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ANALYSIS OF MATHEMATICAL MODELING IN BIOTECHNOLOGICAL OBJECTS

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Abstract

Various aspects of mathematical modeling of biotechnological processes and systems are considered, from setting problems and developing mathematical models to their implementation and interpretation of the results obtained. General information about mathematical models is given, a methodology for studying the influencing factors on the yield of biogas in the process of fermentation of biotechnological processes in a bioreactor is presented. Mathematical models of biotechnological processes are presented, an algorithm of a fuzzy logical model is analyzed, which estimates the effect of the amount of humidity on the yield of biogas, which provides an increase in the concentration of methane. According to the data obtained, on the basis of the dielectric constant of biomass and the tangent of the dielectric loss angle, moisture correlation graphs are shown. In the process of processing agricultural waste, an algorithm for monitoring and managing the output of biogas from a bioreactor is shown.

Key words: *biotechnological object, mathematical modeling, biogas, humidity, dielectric constant, algorithm.*

Introduction. To date, the most widely used control methods and algorithms in the automation of industrial biotechnological processes are based on the strict formalization of the problem and the availability of quantitative estimates of the solution parameters.

However, these methods are not applicable to the management of non-stationary biotechnological objects, and their functioning cannot be formalized by strictly numerical methods. The characteristics that solve these problems include a large share of high-quality information, the associated uncertainty of information and the possibility of contradictory decisions of experts who make management decisions, which makes it possible to classify industrial biotechnological facilities as fuzzy objects. The theory of fuzzy systems and fuzzy logical devices is the basis for the construction of control systems for such objects. In the works of researchers [1-5], the possibilities of taking into account information uncertainty when modeling the process of fermentation technology for biogas production are considered. To solve this problem, a mathematical model of biochemical processes occurring during fermentation is proposed in the first approximation.

The features of biotechnological facilities for biogas production include insufficient theoretical understanding of the processes taking place in them, high variability of their properties due to the presence of uncontrollable factors and violation of the standard prerequisites for statistical analysis. Taking into account these features, it is necessary to develop methods for setting up and analyzing multifactorial experiments to solve a wide range of problems related to the optimization and modeling of biotechnological objects [6-7].

The fermentation stage is characterized by multifactoriality, uncontrollability of numerous parameters of the nutrient medium, seed and medium in the synthesis apparatus, lack of complete and accurate information about the parameters of intermediate and target products, such as biomass, metabolites, concentrations of reagents and their physicochemical and biochemical properties, and to a large extent the influence of humidity on the yield of biogas.

Biogas is a type of biofuel. It is formed naturally as a result of the decomposition of organic waste. By interacting with oxygen under special conditions, the waste breaks down and releases a mixture of gases or biogas. Biogas mainly consists of methane (55-80%) and carbon dioxide (20-45%). The quality of biogas is assessed by the methane content. If additional biogas purification is carried out, it is possible to obtain the so-called biomethane, almost a complete analogue of natural gas, which differs only in its origin. It is important that no waste is generated during the biogas production process. As a result, two products are obtained: the gas itself, which is then used to generate electricity and heat, and biofertilizers for agriculture. Biogas, as well as solar, wind and water, are classified as renewable energy sources. These are natural resources that, unlike fossil fuels (coal, peat, oil, natural gas), are not depleted or renewed faster than they are consumed. And, in addition, they are environmentally friendly, that is, they do not pollute the environment.

Biogas technology – anaerobic digestion. Biogas technology is based on the process of biochemical and thermal treatment of pre-treated waste in an oxygen-free environment under the influence of certain types of bacteria. Biogas plants not only produce "green" electricity, like other renewable sources (solar panels, wind generators, etc.), but also allow you to dispose of waste, preventing its negative impact on the environment. The generation of electricity from natural gas (methane) is one of the cleanest ways to generate electricity, however, methane is extracted from the bowels of the earth, which means that when it is burned, an additional amount of carbon dioxide is released into the atmosphere.

Material and methods. From a fairly general standpoint, mathematical modeling can be considered as one of the most powerful methods and tools of cognition, analysis and synthesis, which are available to specialists responsible for the development and operation of complex technical devices and technological objects (for example, processes, devices and systems of biotechnology). The idea of mathematical modeling is to replace a real object with its "image" – a mathematical model – and to further study the model in order to gain new knowledge about this object. At the same time, the researcher has the opportunity to experiment with the model of the object even in cases where it is almost impossible or impractical to do it on a real object.

Working not with the object itself (phenomenon, process), but with its mathematical model makes it possible to study its properties and behavior in any conceivable situations relatively quickly and without significant costs (the advantages of the theory). At the same time, computational (simulation) experiments with object models make it possible to study objects in detail and in depth in sufficient completeness, which is inaccessible to purely theoretical approaches (advantages of the experiment) [8].

Mathematical modeling is a method of qualitative or quantitative description of objects or processes, whereby a real object, process or phenomenon is simplified, schematized and described by a certain equation. In most cases, the mathematical model is a regression equation, that is, the geometric location of the points of mathematical expectation of the conditional distributions of the objective function.

In the study of a real-life or conceivable technological object, mathematical methods are applied to its mathematical models. Moreover, this application will be effective if the properties of the mathematical model meet certain requirements.

Results and discussions

Let's consider the process of obtaining biogas from various agricultural wastes and the application of a mathematical model.

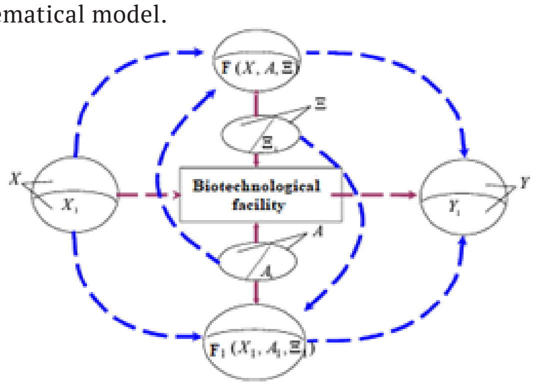

Figure 1. The scheme is based on the concept of a mathematical model.

The cause-and-effect relationship between our parameters will be defined using a set of functional relationships {f} F = (diagram in Fig. 1.), which is defined over the sets. Elements of sets {x}=X, {a}=A,{ξ}=Ξ X, A Y can be numbers or functions, and the elements of F can be functions or operators, respectively. All sets are finite, but the number of elements in them is quite large.

Very often, the set F consists of a system of equations, so the definition of the mathematical model of an object can also be formulated as follows: a mathematical model is a system of equations that relates the output parameters Y of an object with the input parameters X, the internal parameters A in the presence of the influence of perturbing parameters Ξ.

The accuracy of the mathematical model makes it possible to ensure an acceptable coincidence of the real and found with the help of the mathematical model values of the output variables of the biotechnological object that make up the vector

$$y = (y_1, y_2, \dots, y_n) \in R^n. \quad (1)$$

Let – y_i^M и y_i^P be found with the help of a mathematical model and the real value of i of the output variables. Then the relative error of the mathematical model with respect to this variable will be equal to

$$\varepsilon_i = (y_i^M - y_i^P)/y_i^P, \qquad i = \overline{1,n}. \quad (2)$$

As a scalar estimate of a vector $\varepsilon = (\varepsilon_1, \varepsilon_2, \dots, \varepsilon_n)^T$It is possible to take which-or its norm, For example,

$$\varepsilon = \sqrt{\sum_i^n \varepsilon_i^2} \text{or } \varepsilon = \max_{i=1,n} |\varepsilon_i|. \quad (3)$$

Now it remains to find out the adequacy of a mathematical model, which is the ability of a mathematical model to display the output variables of a biotechnological object with a relative error of no more than a certain specified value of δ. In a general sense, the adequacy of a mathematical model is understood as a correct, qualitative, and sufficiently accurate quantitative description of those characteristics of a biotechnological object that are most important in a particular case.

A fuzzy logic model algorithm that estimates the amount of moisture.

To build a mathematical model of biogas production, it is necessary to know the dielectric properties of the processed and studied materials.

One of the important parameters influencing the yield and amount of biogas (methane) is humidity. An analysis of the sources [9-10] of the scientific literature shows that there is a lack of information on the dielectric properties of cattle manure. In determining the dielectric properties, the complex dielectric constant (ε) and dielectric loss angle of cattle manure (tgδ) are defined as the transmission of measurement results of the test material at different humidity (W), at higher frequencies of 40 MHz. The high-frequency method of the dielcometric primary transducer was chosen as a measurement method [11-13].

To solve this problem, let us consider the problems of mathematical modeling of the principle of measuring the basic properties of an electromagnetic wave (EMW) depending on the mass ratio of moisture, the mismatch of wave impedances and the density of the sample.

The equations for the coefficient of reflection and attenuation of an electromagnetic wave will be derived using the theory of four-pole and propagation of radio waves in various media.

Let the electromagnetic wave propagate as shown in Figure 2.

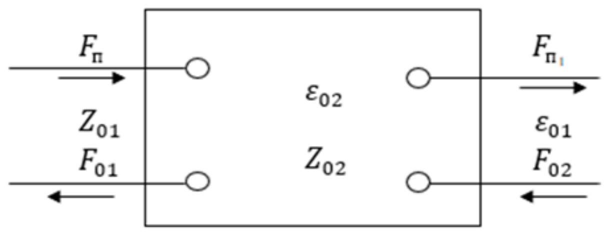

Figure 2. Scheme of four-pole and electromagnetic wave radiation.

Here $F_п$ -the complex magnitude of the amplitude of the wave falling from the generator to the four poles;

$F_{п1}$-the complex magnitude of the amplitude of an electromagnetic wave passing through four poles;

F_{01}-the complex magnitude of the amplitude of the reflecting electromagnetic wave from the first limit towards the generator;

F_{02}-the complex magnitude of the amplitude of the reflecting electromagnetic wave from the second limit towards the generator;

Z_{01} Z_{02} -wave resistors.

Then, for the existing Brewster angle at the normal polarization of the wave, when the last wave moves to the second medium, the following inequality must perform [14].

$$\varepsilon_{01} \neq \varepsilon_{02} \text{ и } \mu_1 \neq \mu_2$$

or in the general case

$$0 < \frac{(1-\mu_1\varepsilon_{02}/\mu_2\varepsilon_{01})}{(1-\mu_{1,}/\mu_2)} < 1$$

Where ε and μ are the dielectric and magnetic permittivity of the medium.

Most emissions are dielectrics whose magnetic permeability is almost equal to the magnetic permeability of air, i.e.:

$$\mu_x = \mu_в \cong 1.$$

It follows that a normally polarized wave, at any limit, is reflected at its angle of incidence.

When the input depth of the wave is Δ^0 dielectric conductivity $\varepsilon_{02} = \varepsilon_{min}$ for biomass moisture, we assume that d is twice the material thickness, i.e.:

$$\Delta^0 = \frac{1}{\omega\sqrt{\frac{\varepsilon_0}{2}\sqrt{1+tg^2\delta}-1}} < 2d. \quad (4)$$

Without it, we may not be able to judge the effect of the reflected wave on the boundary partition. In this case, using the conditions of linearity and passivity of the received four-polar we can write: [15],

$$|F_{02}| = |s||F_{\Pi}|. \quad (5)$$

Here $|s| = \begin{vmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{vmatrix}$ - matrix.

S_{in} consists of some complex coefficients describing the relationship between reflected waves, the physical meaning of which is as follows:

S_{11} reflection coefficient in the partition of the environment from the first limit;

S_{12} – energy transfer coefficient from input to output;

S_{21} – energy transfer coefficient from output to output;

S_{22} – coefficient of reflection of the partition of the environment from the second limit;

In the framework of the above approximation, we can write as follows

$$S_{22} = R = \frac{F_{01}}{F_{\Pi}}. \quad (6)$$

This equation is obtained in a flat boundary proposition at infinite distance. Under Real conditions, biomass can have a fuzzy limit of finite dimensions, indicating the complex functional dependence of electromagnetic waves.

For the instrumental implementation of mathematical model algorithms, a high-wave frequency moisture meter instrument was developed, which allows us to measure the separation of electric waves by means of electromagnetic waves at the limit of the medium.

Taking into account the fact that the state standards (GOST) have not been developed in the Republic of Uzbekistan when measuring the humidity of various types of waste, we applied the state standard of the Russian Federation. The values of the extended uncertainty of this gost measurement result are: ε and tgδ (0.00005 to 0.01), gost was estimated at the level of the confidence interval 0.95 according to P54500.3 and with an interval coefficient not exceeding 2. [16]:

- 1%, ε = 1.2 to 10;
- 1.5%, ε =10 to 60;
- 2%, ε = 60 to 100;
- 3%, ε =100 and above;
- for tgδ- $(10)\frac{3\cdot10^{-3}}{tg\delta})$ %;

The biomass under study and its moisture content were measured by measuring complex dielectric permeability (ε) and tangency of dielectric loss angle (tgδ) using the Agilent E5071C electron chain analyzer [17-19].

The results of measuring biomass dielectric conductivity parameters of cattle waste are shown in Table 1. Calculated humidity (W) calculated according to GOST5180-2015:

$$W = \frac{m_1 - m_2}{m_1} \cdot 100\%. \quad (7)$$

Where m_1 is the mass of the primary material, m_2 is the mass of the dried material.

1- table

Results of detection of dielectric conductivity of waste at a frequency of 40 MGs

Measurement time, minutes	Dielectric permeability, ε	Dielectric loss tangent angle, $tg\delta$	Weight, g	Calculation humidity,%
Primary material	43,25	0,5581	184,6	71
2	39,78	0,44602	163,9	67
4	34,76	0,3591	139,8	61
6	27,87	0,29163	109,3	51
8	15,25	0,2523	80	32
10	2,81	0,2135	60	10
10,30	1,9	0,1	53,9	0

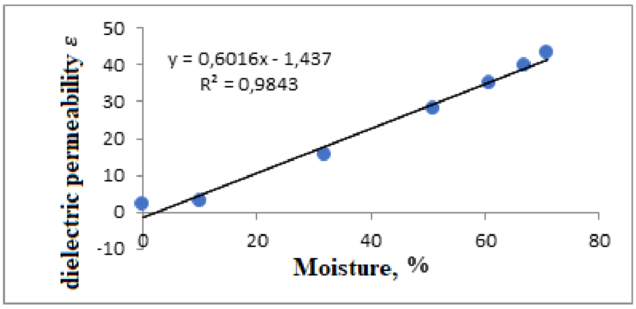

Fig 3-dielectric permeability (ε) moisture relation graph

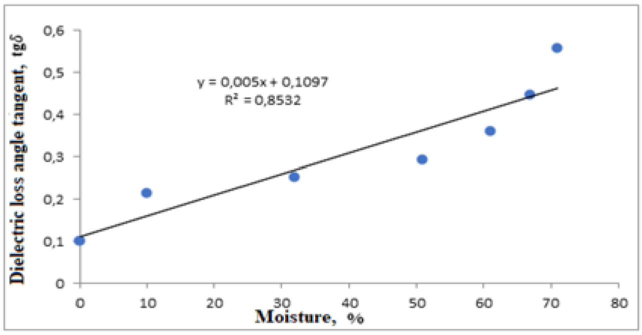

Fig 4. Tangent of dielectric loss angle (tgδ) moisture correlation graph

According to the data obtained, in figures 3.8 and 3.9, the biomass dielectric permeability (ε) and the tangent of the dielectric loss angle (tgδ) are shown with a moisture correlation graph. (Figure 3).

The agricultural waste processing jaraen shows a control and management algorithm. (See Figure 5).

The principle of operation of the presented algorithm:

Step 1. Loading organic waste into the device,

Step 2. Measurement of the initial values of the device's dielectric conductivity (ε) and dielectric loss angle tangent (tgδ) and exhaust temperature t_0.

Step 3. Calculation of humidity W (ε),

Step 4. If the moisture W(ε) value (W(ε) ≈ 10 – 15%) fulfills the condition, the recycled material will not be sent to dry. If the obtained value does not fulfill the condition is sent to step 5, °C.

Step 5. If the moisture value obtained satisfies the required condition changes φ (ε) < 10 – 15%, in which case the moisture in the treated material is increased to the wetting system. If the obtained value does not fulfill the condition, it is sent to step 6.

Step 6. Mathematical modeling of the processing process,

Step 7. Processing,

Step 8. Resize. Step 2.

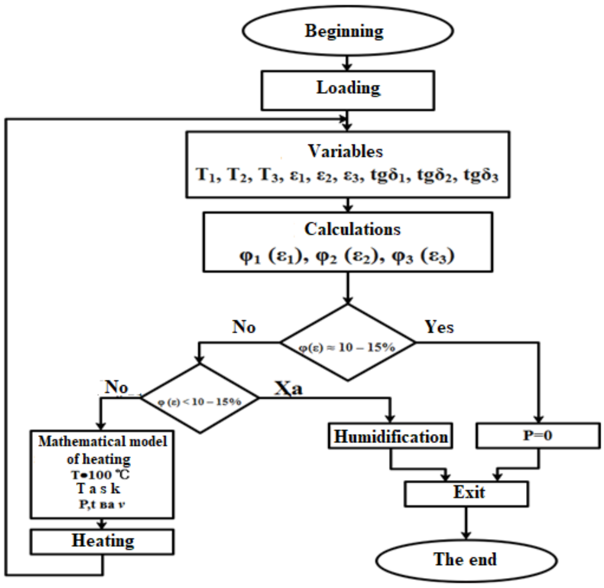

Figure 5. Algorithm for monitoring and managing the processing of agricultural waste Indians

Conclusions

As a result of the introduction of Information Management System Analysis, mathematical modeling, information management of agricultural organic waste processing technologies in the acquisition of existing biogas, it made it possible to identify ways to improve biogas production. Improved Metrological classifications of measuring instruments have been achieved in adaptive (neuro) control of parameters of biomass and in obtaining and processing information from it.

Based on the results of the obtained experimental measurements, it was possible to develop a multi-layered mathematical model of control, through information-management, one of the main factors, taking into account the production of biogas, to determine and assess the degree of influence on obtaining biogas, by adjusting the humidity and it. This made it possible to introduce adaptive (fuzzy) control.

A methane output prediction algorithm has been developed based on the construction of approximate models in the form of adaptive non-linear networks trained in actual data samples obtained from the study. Based on the proposed algorithm, it is possible to create an approved predictive model and introduce the results obtained on the calculation of their data in the information management system at the production enterprise

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