U_{m}^{1}] - m \times r
\end{align*}
\]

The problem of identifying coefficients \( \vec{a} \) and \( \vec{b} \) is reduced to solving a linear system

\[
Y = A * X + \xi
\]
in which \( y = y_{k,m} \), \( A = [Y:U] \), \( X = [\begin{bmatrix} x_1 & \cdots & x_n \end{bmatrix}] \), \( \xi = \xi_{k,m} \)

The classical method of solving system (4) gives the least squares method:

\[
\hat{X} = (A^T A)^{-1} A^T y
\]

(5)

The justification for the effectiveness of this method is the Gauss-Markov theorem, according to which \( \hat{X} \), found from equation (5), is the best linear unbiased estimate. Its error is given by the ratio

\[
M\left( (X - \hat{X})(X - \hat{X})^T \right) = \sigma^2 [A^T A]^{-1}
\]

(6)

Such an estimate can be applied only in the case when the matrix is nondegenerate. In the case when the matrix is close to degenerate (multicollinearity), the problem of determining the parameters becomes incorrect. An extreme problem is called Hadamard-correct if its solution exists, solely and continuously depends on the initial data and the error of the computational process.

**Conclusion**

Achieving the required efficiency of the acid mine water treatment complex is impossible without creating appropriate monitoring mechanisms for technological processes that ensure that the prerequisites for the occurrence of abnormal and emergency situations are minimized. The introduction of intelligent systems for monitoring the process of mine water treatment is aimed at improving the reliability of control in conditions of distortion of measurement results by measurement errors and the non-stationary nature of changes in hydrochemical indicators and water flow rates. To prevent disruption of the control system that occurs at a random moment in time, it is necessary to manage the quality of its functioning by forming corrective measures, which determines the choice of a process approach that meets the ISO 9000 series standards. The quasi-stationarity of the projected mobile technological complex for the processing of SRW requires solving the problem of parametric identification of the predictive model from a limited sample. The sample size is determined from the conditions of a compromise between the need to have numerically stable estimates of the model coefficients and the desire to minimize the averaging of the time-varying signal.

**References**


5 Zobnin B. B., Kochetkov V. V. Justification of the complex of controlled parameters in the primary processing of acid mine waters by the "reagent-free" method [Text]/VII International Scientific and Practical Conference, environmental and technical safety of Mining Regions, 2019[ Zobnin B. B., Kochetkov V. V. Justification of the complex of controlled parameters in the primary processing of acid mine waters by the "reagent-free" method [Text]/VII International Scientific and Practical Conference, environmental and technical safety of mining regions, 2019]

6 Zobnin B. B., Azhipa I. A. Multi-pass modeling of dust and gas flow purification [Text]/Automated technologies and production, N4(14), 2016 (In Russ)]

7 Zobnin B. B. Approaches to forecasting processes in natural and natural-technological complexes [Text]/Probabilistic constructions and their applications. Collection of scientific papers, USTU Yekaterinburg, 1998 (In Russ)]

8 Zobnin, B., Yendiyarov, S., Petrushenko, S. Expert system for sintering process control based on the
Разработка виртуальных лабораторий по теме «Изучение строения и развития губок на примере пресноводной бадяги». Тип Spongia, класс Demospongia, отряд Spongillidae, представитель Spongilla

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Аннотация. В данной статье исследуются вопросы разработки компьютерных имитационных моделей по лабораторным работам предмета «Зоология безпозвоночных». В частности показана имитационные модели по следующим лабораторным работам: внешнее строение губки, скопление амебоцитов, внутреннее и внешнее строение губки, стрекательные клетки, циркуляция воды, движение пресноводной и продольный разрез гидры, общий вид колонии, колония гидроидного полипа в крупном плане, отпочковывание медуз в бластостиле, паренхимула, планула, образованные новой колонией.

Действительность указывает на то, что до настоящего времени эти предпосылки не нашли должной теоретической разработки и практической реализации. Но, как показывают работы в этом направлении, как отечественных, так и зарубежных авторов, один из наиболее приемлемых путей оптимального использования компьютера в процессе обучения это создание компьютерных учебников, причем, как мы считаем, в большей степени виртуальные лабораторные работы, используемые в комплексе с другими учебными средствами, включая новейшие интерактивные технологии. Отсюда можно прийти к выводу, что компьютерное и информационное моделирование необходимо для исследования учебного процесса в полном объеме; кроме того, также проводится поиск по методике преподавания отдельных дисциплин.

Теперь перейдем к описанию содержание виртуальных лабораторных работ по внешнее строение губки, скопление амебоцитов, внутреннее и внешнее строение губки, стрекательные клетки, циркуляция воды, движение пресноводной и продольный разрез гидры, общий вид колонии, колония гидроидного полипа в крупном плане, отпочковывание медуз в бластостиле, паренхимула, планула, образованные новой колонией.

Тип Губки включает наимпримитивнейших многоклеточных животных, обладающих парагастральной полостью, наружным слоем воротничково-жгутиковых клеток и лежащей между ними мезоглеей с твердым скелетом. Для изучения организации этих животных достаточно рассмотреть строение морской одиночной губки сикон и пресноводной колониальной бадяги.

Соответственно вышеизложенному была разработана компьютерная модель к лабораторной работе «Изучение строения и развития губок на примере пресноводной бадяги» которая состоит из 8-анимаций.

Как видно из первой анимации, одиночные губки имеют форму мешка или глубокого бокала, который основанием прикреплён к субстрату, а отверстием (устьем) обращён кверху.