MODELING AND ADJUSTMENT OF A FUZZY CONTROLLER IN A BIOREACTOR CONTROL SYSTEM

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Annotation. The article describes the modeling and configuration of a fuzzy controller for the control system of the bacterial oxidation of hard-to-enrich gold-bearing sulfide ores. The simulated logical fuzzy controller allows you to save the consumption of refrigerant water consumed in the process by 4,3%, using it to control the process of bacterial oxidation.

Keywords. Fuzzy controller, intelligent control system, bacterial oxidation, modeling, fuzzification, defuzzification.

Introduction. It is very important to control the process of bacterial oxidation of refractory gold-bearing sulfide ores under conditions of uncertainty. In this case, the parameters of the control object and the use of the control system for the purposes of managing models, the effects of which are not sufficiently consistent with the control object, may be due to changes in external influences over time and operating conditions, the normality of control systems and their selection criteria, etc.

The rapid development of the software and technical foundations of modern control systems leads to the complication of the functional and algorithmic appearance of the control system [1]. As you know, the level of use of automatic control devices in the control of various technological processes is now growing, and new methods of automatic and automated process control are being developed and widely used in practice. His turn leads to the creation of new mathematical methods for solving problems of functional control. In particular, one of the modern methods of controlling the process of bacterial oxidation plays an important role in the application of intelligent control systems based on a fuzzy controller. Therefore, in order to determine the possibility of using this system in the control of bacterial oxidation processes, the characteristics of intelligent control systems based on a fuzzy controller were analyzed [1, 7].

On the basis of fuzzy logic, it is customary to consider intelligent control systems as data processing algorithms that somehow reflect the logic of human thinking. These usually include fuzzy
logic methods, genetic algorithms, expert systems, etc. The considered methods are universal in nature and are widely used in various fields of science and technology [2-5].

To solve this problem, a number of authors proposed the development of intelligent control systems based on the joint use of the fuzzy logic method and traditional methods of automatic control theory L.Zade, P.A. Aliyev, N.R. Yusupbekov, M.F. Azeem, P.B. Taskin is based on the fact that the use of the fuzzy logic method in the control of the bioreactor plant of the sulphide complex processing plant is highly effective. In these works, at a high level, the issues of the intellectualization of control systems for bioreactor plants using fuzzy control algorithms are considered.

**The problem to be solved and problem statement.** In the process of bacterial oxidation, various production problems arise, and in some cases the reasons for its occurrence remain unclear. This complicates the management and decision making of the bacterial oxidation process. Therefore, the solution of management issues of such facilities becomes one of the topical issues.

Based on a fuzzy controller, it is used when there is insufficient knowledge about the control object, but there is experience in managing it. A qualified operator manages such objects, using the readings of measuring instruments and accumulated experience. Since the information received from the operator is expressed in words, linguistic variables and fuzzy set theory are used in fuzzy PID controllers [9-10].

**Experiment and analysis of the obtained results.** Analyzing the design of a fuzzy PID controller as a fuzzy controller, let's consider its design. The structure of building a fuzzy PID controller basically corresponds to the structure of a fuzzy model and depends on the control object and its quality indicators. Since the scope of the fuzzy control system is very wide, various controller structures are being developed that differ in the number of inputs and outputs, their fuzzy sets, membership functions, fuzzification block, rule base formation, defuzzification block [11, 13].

In the fuzzy controller, cases were considered when the input error e=“error” and the control effect u=“control actions” linguistic variables, triangular and Gaussian types of 7 different membership functions were considered in the fuzzy controller. The PID controller uses the signal e=“error” as input and the signal u=“controls” as the output effect. Its mathematical expression is as follows:

$$u_{PID} = u_p + K_P \left( e(t) + \frac{1}{K_I} \int_0^t e(t) dt + K_D \frac{de(t)}{dt} \right)$$

(1)

Searches [4, 8] present a generalized fuzzy controller circuit with one to three input variables $e_1$, $e_2$, $e_3$ and an output variable $u$. This is defined as an input error:

$$e_1(k) = y_0(k) - y(k)$$

(2)

where, $e_1(k)$ is the difference between the set value $y_0(k)$ and the current value $y(k)$, the rate of change of the input error is expressed as follows:

$$e_2(k) = e_1(k) - e_1(k-1)$$

(3)

where $e_2(k)$ is the rate of change of the input error, the acceleration of the change of the input error is expressed as follows:

$$e_3(k) = e_2(k) - e_2(k-1)$$

(4)

where, $e_3$ – k=1,2,...,N is the acceleration of the change in the input error at a discrete time. The PID controller tuning algorithm is expressed as follows:

$$u(k) = k_P(e(k) - e(k-1)) + k_I e(k) + k_D (e(k) - 2e(k) + e(k-2))$$

(5)

Consider the basic operations performed in the fuzzy controller. The transformation of the actual input values with the gain factor is done by converting to values, i.e. a scaling operation is performed:

$$\hat{e}_1 = K_P e_1$$

(6)
where $L_i^{\min}, L_i^{\max}, i = 1, 2, 3$ are the minimum and maximum limits of the input variable $\hat{e}_i$. Similar ratios $e_2$ and $e_3$ can be obtained for other inputs. In practice, the following normalized intervals are common

$[L_i^{\min}, L_i^{\max}] = [0, 1]$ и $[L_i^{\min}, L_i^{\max}] = [-L, L]$, здесь $L=1, 2$.

Using the fuzzification block, it transforms the input data into the corresponding fuzzy input data $E_i, i = 1, 2, 3$. The fuzzy inference engine determines the fuzzy inference $U$ based on the fuzzy inputs $E_i, E_2, E_3$ and the rule base. And the defuzzification block converts the fuzzy output $U$ into the form of a control signal $u(k)$.

The fuzzy logic solution generation block is the main element of the fuzzy controller. In it, the fuzzification block, the development of fuzzy conclusions, the compilation of the rule base and the defuzzification block perform actions sequentially. So the transformation performed by the discrete operator can be expressed as:

$$[\hat{e}_i(k), \hat{e}_i(k)]_{	ext{Faz}} \langle E_i, E_1, E_1, QB \rangle \langle U \rangle_{\text{Defaz}} \langle \hat{u}(k) \rangle$$ (7)

MATLAB software was used to simulate a control system based on a fuzzy controller. The second stage of computational experiments is to analyze the properties of an optimally tuned fuzzy logic controller. For this purpose, a number of computational experiments were carried out in the simulation model for various values of the transfer function along the tuning and perturbation channels.

Temperature controller tuning consists of setting proportional, integral and differential values for better process control. If there is no auto-tuning algorithm when tuning the thermostat, or if the auto-tuning algorithm does not support proper process control, it is possible that the temperature control unit is tuning several times or with errors. If the regulator is properly adjusted and used, control stability can be achieved.

Based on the analysis, it was proposed to use the PID controller in setting up the main control channel. Because one of the main requirements for the object is to ensure high accuracy and speed.

It should be said that the control system for the process of bacterial oxidation is a complex object and has the property of non-stationary. To control such a system, PID controllers are widely used, represented by the following transfer function [9]:

$$W(p) = K_p + \frac{K_i}{p} + K_d p$$ (8)

Where $K_p, K_i, K_d$ the definition of the coefficients is determined by fuzzy logic.

The synthesis of an automatic control system with a fuzzy PID controller mainly consists of two stages: building the controller itself and adjusting the PID controller coefficients.

The process of adjusting the controller using a fuzzy logic block begins with finding the initial values of the adjustable parameters $K_p, K_i, K_d$ of the controller. Based on this, an algorithm for the synthesis of a fuzzy PID controller was developed:

- The input and output variables of the fuzzy logic controller are determined.
- The scaling and normalization factors of the fuzzy controller are determined.
- A logical base of fuzzy controller rules is formed.
- For each linguistic variable, a standard linear-fuzzy logic PID controller with 7 terms and 49 rules was introduced into the system, which serves to dampen oscillations.

The control law of the nonlinear fuzzy controller is optimized by shifting the center of the intermediate terms of the input linguistic variable "control error". The controller parameters are chosen in such a way as to reduce the static error.

Then, based on the results of the experiment, a set of knowledge base rules was created and a fuzzy inference rule was developed. For this, linguistic variables were introduced: input error $e$, input error change $de/dt$.

The rule base developed for the proportionality factor $K_p$, is presented in Table №1 below.
The developed rule base for the integration time $K_i$ is shown in Table №2 below.

**Table №2**

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The developed rule base for the differentiation time $K_d$ is shown in Table №3 below.

**Table №3**

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Based on the knowledge of techno experts, a rule base was created. This allows you to determine the values of the coefficients $K_p$, $K_i$, $K_d$ of the PID controller based on fuzzy logic inferences. The center of gravity method was used to convert fuzzy variables into exact values. Based on them, 49 fuzzy inference rules are formed, which are associated with changing the parameters of input variables.

The synthesis algorithm for a fuzzy-logical PID controller for controlling the bacterial oxidation process differs from others in its simplicity and convenience, which allows using standard forms of membership functions and minimum values of control rules.

Modeling of fuzzy controllers is performed using the Fuzzy Logic Toolbox package in the MATLAB environment. The fuzzy controller is actually programmed into the controller and operates in discrete mode.

To enter the rule base developed above, the Fuzzy Logic Designer window was opened by entering the fuzzy command at the command line of the MATLAB program and pressing the Enter key on the keyboard.
The Mamdani model was chosen when developing fuzzy linguistic variables. The input error $\varepsilon$ and the error change $\frac{de}{dt}$ were used as input variables, and the PID controller coefficients were introduced as output variables using the commands $K_p$, $K_i$, $K_d$ Edit, Add Variable, Input and Output.

To enter the $\varepsilon$ input error membership functions, open the Membership Function Editor window, set the membership function range to $[-3, 3]$ from the Range panel, and set the value range of the 7 linguistic variables.

The membership functions of the change in the input error $\frac{de}{dt}$ are shown in Figure 2 below. Open the Membership Function Editor window to enter the membership functions of the fuzzy PID controller coefficients $K_p$, $K_i$, $K_d$ and set their values as shown in Figure 3 below.
Using the Rule command, the Rule Editor window opens in the FIS Editor window and a rule base is formed in the form of the "IF... AND... THEN..." rule. 49 rules are formed here.

![Rule Editor](image1)

*Figure 4. Rule bases of the fuzzy controller.*

To see the operation of the fuzzy controller, the graph of changes in its input and output linguistic variables after the defuzzification block is shown in Figure 5 below.

![Graphical interface](image2)

*Figure 5. Graphical interface of input and output variables of the fuzzy controller.*

An overview of fuzzy inferences based on the rules of the developed fuzzy controller is shown in fig. 6.
Areas of application of the obtained results. The resulting graphs characterize the change in the input variable of the fuzzy controller in relation to the output variable. The improvement of quality indicators of tuning by programming programmable logic controllers with the use of a fuzzy controller for the automatic tuning system of a bioreactor in the process of bacterial oxidation is considered. The simulated fuzzy logic controller saves 4.3% of the cooling water consumption in the technological process through the use of control of the process of bacterial oxidation of refractory gold-bearing sulfide ores.

Conclusion. Under conditions of uncertainty of changes in the external environment affecting the process of bacterial oxidation, the synthesized automatic control system with a fuzzy controller ensures stable maintenance of the temperature of the bioreactor at the required value and allows you to control the quality of the process even when the parameters of the object vary over a wide range.

References


