HEAT EXCHANGE IN BIOTECHNOLOGICAL PROCESSES

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Abstract. The article describes the main aspects of modeling biotechnological processes. The kinetics of population growth depending on thermal conductivity is investigated. Physical laws determining the processes associated with heat propagation, the Fourier law and Newton's equation, which describes the surfaces of a solid and a flow, are formulated. The analysis of thermal conductivity of biotechnological processes based on a mathematical model is considered.

Key words: biotechnology, thermal conductivity, secondary metabolism products, specific growth rate of microorganisms, limiting factors, metabolic processes, enzymatic reaction, nutrients, convective heat transfer, isothermal surface.

The article considers the main aspects of modeling biotechnological processes and systems. The classification of mathematical models, their structure, properties and basic definitions are given, allowing to determine the goals and objectives of modeling and its role in the study of complex biotechnological systems. The concepts of the main stages of modeling are given. Particular attention is paid to the fundamental models of microorganism growth, accumulation of metabolic products and temperature changes during biotechnological processes. The influence of various environmental factors on the kinetics of these processes is estimated. The basis of the modern cybernetic approach to solving problems of analysis and synthesis of biotechnological objects is systems analysis. The essence of systems analysis is determined by its strategy, which is based on general principles applicable to solving any systems problem. Modeling is the process of constructing a model of a real object and setting up computational experiments on this model in order to either study the behavior of this system or evaluate the efficiency of various algorithms for its functioning, using computational algorithms implemented on computers. Thus, the modeling process includes both the construction of the model and its application to solve the problem: analysis, research, optimization of biotechnological processes.

In the process of modeling, the researcher deals with three objects: a system, a mathematical model, and an application program for computers that implements an algorithm for solving the equations of the model.

Numerous experimental and theoretical studies expand and deepen our understanding of the process. However, despite significant successes, at all levels of mathematical modeling, a number of important unsolved research problems remain. At the

ISSN 2277-3630 (online), Published by International journal of Social Sciences & Interdisciplinary Research., under Volume: 14 Issue: 06 in June-2025
https://www.gejournal.net/index.php/IJSSIR

kinetic level, the kinetic model of the process needs to be refined and clarified. It is also necessary to supplement the scheme of biochemical transformations with stages that take into account the regularities of the process.

A mathematical model of a technological process is created for a targeted study of the mechanism of the process as a whole or for studying its individual aspects or phenomena, such as, for example, the transfer of heat, mass, momentum. Therefore, when developing a model, individual processes (or phenomena) that take place in a specific modeling object are first analyzed. Based on the above, mathematical modeling of any biotechnological process, apparatus or system comes down to assessing the rate of biochemical processes, which is determined by the rate of biochemical activity of micro-objects depending on one or more parameters of the environment that ensures the flow of metabolic processes.

Meanwhile, during the process, there is a regular change in the kinetic characteristics of growth, biosynthesis of the metabolic product, and consumption of the substrate. All these changes are subject to certain kinetic dependencies, which are essentially the basis of the theory of the process of cultivating microorganisms and biosynthesis of metabolic products and are the objects of study of the kinetics of fermentation processes.

The kinetics of fermentation biotechnological processes studies the patterns of change in the growth rate of microorganisms and biosynthesis of metabolic products depending on the current concentrations of substrates, biomass, metabolic products, temperature and pH of the environment. Let us consider the kinetic patterns of biotechnological processes in more detail. The most common equations describe the kinetics depending on the concentration of only one substrate, which is called limiting; other substrates are assumed to be in excess and do not affect the growth rate.

The simplest kinetic model follows from the very definition of the specific rate of change μ of the concentration of substance C and has the form

$$\frac{dC}{dt} = \mu C \qquad (1)$$

This model implicitly assumes that the value of μ is constant here, but this is not the case – it depends on the concentration of the substrate. The task is to find this dependence. Depending on the type of microorganism, as well as the substrate, the relationship μ(S) can have a very different character.

The Monod model consists of the enzymatic kinetics of biochemical transformations occurring in cells, which is widely known:

$$\mu = \frac{\mu_m S}{K_S + S}$$

Where μ_m - maximum growth rate when there is no secondary metabolism (waste of microorganisms after consumption of substances) of microorganisms, ч$^{-1}$, K_S - const.

Then formula (1) takes the form

ISSN 2277-3630 (online), Published by International journal of Social Sciences & Interdisciplinary Research., under Volume: 14 Issue: 06 in June-2025
https://www.gejournal.net/index.php/IJSSIR

$$\frac{dC}{dt} = \mu_m \frac{S}{K_S + S} C$$

The Mono model is based when there is no secondary metabolism of microorganisms in the process.

The model takes into account inhibition with secondary metabolisms of microorganisms and is described by the equation

$$\mu = \mu_m \frac{k_{ps}}{k_{ps} + S_0 - S}$$

This model is based on the fact that the consumption of substances by microorganisms is proportional to secondary metabolisms.

In this regard, this paper examines the patterns of change in heat transfer in fermentation processes.

Heat transfer is possible in three different ways: conduction, convection and radiation.

Thermal conduction is the transfer of heat during direct contact of bodies (or parts of one body) with different temperatures. This process can be imagined as the spread of heat from particle to particle in the absence of their movement. In its pure form, thermal conductivity is observed in solids, and in liquid droplets and gases - only in the absence of convective currents in them.

Convective heat transfer, possible only in liquids and gases, occurs as a result of the movement of their particles in the volume. Depending on the cause causing the movement of liquid or gas particles, a distinction is made between convective heat exchange in free convection and in forced convection. Free convection involves the movement of particles caused solely by the difference in liquid or gas densities in different parts of the volume they occupy due to the difference in temperature. Convection is called forced when the movement of liquid or gas particles occurs under the action of external forces (pumping, compressors, etc.).

Radiant heat exchange is the process of heat transfer in the form of electromagnetic waves, accompanied by the transformation of thermal energy into radiant energy and vice versa from radiant to thermal energy.

In technology, the above methods of heat exchange are rarely encountered in isolation: most often we have to deal with a combination of two or even all three methods in their sequential or simultaneous action. A special place is occupied by heat exchange, accompanied by a change in the aggregate state of the bodies participating in this process (evaporation of liquid, condensation of vapors). There are two cases of heat exchange: heat transfer and heat transmission. Heat transfer is the process of heat exchange between a solid body (for example, the wall of an apparatus) and a liquid or gas in contact with it. Heat exchange between liquids, gases, liquid and gas separated by a wall is called heat transfer.

Let us formulate the physical laws that determine the processes associated with the distribution of heat.

ISSN 2277-3630 (online), Published by International journal of Social Sciences & Interdisciplinary Research., under Volume: 14 Issue: 06 in June-2025
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1. Fourier's law: the amount of heat dQ, transferred by heat conduction through the cross-sectional area S of the isothermal surface of the body during time $d\tau$ is expressed by the basic equation of heat conduction

$$dQ = -\lambda S \frac{dT}{dn} dt, \qquad (2)$$

The negative sign on the right side of the equation is a consequence of the temperature drop in the direction of heat transfer. The proportionality coefficient λ in the equation is called the thermal conductivity coefficient, λ [W/(m·deg)]. It is expressed by the amount of heat transferred in 1 s through 1 m2 of the body surface with a temperature gradient of 1 °C per 1 m of the length of the normal to the isothermal surface. The value of λ depends on the nature of the substance, being its individual property. The numerical values of λ are determined empirically. The value of λ varies greatly for different substances, and for the same substance it depends on temperature, density, structure, humidity and other factors. 2. Newton's equation: heat flow

$$\frac{dQ}{dt} = \alpha\left(T_c - T\right)S,$$

where Tc, T are the surface temperatures of the solid body and the flow, respectively; α is the heat transfer coefficient, W/(m2 deg).

The heat transfer coefficient α expresses the amount of heat given off by a unit of surface S=1 m2 per unit of time t=1 s with a temperature difference of (Tc−T)=1 deg. Note that α is not a constant value, but depends on many parameters, primarily on the hydrodynamic situation near the heat-giving surface.

The amount of heat that must be imparted to a homogeneous body to increase its temperature by ΔT is equal to

$$Q = cm\Delta T = c\rho V \Delta T,$$

where c is the specific heat capacity, J/(kg · deg); m is the mass of the body, kg; ϱ is the density of the body, kg/m3; V is the volume of the body, m3.

The nature of temperature distribution in biotechnological processes is extremely important when analyzing the processes occurring in it, since temperature is one of the main parameters of the technological process. Firstly, the state of biochemical equilibrium and the maximum achievable degree of growth of microorganisms depend on temperature. Secondly, the rate of biochemical reactions depends on temperature

$$\mu\left(T\right) = k_0 \exp\left(-\frac{E}{R}\left(1 - \frac{T}{T^{onm}}\right)^2\right),$$

where, is the kinetic constant, h-1; E is the activation energy, J/(K·mol); is the temperature corresponding to the maximum growth rate, K; R is the universal gas constant, R = 8.31 J/(K·mol); T is the temperature of the nutrient medium, K.

Violation of uniform temperature distribution in fermentation processes can lead to undesirable side effects, to destructive disturbances of the process.

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Temperature change in the fermentation apparatus occurs due to the processes occurring in it, air supply to the apparatus for which it is necessary to maintain dissolved oxygen in the nutrient medium, heat exchange of the apparatus with the environment, as well as due to the accompanying release of heat. This means that biotechnological processes in the apparatus occur under isothermal conditions, therefore, to determine heat release in the studied aerobic processes, the method of calculation by secondary indirect parameters is used - where, and is the stoichiometric coefficient for dissolved oxygen, kg/kg.

The hydrodynamic situation in the apparatus has a significant impact on the nature of the temperature distribution. For example, in an ideal displacement apparatus, all process parameters, including temperature, are the same at any point in the apparatus at a given time. On the contrary, in a displacement reactor, the temperature may be different at different points in the apparatus. The intensity of mixing also affects the intensity of heat exchange in the apparatus. When calculating the productivity of the apparatus, it is necessary to jointly solve the system of heat and final product, of which the first takes into account the change in the amount of substance, and the second - the change in the temperature of the nutrient medium, the third - the amount of concentration of microorganisms during the fermentation process.

$$\begin{cases} c\rho\dfrac{\partial T}{\partial t} = -\dfrac{\alpha}{l}\left(T - T_b\right) - 2\dfrac{\alpha_{cm}}{r}\left(T - T_{ов}\right) + \Delta H \cdot \mu\left(S,T\right)\cdot X \\ \dfrac{\partial X}{\partial t} = -DX + \mu\left(S,T\right)\cdot X \\ \mu\left(S,T\right) = \mu_m \dfrac{k_{ps}}{k_{ps} + S_0 - S}\exp\left(-\dfrac{E}{R}\left(1 - \dfrac{T}{T^{опт}}\right)^2\right) \end{cases} \quad (4)$$

with initial conditions

$T(0) = T_0,\ S(0) = S_0,\ X(0) = X_0,$

where X is the concentration of microorganism biomass, kg/m³; $T_ь$ – air temperature, *K*; α, α_{cm} - heat transfer coefficients of the nutrient medium and the apparatus wall from the environment, Вт/(м²·K); *c*- specific heat capacity of the nutrient medium, Dж/(кг·K); ρ - density of nutrient medium, kg/m³; *l*, *r* – length and radius of the device, *м*; D - the rate of dilution of the nutrient medium,

$ч^{-1}$; μ, α^S - specific rates of biomass accumulation and consumption of limiting substrates, respectively, $ч^{-1}$; *S*– concentration of limiting substrates, kg/m³; *t* – time, h.

Computer experiments to study the dynamics of the main variables of the state of the resulting model of a continuous mode for biomass production show that the behavior of the system is divided into two typical periods - some time from the beginning of the calculation, a transient process is observed, after which the system enters a stable equilibrium mode of operation.

Thus, the mathematical model of the state of the system allows obtaining significant information about the fermentation process in devices based on the identification of

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https://www.gejournal.net/index.php/IJSSIR

quantitative patterns between the influencing and output parameters, and allows predicting its results under non-stationarity conditions.

REFERENCES:

1. Бирюков В.В. Основы промышленной биотехнологии. – М.: Колосс, 2004. - 296 с.

2. Кафаров В.В. Основы массопередачи. –М.: Высшая школа, 1972. – 496.

3. Компьютерное моделирование биотехнологических процессов и систем: Учеб. пособие / Д.С. Дворецкий, С.И. Дворецкий, Е.И. Муратова, А.А. Ермаков. Тамбов: Изд-во Тамб. гос. техн. ун-та, 2005. 80 с.

4. Мошинский А.И. Математическое моделирование химико – технологических и биотехнологических процессов. Санкт-Петербург. Кнорус. 2021. -336 с.

5. Процессы и аппараты биотехнологии: ферментационные аппараты. Учебное пособие для вузов / А. Ю. Винаров [и др.] ; под редакцией В. А. Быкова. — 2-е изд., перераб. и доп. — Москва : Издательство Юрайт, 2021. — 274 с.

6. Salimov D.T. Study of the kinetics of fermentation process. ASIA PACIFIC JOURNAL OF MARKETING & MANAGEMENT REVIEW ISSN: 2319-2836 IMPACT FACTOR: 8.071 Vol 13, Issue 04, 2024.

ISSN 2277-3630 (online), Published by International journal of Social Sciences & Interdisciplinary Research., under Volume: 14 Issue: 06 in June-2025
https://www.gejournal.net/index.php/IJSSIR