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STUDY OF THE KINETICS OF FERMENTATION PROCESSES

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Abstract: To describe the actual picture of changes in concentrations or temperature in the apparatus, it is necessary to have some quantitative measure of the degree of mixing, i.e. the degree of deviation of the real hydrodynamic structure of the flow from the structure corresponding to ideal displacement or ideal displacement. To find such a measure, expressed in numerical values of one or more parameters, one usually resorts to describing the flow structure using one or another simplified model or physical scheme that more or less accurately reflects the actual physical picture of the flow movement.

Keywords: mathematical model, industrial reactor, technological process.

This idealized physical model corresponds to a mathematical model - an equation or system of equations by means of which the type of the residence time distribution function is determined by calculation. Next, the actual experimentally obtained form of the distribution function is compared with the calculation result based on the selected ideal model for different values of its parameters. As a result of the comparison, it is determined whether the selected model corresponds with a sufficient degree of accuracy to the real hydrodynamic structure of the flow in an apparatus of this type, i.e., whether the model is adequate to the object. Then those numerical values of the model parameters are found for which the agreement between the experimental and calculated distribution functions is the best. The specified values are subsequently used when calculating the process in a specific apparatus. Summarizing these data, equations are obtained for calculating the values of the model parameters under different hydrodynamic operating conditions and sizes of devices of this type.

Obtaining reliable modeling results and making biotechnological decisions based on them is possible only on the basis of a theoretically based kinetic model of the process. The decision-making process when synthesizing a mathematical model should be based on knowledge about the mechanism of interaction between biochemical, heat and mass transfer, and hydromechanical processes in the reactor, taking into account which allows us to build the most reliable and simplest possible model. This requires knowledge of the kinetic model of the process and the conditions for its implementation in an industrial reactor.

Numerous experimental and theoretical studies expand and deepen our understanding of the process. However, despite noticeable successes, a number of important unsolved research problems remain at all levels of mathematical modeling. At the kinetic level, the kinetic model of the process needs to be refined and refined. It is also necessary to supplement the scheme of biochemical transformations with stages that take into account the laws of the process.

Of great importance, both in periodic and continuous organization of the process, is the nature of the flow movement. Structure of flows in the apparatus; (complete displacement, complete mixing, or a combination of both) determines the choice of a mathematical model of the process, including equations describing the dynamics, as well as boundary and initial conditions and other characteristics of the process. The compilation of a mathematical model in each particular case is carried out in accordance with a systematic approach to the process. The process is divided into elementary stages arranged in a hierarchical order. At the first level of the mathematical model, there are usually dependencies that describe the equilibrium conditions, as well as the nature of biochemical transformations. The second hierarchical level describes the patterns of elementary transfer processes occurring in a single microorganism, in one drop, bubble, etc. The third level corresponds to modeling the process of hydrodynamics, heat and mass transfer phenomena in the whole apparatus, including the dependencies of the second level.

A mathematical model of a technological process is created for a targeted study of the mechanism of the process as a whole or to study its individual aspects or phenomena, such as, for example, the transfer of heat (mass), momentum. Therefore, when developing a model, the individual processes (or phenomena) taking place in a specific modeling object are first analyzed.

Mathematical models are a description of processes in a real object using mathematical equations, including differential ones. Computers are now widely used to implement mathematical models. With the help of computer technology, so-called computer simulations are carried out. In this case, you can easily change the time scale to speed up or slow down the process. Using computer technology, it is possible to solve complex equations and predict the course of fermentation processes.

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 microobjects depending on one or more parameters of the environment that ensures the occurrence of metabolic processes.

The description of a set of biochemical processes is a biochemical model of the process. The study of biochemical kinetics provides a kinetic model of the process, which describes the dependence of the rates of reactions included in the biochemical model on temperature and concentrations of reagents.

Meanwhile, during the process there is a natural change in the kinetic characteristics of growth, biosynthesis of metabolic products, and substrate consumption. All these changes are subject to certain kinetic dependencies, which are essentially the basis of the theory of the process of cultivating microorganisms and the 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 changes in the growth rate of microorganisms and the 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

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

This model implicitly assumes that the value of μ is constant here, but this is not the case - it strictly depends on the concentration of the substrate. The task is precisely to find this dependence. Depending on the type of microorganism, as well as the substrate, the μ(S) bond 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 consuming substances) of microorganisms, $ч^{-1}$, K_S - const.

Then formula (1) takes the form

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

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

A model that takes into account inhibition with secondary metabolism 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 metabolism.

One of the main factors influencing the growth rate of microorganisms is the temperature regime and the speed of mixing of the culture liquid. In particular, for most microorganisms the temperature optimum is 309 K. At this temperature, the specific growth rate increases in direct proportion to the increase in temperature. A further increase in temperature leads to a detrimental decrease in the concentration of microorganisms.

Mixing of the culture liquid in yeast production is carried out by supplying air to aeration, which ensures a continuous supply of oxygen to the cells, removes CO2 from the liquid and maintains the cells in a suspended state. The air supply to the apparatus must be in accordance with the supply of culture fluid and the expected rate of reproduction of microorganisms.

A method has been proposed for constructing a kinetic model of the process of growing microorganisms, taking into account:

1) the influence of the concentration of four main elements: oxygen, inhibition, substrate and temperature;

2) hydrodynamic situation in the apparatus;

3) heat exchange condition during biomass accumulation.

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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.

In the real process, there is a continuous consumption of dissolved oxygen from the liquid and at the same time its continuous dissolution - mass transfer from air bubbles. We must keep in mind an important feature of microbiological processes. Microorganisms are not able to consume oxygen directly from gas bubbles. They consume only dissolved oxygen, i.e. oxygen passes into the microorganism cell through two stages: mass transfer from gas to liquid and then consumption of already dissolved oxygen from the liquid. To influence the concentration of dissolved oxygen in a liquid, it is necessary to change either the speed of air blowing through the apparatus, or the rotation speed of the stirrer in the apparatus, or the pressure in it.

The kinetic model of the process is a set of elementary stages, reactions and equations that characterize the dependence of the rate of biochemical transformation on the reaction parameters of pressure, temperature, concentrations of reagents, and others. Such dependencies are determined on the basis of experimental data in the field of changes in reaction parameters, covering the practical conditions of the process. The constructed kinetic model is the first level of the model of any apparatus and the basis for solving dynamic problems that arise during the development of a biotechnological process.

With continuous cultivation, by selecting the flow rate, the growth rate of microorganisms can be stabilized at any point on the exponential growth curve of microorganisms. In practice, the simplest way to stabilize the process is to turn on the substrate flow and remove part of the population.

In this regard, this work examines the patterns of changes in heat transfer of fermentation processes.

The nature of the 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 speed of biochemical reactions depends on temperature

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

Where, k_0 - kinetic constant ч$^{-1}$; E - activation energy, Дж /(К·моль}; $T^{опт}$ - temperature corresponding to the maximum growth rate, К; R - universal gas constant, R = 8,31 Дж/(К·моль); T - temperature of the nutrient medium, K.

Violation of the uniform temperature distribution in fermentation processes can lead to undesirable side effects and disastrous disruptions to the process.

A change in temperature in the fermentation apparatus as a whole or a change in the temperature distribution throughout the volume of the apparatus occurs due to the processes occurring in it, the supply of air to the apparatus for which it is necessary to maintain dissolved oxygen in the nutrient medium, the heat exchange of the apparatus with the environment, and also due to the accompanying release of heat. This means that the biotechnological processes in the apparatus occur under isothermal conditions, therefore, to determine the heat release in the aerobic processes under study, a

calculation method using secondary indirect parameters is used $\Delta H = 3,38 \cdot \alpha$ - где, а α - stoichiometric coefficient for dissolved oxygen, kg/kg.
The hydrodynamic situation in the apparatus has a significant influence on the nature of the temperature distribution. For example, in an ideal displacement apparatus, all process parameters, including temperature, are the same at any given point in time at any point in the apparatus. In contrast, in a plug-flow reactor the temperature can 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 a system of equations for the material and final product, of which the first takes into account the change in the amount of the substance, and the second takes into account the change in the amount of microorganism concentration during the fermentation process.

$$\begin{cases} \frac{\partial S}{\partial t} = D(S_0 - S) - \alpha^S \mu(S,T,C_o) \\ \frac{\partial X}{\partial t} = -DX + \alpha^S \mu(S,T,C_o) \\ \mu(S,T,C_o) = \mu_m \frac{C_o}{k_0 + C_o} \frac{k_{ps}}{k_{ps} + S_0 - S} \exp\left(-\frac{E}{R}\left(1 - \frac{T}{T^{опт}}\right)^2\right) \end{cases} \quad (4)$$

Where, D - rate of dilution of the culture fluid, $ч^{-1}$; μ, α^S - specific rates of biomass accumulation and consumption of limiting substrates, respectively, $ч^{-1}$; X – концентрация биомассы микроорганизмов, кг/м^3; C_o - concentration of dissolved oxygen in the culture fluid, кг/м^3; S– concentration of limiting substrates, кг/м^3 ; t – time, hours
The resulting mathematical model of the process of growing microorganisms takes into account the basic laws of the kinetics of biomass growth, the phenomena of hydrodynamics and heat transfer in the fermentation process.
In conclusion of this article, it is necessary to note the following: obtaining reliable modeling results and making decisions based on them that are interesting in a biotechnological sense is only possible on the basis of a theoretically justified kinetic model of the process.

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