THE HIGH – TECHNOLOGY BIOREACTORS MAKING WAYS WITH THE HELICOID TYPE ROTOR

Ivanov K.A., Ivanov D.A., Rudenko A.P.

The Siberian State Technological University, Krasnoyarsk, e-mail: ivanov.sibstu@yandex.ru

The simulation modeling practical application, with the purpose of the device creating for the mycelial forms cultivation of the microorganisms is considered in the work. The device modeling results for the high – quality production obtaining at the desired performance and the minimum specific energy consumption achieving are given.

Keywords: hydrodynamics, homogeneity, material dispersion, body, strip, cavity, profiling, rotor, suspension, trajectory

So, the microbial cells growth and further development, in the process of their cultivation, is occurred under the influence of the great number of the factors, having determined by the environmental conditions. The most significant of all these factors is: the carbon – containing substrates, the oxygen, the mineral nutrient medium, the physicochemical factors (e.g. pH, the temperature, the pressure and the others).

The biochemical reactor work efficiency, to the large extent, is determined by the interaction conditions in the microorganisms' growing population with the environment. So, the cell population development is connected with the nutrient substances transport from the fluid mass to the cell surface, and the metabolic products diversion from it, when the microorganisms' deep cultivation methods application using in the fermenters.

At the same time, the nutrient substances transport conditions to the cell, its supply of all them the essential ones for the further normal growth and the development, are largely dependent on the hydrodynamic conditions, and the situation in the biochemical reactor. So, the fermentation time, which is necessary for the required substrate utilization and the microorganisms' growth, is completely depended on the currents' and the flows' structure, on the medium mixing conditions throughout the device's entire volume [1].

The transport challenges of the nutrient supply components to the cells, and in the first place, the oxygen at the aerobic microorganisms' cultivation are, particularly, complex and significant at the fermentation in the large volumes. So, the oxygen transfer velocity in the three – phase system, such as the gas – the fluid – the cell is complicated by the cell – cell agglomerates presence, by the non – uniform distribution of the dispersed phase, by the local areas with the oxygen's low concentration presence in the device, and etc.

So, the influence is quite also significant on the fermentation processes such factors, as the dead zones, by – passing flows and the currents presence and so on. So, in the dead zones, where the cells are being left significantly longer time, than the fermentation's estimation time, it is quite possible their lysis and the infective microflora's microorganisms formation, which then is inhibited the cells' further growth process in the reactor. The by – passing flows and the currents presence is resulted in the nutrient substances and the elements break–through, in a number of cases, the much expensive substrate, and also their incomplete and the under – utilization.

So, all these and many other shortcomings of the bioreactors' modern designs are not possible to be obtained the finished product's output volume more than 65 %.

In this connection, the best conditions of the substance transfer and its further consumption in the biosynthesis process of the reactor to be ensured, it is necessary to be created the specific hydrodynamic environment [1].

At this moment, all these goals' achievement is difficult enough task feasible, because of the weak, as theoretical, well as the practical knowledge on the mixing process. At the present moment, many attempts are made to the quite different and the various research methods application to be accomplished this intractable and difficult challenge to be solved, and one of them is the computer simulation.

So, the computer simulation, in particular, the imitation simulation, is quite allowed to us to be solved the significant complexity challenges, thus, having provided any multiple processes simulation with a large number of the elements. So, in such processes, the separate functional dependencies, as a rule, can be described, as the very cumbersome mathematical expressions, the practical use of which is involved the compulsory need for the simplification, having associated with the additional use of the empirically derived dependencies.

At the same time, the imitation simulation can be efficiently used in the scientific researches, exactly the systems with the complex structure, in order specifically identified challenges solutions to be obtained [2]. So, the «Solid Works» program with the «Flow Simulation» application is allowed to be performed the imitation simulation, in the field of the hydrodynamics.

So, the given program has been used at the fundamentally new multifunctional device development with the helicoid type rotor.

So, this work's aim has been the multifunctional mixing device development with the helicoid type rotor, with the help of the «Solid Works» imitation simulation program with the «Flow Simulation» application, by means of its functional efficiency determination in the using process.

Thus, two sets of the liquid flow hydrodynamics researches in the cavity flow of the mixing device with the imitation simulation use have been performed. The rotational speed of the mixing body has been set consistently, in accordance with its following digital series: 100, 200, 300, 400, 500 rev./min. (e.g. clockwise).

The device computer model of the classical cylindrical design with the four vertical reflective strips has been applied in the framework of the researches first set. So, the helicoid type rotor has been used, as the mixing body (Fig. 1).

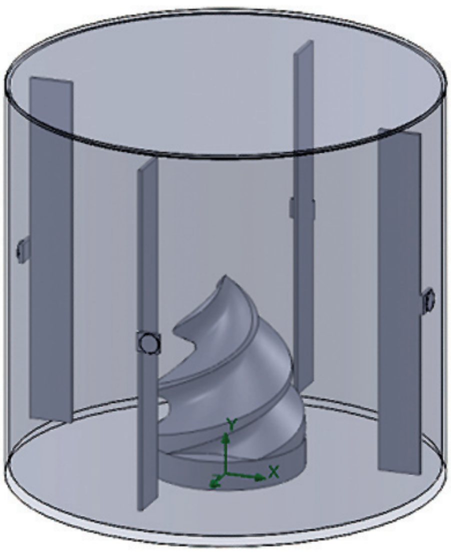


Fig. 1. The Cylindrical device with the helicoid type rotor and with the vertical reflective strips: the 1–1 section; the 2–2 section; the 3–3 section; the 4–4 section; the 5–5 section; the 6–6 section

It had been revealed in the obtained data analysis, that the standard design of the device body with the vertical reflecting strips, as it was expected, is allowed to be excluded the central funnel formation effect, but, for all this, such device design is made the «dead» zones unit and also the large hydraulic losses in the fluid motion, which is negatively affected upon the mixing quality, thus, the power consumption is being increased. In our view, this shortcoming of the reflective strips can be significantly reduced, at the expense of their further modernization – by the creation of the upper movable part of the partition, which will be deflected in the fluid flow direction. This will be given the possibility to be streamlined the fluid flows movement, and the device mixing degree will be increased [3].

So, the device cavity has been divided, by its height, into the six vertical sections, for the axial and the circumferential velocities determination (Fig. 2).

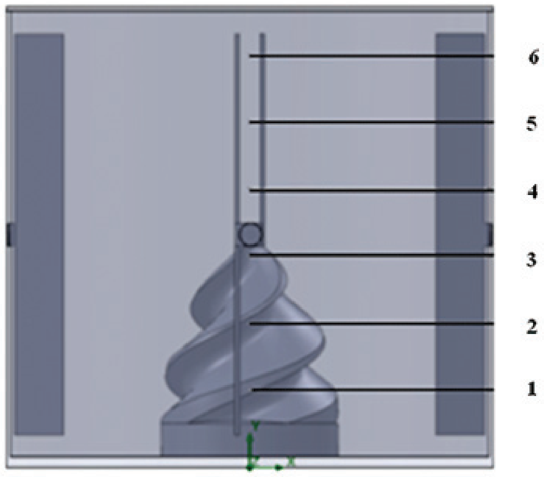
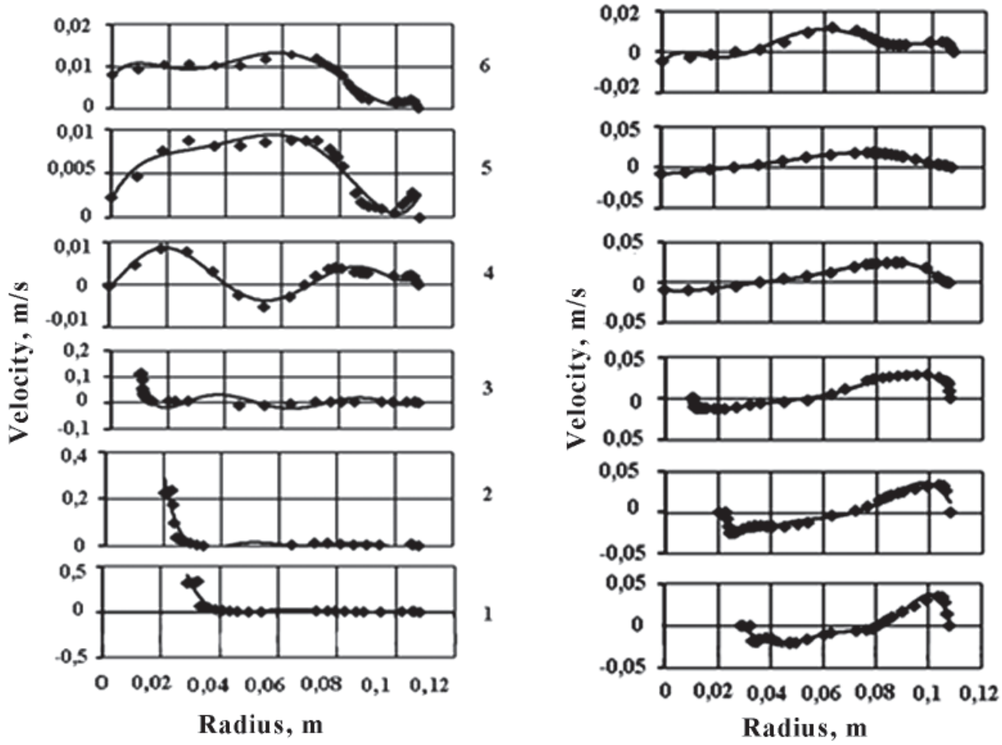


Fig. 2. The sections arrangement by the height unit: the 1–1 section; the 2–2 section; the 3–3 section; the 4–4 section; the 5–5 section; the 6–6 section

Thus, the graphical components construction of the fluid motion dependences velocities has been carried out for each section. Here, below, as the example, the diagram of the circumferential and the axial velocities of the fluid motion at the rotation frequency of the mixing body, which is equal to 100 rev./min, has been given (Fig. 3).

So, the obtained curves on the diagrams are analytically described by the polynominal equations systems of the third order. So, for example, for the axial component velocity at the mixing organ rotation n = 300 rev./min, the equations system is taken the following form:

$$\begin{cases} y = 32{,}13x^3 - 4{,}362\,x^2 + 0{,}180x + 0{,}002 \\ y = -246{,}9\,x^3 + 35{,}37\,x^2 - 0{,}913\,x + 0{,}005 \\ y = -386{,}9\,x^3 + 53{,}30x^2 - 1{,}115\,x - 0{,}007 \\ y = -759{,}2\,x^3 + 129{,}6x^2 - 5{,}280\,x + 0{,}032 \\ y = -1219x^3 + 247{,}9\,x^2 - 13{,}6x + 0{,}166 \\ y = -1335x^3 + 307{,}8x^2 - 20{,}43\,x + 0{,}361 \end{cases} \quad (1)$$



a b

Fig. 3. The fluid velocity schedule at the rotation frequency of the mixing body n = 100 rev./min:
a – the circular velocity component; b – the axial velocity component;
the 1–1 section; the 2–2 section; the 3–3 section; the 4–4 section; the 5–5 section; the 6–6 section

So, it has been revealed in the diagrams analyses, that the peripheral velocity is gradually increased with the rotor's increasing rotational frequency up to 500 rev./min in all the sections of the device. This is due to the fact, that with the rotational frequency increase, the energy transfer to the liquid flow from the rotor is also being increased.

So, the axial velocities values are being increased by the device height, with the rotor rotational frequency increase from 100 rev./min up to 500 rev./min. For all this, with the rotor rotational frequency increase in 5 times, the axial velocity increase is taken its place, approximately in 2–4 times, depending on the device considered section. This is explained by the fact, that the vertical strips presence at the device walls is contributed to the tangential forces transformation of the moving fluid flow into the axial forces.

Thus, the liquid flow resulting velocity, at the different rotational frequencies of the rotor, has been presented in the Table 1.

Table 1

The Liquid Flow Velocity, at the Rotor's Different Rotational Frequencies

Velocity, m/s	100 r./min	200 r./min	300 r./min	400 r./min	500 r./min
Min. velocity	0	0	0	0	0
Average velocity	0,0159	0,0287	0,0372	0,0448	0,0532
Max. velocity	0,485	0,944	1,335	1,6822	2,102

According to the obtained diagrams of the axial velocities, one can be seen, that the vector velocity shift is occurred in the device working cavity, while the fluid motion. So, this shift is caused by the fact, that the fluid flow, having encountered the resistance along its further motion trajectory, is tended to be left to the area with the least resistance.

The vertices of the curves on the diagrams are indicated the maximum flow rate, i.e. the flow, along its further motion trajectory, is occurred with the least resistance. So, the resistance decrease during the fluid motion is allowed to be maximized the mixing degree, the circulation intensity, and the device performance, which, in its turn, will be led to the decrease in the specific energy consumption, when the device operating.

One can be seen in the diagrams reviewing with the axial velocities, that the vertices of the curves (e.g. the maximum values) are located in the definite sequence. If the isoline to be drawn through the vertices, then it is quite possible to be obtained the definite curve, along which the fluid flow has the maximum axial velocity during the motion into the device working cavity from the bottom to its top (Fig. 4).

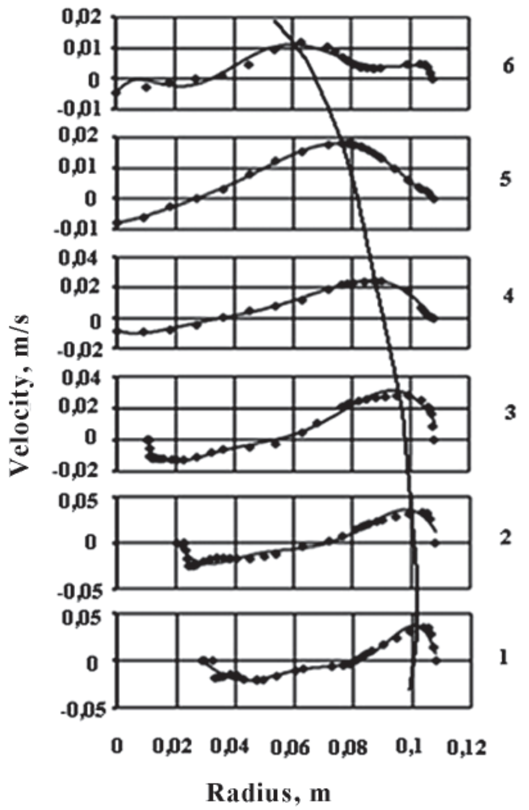


Fig. 4. The Scheme of the isolines construction on the obtained curves tops:
the 1–1 section; the 2–2 section;
the 3–3 section; the 4–4 section;
the 5–5 section; the 6–6 section

On the basis of the given assumption, the lateral surface construction of the device has been made, in the first approximation, which is equal to the radius of the arc:

$$R_{arc} = D_{dev}, \qquad (2)$$

where R_{arc} – is the radius of the arc of the device lateral surface, mm; D_{dev} – is the diameter of the device, mm.

Having used the obtained dependence, the challenge on the lateral surface profiling of the device body is really become the solvable one.

Thus, having performed the lateral surface profiling of the device, the transition geometrical construction is being made from the lateral surface of the device to its lower and the upper parts. So, the given three elements must be conjugated by the surface, having provided the unseparated and the steady circulation of the fluid flow, as it is moved from the mixing organ, through its guide rails, before the mixing body entering.

The best optimum alternative of these given conjugations implementation, by the earlier carried out researches results, is the parabola fragment at the bottom part of the $x^2 = 2Py$ [4] form, but in the upper part – the hyperbola fragment kind of the $\frac{x^2}{a^2} - \frac{y^2}{b^2} = 1$ form. As a result of such the construction, we get the device with the shaped and the profiled body, having shown in the Fig. 5.

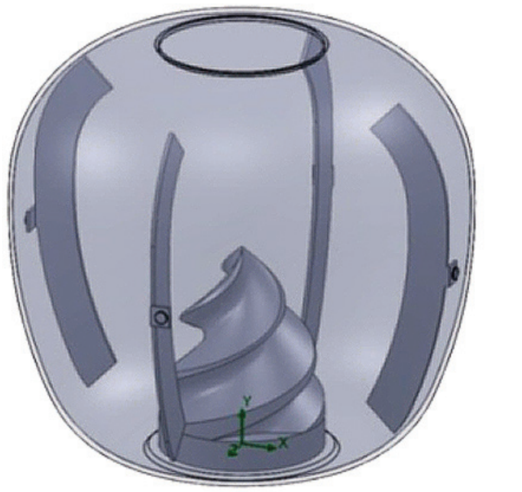


Fig. 5. The shaped body device with the helicoid type rotor

Then, the second research has been carried out on the computer model of the device, having had the shaped and the profiled cross – section. Thus, for the given body, the trajectories for the fluid flow motion and the graphical dependencies have already been received.

By the fluid motion trajectories, it is quite possible to be made the following conclusions: the axial velocities are mostly dominated in the working cavity of the shaped and the profiled body, even at the low frequencies of the rotor rotation, and also there is no presence of the «dead» zones.

The diagram of the circumferential and the axial velocities of the fluid motion, at the rotational frequency of the mixing body 100 rev./min has been given below (Fig. 6).

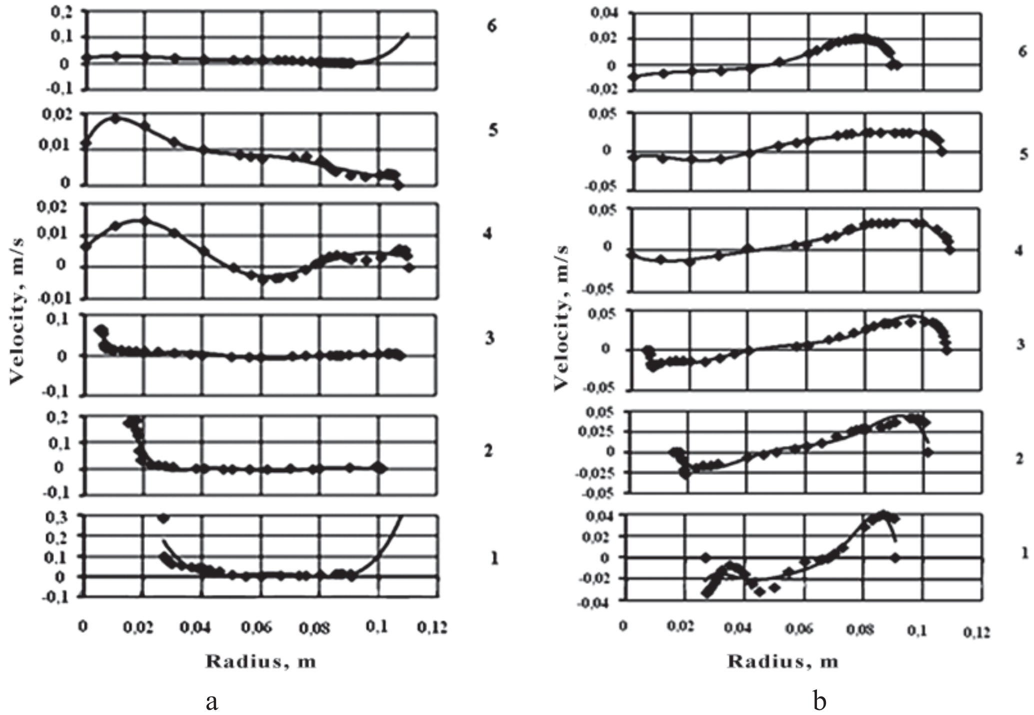


Fig. 6. The fluid velocity schedule at the rotation frequency of the mixing body n = 100 rev./min:
a – the circular velocity component; b – the axial velocity component;
the 1–1 section; the 2–2 section; the 3–3 section; the 4–4 section; the 5–5 section; the 6–6 section

So, the obtained curves on the diagrams are analytically described by the polynominal equations of the third order. And, for example, for the axial velocity component at the mixing body rotation n = 300 rev./min, the equations system is taken the following form:

$$\begin{cases} y = -221{,}5x^3 + 30{,}87x^2 - 0{,}763x - 0{,}006 \\ y = -318{,}8x^3 + 52{,}34x^2 - 1{,}708x - 0{,}004 \\ y = -538{,}7x^3 + 88{,}47x^2 - 2{,}832x - 0{,}008 \\ y = -750{,}6x^3 + 123{,}4x^2 - 4{,}187x - 0{,}004 \\ y = -1158x^3 + 204{,}5x^2 - 8{,}937x + 0{,}064 \\ y = -2265x^3 + 436{,}3x^2 - 24{,}23x + 0{,}352 \end{cases} \quad (3)$$

So, it has been revealed at the diagrams analysis, that the axial velocity is gradually increased with the rotor rotational frequency increase. So, in comparison with the cylindrical construction device, having the installed vertical strips, the shaped and the profiled cross – section body, in average, is given the increase in the axial velocity component up to 55 %. So, with the axial velocity component further increase and the fluid circulation is directly proportional increased in the device. That is why, the liquid circulation time is one of the main characteristics, that are served to be estimated the devices different types with the mixers performance, as it is made the significant impact upon the whole mixing process [5].

Table 2

The Liquid Flow Velocity, at the Rotor's Different Rotational Frequencies

Velocity, m/s	100 r./min	200 r./min	300 r./min	400 r./min	500 r./min
Min. velocity	0	0	0	0	0
Average velocity	0,019	0,029	0,038	0,046	0,054
Max. velocity	0,451	0,841	1,262	1,683	2,104

In general, the absolute velocity has already been grown in the shaped and the profiled body, in comparison with the traditional body of the cylindrical form. For all this, the highest increase is observed in the velocity, at the rotational frequency n = 100 rev./min, and it is made up about 20 %.

It is resulted from the obtained results, that the shaped and the profiled body is allowed to be enhanced the suspensions mixing quality, even at the low rotations numbers of the mixer. For all this, the «dead zones» will not be practically present in the working cavity of the device, that positively be impacted upon the efficiency improving of the device performance, as a whole.

So, the Equations (1) and (3), at the further work, can be used to be found the values of the liquid flow rates at any point of the device working cavity. This will be given the possibility, as quantitatively, well as qualitatively to be estimated the devices performance efficiency with the mixers and the stirrers.

Conclusions

Thus, the developed device for the microorganisms' mycelial forms cultivation is practically permitted:

– to be excluded the «dead zones» appearance possibility, as the stationary, well as the dynamical type;

– to be achieved the hydraulic losses reduction, in the fluid flow motion;

– to be ensured the concentration uniform distribution throughout the device entire volume, at the expense of the further maximizing increase of the suspension circulation degree in the flowing cavity of the capacitive device;

– to be obtained the high – quality final production, at the minimum energy consumption.

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