

Bioengineering, waste processing and fermentation process control for biogas production

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Abstract. The article discusses the analysis of the state of control of the processes of biogas production from animal waste by methane digestion. The article discusses the problems of synthesis of automated control systems of biotechnological processes under conditions of information uncertainty. The analysis of the current state of control of fermentation stage processes shows that insufficient attention is paid to the problem of synthesis of second-tier banks under conditions of information uncertainty. Construction of mathematical modeling of biosynthetic processes is a kinetic model, where experimental and analytical methods are used due to the difficulty of identifying patterns in microbiological processes. The article discusses the application of methods and algorithms for intellectualization of problem solving in ACS for the synthesis of complex biotechnological objects in conditions of lack of information, that they should be attributed to priority tasks. The results of research on the application of a neuro-fuzzy system for controlling fermentation processes under conditions of uncertainty and multimode of processes, as well as a forecasting algorithm using nonlinear sets and neural networks are presented.

1 Introduction

Biotechnological processes and equipment for the processing of animal manure can be divided into anaerobic and aerobic depending on the microorganisms used. There is considerable experience and promising methods of biotechnological anaerobic processing of animal waste by methane digestion. In the process of methane digestion, manure is processed (fermented) into biogas and fertilizer.

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Along with biotechnologies for the production of biogas and the subsequent biosynthesis of feed bioproducts, the production of organic inorganic fertilizers is another area of effective use of livestock waste.

Waste-to-biogas production is based on the anaerobic decomposition of cellulose and nitrogen-containing organic matter by a mixed population of microorganisms, including bacteria that break down cellulose into organic acids and bacteria that convert these acids into methane. In recent years, various technologies for the treatment of industrial waste, including thermal neutralization and biothermal neutralization methods, have been developed and commercialized. However, there is a legitimate need to develop rapid, low-cost and rapid methods of waste treatment, and small and medium-sized enterprises should also develop such methods.

The aim of the study is to build fuzzy and neuro-fuzzy control systems that increase the efficiency of automation of fermentation processes of biotechnological processes in bioreactors. To solve this problem, it is necessary to develop the methodological basis for the creation of intelligent automatic control systems (ACS) for complex biotechnological processes (SBTP) and system and technical solutions for their implementation in the general task of automation of biotechnological processes (BTP), as well as to solve the issue of developing scientifically based recommendations for their application.

2 Materials and methods

The implementation of the tasks is carried out using a system approach based on applied methods of automatic control, basic methods and principles of the theory of robust and intelligent systems, and the theoretical solution of the problem is confirmed by the results of modeling in the MatLab instrumental environment.

The obtained results are of great practical importance and make it possible to increase the efficiency of the functioning of complex BTPs under conditions of uncertainty through the use of robust, fuzzy and neural network control systems.

In this regard, we will consider the process of biogas production by fermentation of plant and animal waste and the analysis of the features of fermentation processes as objects of control. Biogas is one of the most versatile types of renewable energy, suitable for the production of electricity and heat.

In order to obtain biogas from biomass, organic matter is subjected to a fermentation process in special biogas plants. The fermentation process produces the combustible gas methane, which is purified of by-products and then converted into an energy source on demand. When biogas is burned in a cogeneration module (cogenerate), the energy stored in the biomass is released. Bioenergy derived from biogas is suitable for powering motors and producing heat and electricity. Compared to other renewable energy sources such as wind and solar, biomass and biogas energy has another decisive advantage. Biogas can not only be produced continuously, but also stored and stored for continuous use.

3 Results and discussion

At present, the development of applied biotechnology involves the creation of processes for various purposes that take place under conditions of information uncertainty. Analysis of metabolic processes makes it possible to classify the fermentation process as a complex biotechnological system (BTS).

The systems approach is applicable to the study of BTS, especially their individual devices, for example, fermenters, which are complex systems from the point of view of

systems analysis. The objective function of the cell is to maximize the specific growth rate of the microbial population [1]:

$$\frac{1}{x} \frac{dx}{dt} \rightarrow \frac{\max}{\bar{U}}, \quad (1)$$

Where x is the biomass concentration, t is the time, and U is the intracellular regulation vector. The most important task of any living microorganism is to maintain constant conditions (concentration, composition, etc.) under the influence of the external environment. The growth of biomass occurs exponentially and can be represented by a single limiting reaction. In this case, the biomass growth is balanced and is determined by the equation [2]:

$$\frac{1}{x} \frac{dx}{dt} = a^T \vec{y}. \quad (2)$$

The matrix qualitatively determines the composition of the microbial population. The quantitative composition of intracellular components is determined by the vector of specific rates of formation of reaction products. In this case, the target function of the cell takes the form $a^T \vec{y}$ [3]:

$$J = \max \left(\frac{1}{x} \frac{dx}{dt} \right) = a^T \max_{\vec{y}} \{\vec{y}\}. \quad (3)$$

Thus, according to the system approach, the results of the objective activity of the biosystem can be the factors that form the system. The basis of mathematical modeling of biosynthetic processes is the kinetic model, in its construction experimental and analytical methods are used due to the difficulty of identifying patterns in microbiological processes. The least explored aspect of solving this problem is the choice of an interpretive criterion to determine the constants of the model. When choosing this criterion, it is necessary to know the law of the distribution of measurement errors, which is often unknown.

Due to these features, the development of a perfect control system for technological processes of biotechnological production, based on cyclic and continuous fermentation processes, is a complex and complex task, the solution of which occupies an important place in the development of applied mathematical support for automated process control systems [4].

To date, one of the main problems in solving the problems of BTS control is the creation of dynamic models of physical and chemical processes in the absence of complete and accurate information about the behavior of BTSs.

The main factors that determine the manifestation of uncertainty in the management of biotechnological facilities are:

- complexity of a formalized description of biotechnological processes for solving management problems. Today, it is not possible to develop a mathematical model of the fermentation process that describes all the factors that influence the process;
- non-stationarity of biotechnological processes;
- poor reproducibility of the fermentation process due to changes in the biological activity of seeds, storage time and other unknown factors;
- A priori uncertainties in the environment, the fermentation process and the functional conditions of the control system.

Due to these features, simplified BTP models are used in the construction of control systems.

3.1 Identification and assessment of influencing factors

3.1.1 Temperature

Based on the above data for the selection and evaluation of the main factors, with respect to the temperature factor, all methane-producing microorganisms can be divided into three groups according to the optimal temperature of growth and development:

1. Thermophilic (45-70). In this group of methanogens, although their growth is significant at higher temperatures relative to development, it is much more likely to slow down at temperatures below 45°C.
2. Mesophilic (15-45°C). The optimum growth temperature of methanogens in this cluster is 35 (mesophylls) and 25 (submesophylls).
3. Psychrophilic (temperature below 15°C). This group of microorganisms is the least studied. The use of anaerobic processes at low temperatures causes a number of problems. The vital activity of microorganisms determines the direction of diffusion of nutrients, forming a concentration gradient between them and the liquid medium.

Oxygen reactions, as well as anaerobic reactions, proceed faster in high temperature conditions. Therefore, experts often recommend choosing a small but heat-protected cleaning equipment. Fermentation takes place at an optimal rate at a temperature of 30-60 °C (aerobic flora develops first, then thermophilic flora). The harsher the climatic conditions, the more favorable the equipment for the development of mesophilic flora.

3.1.2 pH level

The optimal pH level for anaerobic processes is in the range of 6 to 8. The activity of methanogenic bacteria decreases significantly when the pH drops below 6, and they become inactive when the pH drops below 5.5. It is believed that the optimal pH value should be maintained in the range of 6.7 to 7.6. This can be adjusted by adding lime to the solution.

3.1.3 Inhibiting substances

The main inhibitors of anaerobic processes are the following toxic substances: ammonium, hydrogen sulphide, cyanide, trichloromethane, nickel and formaldehyde. They act on methanogenic bacteria and determine the course of fermentation. If there is a sufficient concentration of toxic substances in the effluent, the decomposition reaction slows down or stops altogether.

3.1.4 Pressure

One of the important factors influencing methane fermentation in the production of biogas is the need to determine the pressure created by carbon (C) and nitrogen (H) gases in the processed feedstock. The most favorable ratio of carbon and nitrogen for the microbiological conversion of organic matter corresponds to the value of $C/H = 10...16$. If the C/N ratio is excessive, nitrogen deficiency is a limiting factor in the methane fermentation process. If this ratio is too low, large amounts of ammonia are formed, which is toxic to bacteria.

3.1.5 Humidity

The moisture content of the substrate plays an important role in the fermentation process. The moisture content of the biomass should be in the range of 75-95% so that the bacteria are evenly mixed and broken down steadily. The operating pressure in the bioreactor plays a big role in the formation of biogas, so most bioreactors operate at pressures above atmospheric pressure.

The research was carried out at the National Research University "Tashkent Institute of Irrigation and Agricultural Mechanization Engineers" in the period 2022-2023. It has been found that there are several factors that negatively affect the amount of methane produced and its composition of biogas, including: humidity, temperature, external environment, and

various other solids. In studies, the most important influence on the concentration and yield of biogas has been observed is humidity. It was found that moisture affects the fermentation of moisture-containing products and the methane content in the composition of biogas in the processing of agricultural products (animal waste, sheep waste, poultry farming and organic plants) in the anaerobic process of waste processing, and the heat capacity of its combustion and combustion properties are insufficient.

Figure 1 shows a model of a biogas production facility.

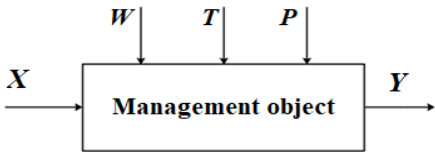


Fig. 1. Model of the biogas production facility.

In the development of the model, a device (Bioreactor) for the production of biogas was selected as the control object (MO), the initial product entering the control object (X), i.e. the concentration of methane in the output parameter of biomass (Y) biogas was obtained, the main parameters affecting the control object were: (W) humidity, (T) temperature and (P) pressure created inside the bioreactor, the main parameters were determined, and on this basis a mathematical model of the process was developed, Its structural diagram is shown in Figure 1. In practice, various schemes of anaerobic digestion of organic waste have been developed, a special laboratory device has been developed for research [5], which consists of a biogas device and control and measuring devices. A diagram of such a laboratory device is shown in Figure 2.

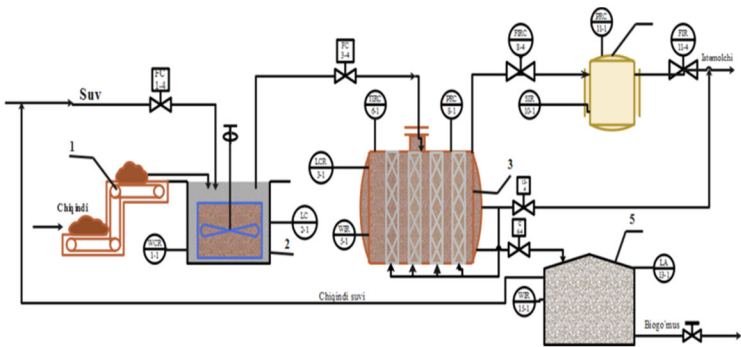
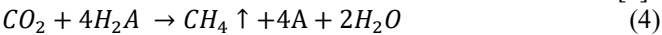


Fig. 2. Diagram of the pilot plant.

One of the main factors influencing the intensity of biogas production is the amount of acid in the sludge (pH level). The main reaction to methane formation can be written as [6]



The process of simulating (stabilizing) raw sludge with methane is divided into three and sometimes four phases. However, in one way or another, everything corresponds to the two-phase scheme of the fermentation process proposed by Barker [7].

3.2 Prediction algorithm using nonlinear sets and neural networks

Let's consider a typical forecasting algorithm performed using neural networks [8].

3.2.1 Selection of important factors

At the first stage, the maximum number of important factors influencing the forecast is highlighted. Such additional factors that affect the behavior of the predicted value are called exogenous (external) or artifacts. Here the observation interval (sliding window) is selected, that is, the forecast is determined by how many previous values of the time series are completed.

3.2.2 Data pre-processing

At the second stage, information that, in the opinion of the expert, is not relevant to the case and does not affect the forecast, is destroyed. If necessary, the missing information will also be restored. Skillfully processed data in advance can significantly improve the quality of the forecast.

3.2.3 Build a model

At the next stage, the most appropriate paradigm and structure of the neural network, as well as the algorithm and parameters of its training, are selected to analyze this process.

3.2.4 Predictions

Experiments are carried out according to a scheme similar to that used for training.

3.2.5 Experience calculations

Using the neural network function, we train our system (see Figure 1) and plot its propagation, and the data obtained after reading the neural network function. The fuzzy system is shown in Figure 3 of the graph of adaptation of the system's training data [9-10].

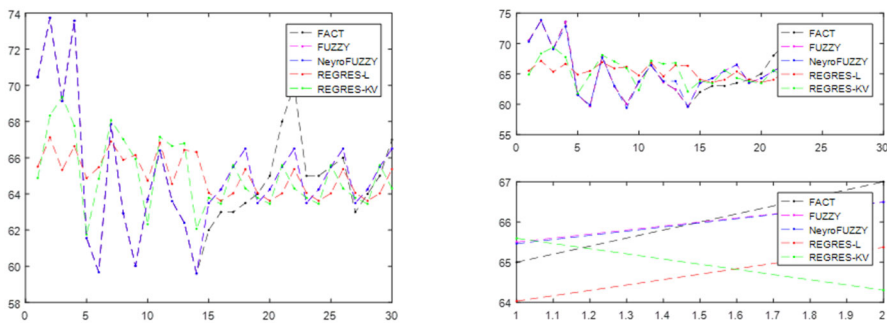


Fig. 3. Structure of the Neuro-Fuzzy Model.

As can be seen from the graph, the neuro-fuzzy system was able to correctly describe the learning pattern. Production forecasting is structured according to factors, the forecasting indicators of the production system are shown in Figure 4.

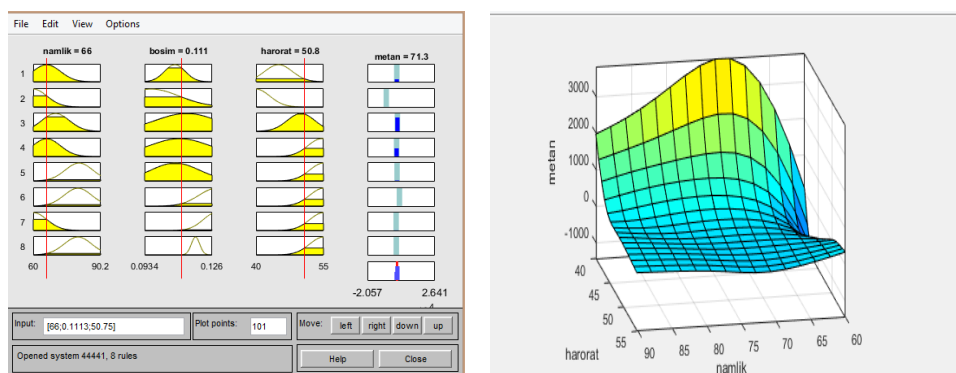


Fig. 4. Production Forecasting System.

The production forecast depends on the factors on the basis of which the production forecasting schedule is built [11-13].

4 Conclusion

The analysis of the study is carried out from the standpoint of a system approach, where the interrelated processes of fermentation stages are considered, and the possibility of increasing the efficiency of automation of biotechnological production by developing an automated control system for the fermentation process based on approximate algorithms and intelligent methods of robust control, recommended in the absence of a complete and accurate mathematical description of the dynamics of the controlled process, is shown.

In the presence of uncertainty, the solution of the problem of developing methods for controlling the output to a given mode, controlling the flow of the substrate, methods for selecting and stabilizing products is associated with serious difficulties, since it is necessary to simultaneously take into account various uncertainty factors, and it is almost impossible to form a closed-loop analytical algorithm for the operation of automatic control systems with the necessary performance indicators. In this regard, it is very expedient to use complex, non-linear and non-formalized intelligent methods of automatic control of biotechnological processes.

The development of reliable and intelligent control systems for sterilization and fermentation processes, taking into account the variation of BTO parameters, delay, nonlinearity, the presence of unpredictable perturbations and other factors that characterize the uncertainty of the mathematical description of microbiological processes, is a real problem today.

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