INVESTIGATION OF THE OPERATION OF MACHINES AND EQUIPMENT

SELECTION OF AN OPTIMAL BIOCHEMICAL REACTOR FOR MICROBIOLOGICAL SYNTHESIS

P. I. Nikolaev and D. P. Sokolov

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Biochemical reactors (fermentation units) are a characteristic kind of equipment for microbiological processes. The volume of fermentation units in the medical industry is 50-100 m^3, and the volume of fermentation units for the production of feed yeasts ranges up to 1300 m^3. In industrial fermentation units of various designs, streams of liquid and gas phases circulate, forming complex systems of circulation circuits. Figure 1 shows a diagram of the material streams which is typical of many fermentation units. Three zones differing in functional purpose and determining the overall reaction volume of the unit can be isolated in the diagram.

In zone I, the fed air Q_g is dispersed and mixed with the liquid circulation stream Q_l, which contains the recirculation stream of spent air Q_r. This zone is characterized by the energy N_{mi} expended by the mechanical dispersing device or jet mixers for dispersion of the phases using the energy of the liquid or gas stream. During simultaneous throttling of the liquid and gas streams through jet mixers, the determining parameter of the mixing zone is its pressure drop ΔP_{mi}.

In zone II, mass transfer occurs between the dispersed gas phase and the suspension of microorganisms. This zone constitutes a large part of the reaction volume of the fermentation unit. To prevent coalescence of the gas bubbles in this zone, energy N_t is expended for stream turbulization, which is introduced by mixing devices distributed with respect to volume or by arrangement of various turbulizers on the path of the gas–liquid stream. In the latter case, the determining parameter of the reaction zone is its pressure drop Δp_t.

In zone III, the spent air is separated. The gas–liquid emulsion can be separated with various mechanical foam suppressors or devices with natural foam suppressors or devices with natural foam breaking not requiring additional energy expenditures.

A structural diagram of the fermentation unit ensuring circulation of the streams of the liquid and gas phases is shown in Fig. 2. Figure 3a, shows a diagram of a fermentation unit which provides for the use of mechanical mixing with energies in the mixing zone N_{mi}, reaction zone N_r, and separation zone N_s. Figure 3b shows a fermentation unit which provides for the use of only the energies of the streams of the liquid N_n and gas N_k phases in all the zones of the unit.

In the diagrams of the units shown in Fig. 3, pumps and compressors are used for transport of liquid and gas, a mechanical or jet mixer is used for mixing of liquid and gas, mixing devices or grid flow turbulizers

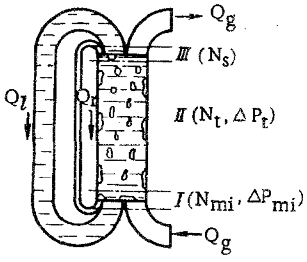

Fig. 1

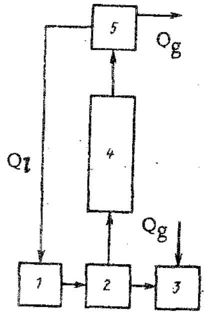

Fig. 2

Fig. 1. Diagram of the streams in the fermentation unit: Q_g) gas stream; Q_l) liquid circulation stream; Q_r) gas circulation stream carried away by the liquid.

Fig. 2. Structural diagram of the fermentation unit: 1) pump; 2) mixer; 3) compressor; 4) reactor; 5) separator.

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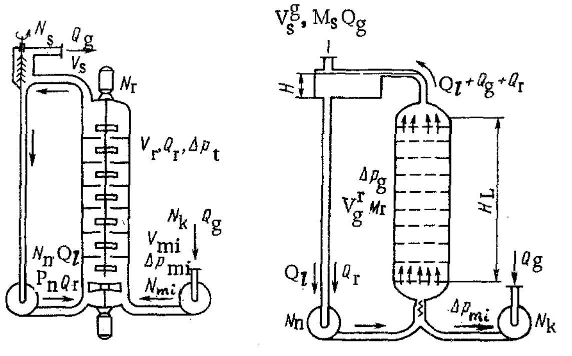

a) b)

Fig. 3. Diagram of a fermentation unit with mechanical devices (a) and with jet devices (b).

are used for flow turbulization in the reaction zone, and a centrifugal plate separator or cyclone is used for separation of the gas phase. Since in these units the operating conditions of individual components can be chosen independently and technically improved equipment (pumps and compressors) can be used, the problem of optimal design of the unit for a specific process is simplified.

At the same time, new components combining several functions can be included in the fermentation units. Thus, many technical decisions are directed toward excluding pumps or compressors. Instead of pumps, injectors and air-lift devices are used as the devices for creating the liquid flow rate, and instead of a compressor, rotating or fixed ejectors are used. In addition, streams are mixed in injectors and ejectors. Various mixing devices or jet mixing is used for turbulization of the medium in the reaction volume. Combining several functions in one component leads to simplification of the designs of the units, easier servicing, and reduced capital expenditures, but simultaneously complicates the problem of design optimization. Many new components performing various functions simultaneously have low hydromechanical indexes.

Since existing designs of industrial fermentation units are, to some degree, variants of the units whose diagrams are shown in Figs. 2 and 3, it seems appropriate to find the optimal variant of such a diagram for a specific microbiological process.

We can take as one of the particular criteria for optimality of fermentation units the overall energy expenditures for oxygen absorption with an identical preassigned specific rate of oxygen absorption M.

For the unit shown in Fig. 3b, the overall specific rate of oxygen absorption M is determined by two components: the rates of oxygen consumption in the reaction zone and the separation zone. The problem of optimal design in the considered case amounts to determining the design and technological parameters of the unit. The design parameters are the height of the reaction zone H_r, the geometric volume of the separation zone V_s^g, and the geometric volume of the reaction zone V_r^g. These parameters and also the pressure drops in the mixing and reaction zones must be determined from the conditions of the minimum value of the specific power N for a given rate of oxygen absorption in a unit of geometric volume of the fermentation unit:

$$N = f\,(H_r,\ V_r^g,\ V_s^g\ \Delta p_s,\ \Delta p_t,\ H_s\ Q_l,\ Q_g\ \sigma,\ \nu,\ M_r), \tag{1}$$

where M_r is the rate of microbiological oxygen consumption, kg $O_2/(m^3 \cdot h)$; H_s is the height of the separation zone, m; σ is the coefficient of surface tension of the medium, dyn/cm; ν is the coefficient of kinematic viscosity of the medium, cm^2/sec.

The indicated parameters should be determined by taking into account the relations describing hydrodynamic and mass-transfer processes which occur in individual interrelated components of the unit. These relations are generally known [1-3].

One of the important problems is the choice of the correlation of the rates of diffusion and biochemical reactions in fermentation units. In the reactive zone of industrial fermentation units, it is economically appropriate to carry out the processes in the near-transition region. In this case, the process will occur in the diffusion region in the separation zone.

Beginning with a specific low value of the concentration of dissolved oxygen C_{od}, the rate of microbiological oxygen consumption M_r depends on the zero-order reaction rate and on the concentration S of the oxidized substrate;

$$M_r = b X \mu\ (C,\ S), \tag{2}$$

where b is the oxygen consumption for formation of a unit of biomass; X is the biomass concentration, kg/m^3; μ is the coefficient of the specific growth rate of microorganisms, h^{-1}.

The value of M_r is found from the condition of the minimum of the specific power N, and correlation (2) is used to determine the parameters X and S of the corresponding technological conditions.

In solving the problem of optimal design of units for cultivation of microorganisms, it is necessary to use not only the hydrodynamic characteristics of the process taking into account the structure of the streams of the gas and liquid phases, but also the kinetic characteristics taking into account the nonsteady-state nature of the cultivation conditions [4]. The effect of the nonsteady-state nature of the cultivation conditions on the growth of microorganisms was investigated previously primarily with pulsed influences on the steady-state process. Under such conditions, microorganisms cannot adapt to periodically changing environmental conditions during prolonged cultivation. Therefore, methods for investigating processes for the cultivation of microorganisms under prolonged nonsteady-state conditions and a mathematical description of these processes were developed. The cultivation of *Saccharomyces cerevisiae* yeast under discontinuous-aeration conditions was investigated as an example. As a result, the effect of continuation of intensive growth of yeast after rapid transition from aerobic cultivation conditions to anaerobic ones was revealed. To explain this effect, the most probable hypothesis seems to be that of the formation in the cells of a significant amount of intermediate oxidation products at period τ_1 of the aerobic-growth phase and their consumption in the anaerobic phase at period τ_2.

The change in the growth rate of the microorganisms in going from steady-state conditions to nonsteady-state ones can be taken into account with the nonsteady-state coefficient

$$\eta = \frac{\tau_1}{\tau_1 + \tau_2} + \frac{\alpha_3}{\tau_1 + \tau_2}\,\frac{[1-\exp(-\alpha_1\tau_1)][1-\exp(-\alpha_2\tau_2)]}{1-\exp(-\alpha_1\tau_1-\alpha_2\tau_2)}, \tag{3}$$

where α_1, α_2, and α_3 are coefficients determined experimentally.

In solving the problem of optimization of the unit for cultivation of microorganisms, it is necessary to consider simultaneously the nonsteady-state nature of hydrodynamic and mass-transfer processes in large-capacity fermentation units and the cell growth kinetics.

For a fermentation unit with a large separation zone, it is possible to determine the residence time of the biomass circulating in the circuit under aerobic and anaerobic conditions.

$$\tau_1 = \frac{V_r}{Q_l}; \tag{4}$$

$$\tau_2 = \frac{V_s}{Q_l}. \tag{5}$$

The consumption of oxygen dissolved in the liquid occurs primarily in the reaction zone; the rate of its consumption in this zone is higher than the average rate for the entire unit, and it can be determined from the correlation

$$M_r = bX\mu\,(S,\ C,\ \tau_1,\ \tau_2)\,\frac{\tau_1 + \tau_2}{\tau_1}, \tag{6}$$

which, by taking into account dependence (3), assumes the form

$$M_r = bX\eta\mu\,(S,\ C)\,\frac{\tau_1 + \tau_2}{\tau_1}. \tag{7}$$

It should be noted that the short-term increase in the rate of absorption of oxygen by the microorganism suspension may be significant in comparison with the average rate.

In experiments for cultivation of *Saccharomyces cerevisiae* at $\tau_1 = 0.15$ min and $\tau_2 = 3$ min, the average rate of oxygen absorption was 2 kg of $O_2/(m^3 \cdot h)$, under aerobic conditions, 20 kg $O_2/(m^3 \cdot h)$.

Thus, the problem of optimal design of the fermentation unit can be reduced to finding the equipment and technological parameters from the condition of the minimum value of the specific power N according to correlation (1) taking into account dependences (3)-(5) and (7).

According to dependence (7) for nonsteady-state conditions of cultivation of microorganisms, it is possible to increase significantly the volume of the nonaerated separation zone without a significant decrease in the average growth rate of the cells, with the rate of oxygen consumption in the reaction zone increasing just as many times.

The considered characteristic of microorganisms to adapt to nonsteady-state aeration conditions makes it possible to obtain satisfactory productivity of fermentation units with insufficiently uniform aeration and mixing.

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THE EXTERNAL CHARACTERISTICS AND PRESSURE FLUCTUATIONS OF A TWO-STAGE PNEUMATIC-CONTROLLED PUMPING SYSTEM

S. V. Lovchev, F. M. Mir-Kasimov,
E. P. Moroz, and L. I. Sokov

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Contemporary methods of drilling oil and gas wells present increased demands on pumping equipment, the main ones of which are for increased pressure and power. To achieve higher pressures in existing well pumps would require increasing their weight, overall dimensions, and drive motor power. In addition, increasing the pressure drop on such removable parts and components of pumps as pistons, valves, sleeves, etc., significantly reduces their service life.

One method of increasing the pumping equipment pressure is to use two or more reciprocating pumps connected in series system designed to divide the pressure drop and power between them. However, in practice this principle can only be accomplished using control devices which can equalize ideally the input to the piston pumps. In order to resolve the question of the usefulness of such pumping equipment a special investigation has been carried out in the All-Union Scientific-Research Institute of Petroleum Engineering.

The investigations were conducted on a rig [1] including two type 11Gr piston pumps connected in series and fitted with a fast-acting pneumatic system for controlling the feed over the entire working range. The present work presents certain results from an investigation of the experimental basis for the possible use of a two-stage pneumatically controlled pumping set to distribute uniformly the pressure drop and power between piston pumps, determining the pump and overall unit efficiencies and the pressure fluctuations in various chambers of the equipment in series pump operation.

During testing, the first pump stage of the experimental equipment was fitted with standard 90-mm-diameter cylinder sleeves and pistons, while the second stage was fitted with 80-mm-diameter components. The use in the first stage of larger-diameter sleeves and working pistons was due to the need to provide the best filling of the second-stage pump cylinders under any working condition. The sleeve and piston separators of the pneumatic controllers for the first and second pumps were, respectively, 120 mm and 100 mm in diameter. The double-acting frequency was 100 per min for both pumps. Process water was used as the pumped fluid. A typeVK-5 pneumatic compensator having a useful gas volume of 5 dm^3 was fitted immediately before the inlet collector of the second pump at the end of the intermediate piping. From the conditions of conducting the experiments designed to achieve uniform power and pressure drop between the pumping stages, the gas pressures in the pneumatic systems of the first and second stages were in the ratio 1:2 and were assigned as follows: 2 and 4; 2.5 and 5; 3 and 6 MPa.

The following parameters were determined during the experiments: pump inlet and outlet pressures; pressures in the working chambers of the pumps; gas pressures in the pump pneumatic systems; gas pressure in the pneumatic compensator at the inlet to the second pump; pump feed rate; indications of the dead points of the piston pumps; power and current for the electric motors of both pumps. The mean pressures were measured by a class 0.2 manometer. In addition to this, during the experiments oscillograph recordings were made of the pressures stated as well as the power and current to the pump electric motors.

The pressures were determined by means of type TDD-2-NATI strain gauge transmitters. The equipment used for pressure recording consisted of two type 8ANCh-7M 8-channel amplifiers and two type K-115

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