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RESEARCH OF THE HOMOGENIZATION PROCESS IN THE OPERATION OF A THREE-LEVEL CLOSED TURBINE MIXER

Об'єктом дослідження є триярусна турбінна мішалка закритого типу, розроблена та виготовлена у натуральному розмірі за допомогою 3D принтера.

Одним з найбільш проблемних місць процесу ферментації у біореакторі є гомогенізація середовища. Під час процесу перемішування у більшості ферментерів утворюються застійні зони, у цих зонах середовище є неоднорідним, гірше прогрівається, отримує недостатню кількість повітря (якщо середовище аеробне) та спричиняє відмирання мікроорганізмів, що культивуються. Таким чином, кінцевий продукт не на 100 % однакової структури, а відповідно, і якості, що для фармацевтичної продукції є критичним.

В ході дослідження використовувалися 2 різні методи, що були покликані підтвердити або спростувати один одного, а саме: метод комп'ютерного моделювання та метод експерименту. Експеримент полягав у виготовленні розробленої моделі мішалки та проведенні процесу перемішування з її використанням. Перемішування проводилось на різних швидкостях, з різними типами мішалок та з використанням контрастного трассера для візуалізації виду потоків, що утворились. Графічне моделювання полягало у створенні аналогічної до експериментальної моделі мішалки та проведенні графічного моделювання у блоці CFX програми ANSYS. Цей метод дав змогу під різними кутами побачити створені потоки, знайти найбільш динамічні зони та зсередини дослідити фізику процесу.

Отримано результат, який показує, що триярусна закрита турбінна мішалка показує кращі результати по швидкості гомогенізації, ніж типова закрита турбіна. Це пов'язано з тим, що запропоноване рішення має ряд особливостей, зокрема порожнисту структуру вала.

Запропоновані розрахункові моделі в ANSYS дозволили отримати поля швидкостей та встановити величину і напрямок векторів швидкості.

Подібна методика оцінки ефективності гомогенізації може бути використана при проектуванні нових конструкцій механічних перемішуючих пристроїв.

Ключові слова: *культивування мікроорганізмів в біореакторі, гомогенізуючі пристрої, закрита турбінна мішалка, гідродинаміка потоків.*

1. Introduction

The main physical processes that occur during the cultivation of microorganisms in a bioreactor include hydrodynamics, heat transfer and mass transfer [1]. To establish the optimal cultivation parameters, it is necessary to take into account the features of these processes with certain limitations. The main limiting parameters of cultivation include: pH level, temperature gradient, concentration of nutrients and metabolites, shear stress in the fluid and aseptic conditions. To ensure optimal cultivation conditions, modern bioreactors are equipped with homogenizing devices for introducing energy into the liquid, which are conditionally divided into hydraulic, pneumatic and mechanical. The correct selection of a mechanical mixing device is the key to efficiently making a bioreactor. The rate of homogenization of a liquid culture medium depends directly on both the physical properties of the liquid itself and the distribution of velocity vectors over the working volume created by the mixer [2–4]. Now there are a large number of different designs of mechanical mixing devices, but each of them has both advantages and disadvantages. Therefore, the creation of new designs that will allow you to efficiently and quickly carry out the homogenization process is an urgent task. This study is devoted to the study of hydrodynamics during operation of a specially designed closed turbine mixer. Thus, *the object of research* is the hydrodynamics of flows during the operation of a three-level turbine mixer. And *the aim of research* is simulation of the mixing process in ANSYS and its comparison with a real experiment. Studying the features of hydrodynamics during the operation of the mixer of the proposed design will allow to establish optimal parameters and evaluate the possibility of using such mixing devices in mass transfer apparatus [5].

2. Methods of research

2.1. Simulation of the hydrodynamics of a three-level closed turbine mixer of the proposed design in the ANSYS environment. Based on experience with mechanical mixing devices [6, 7] and based on engineering considerations,

the design of a three-level closed turbine mixer, which is built in SolidWorks environment, is proposed (Fig. 1).
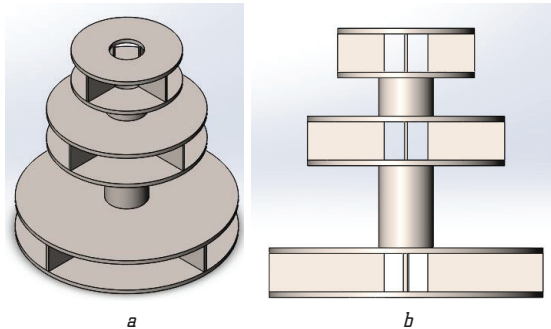

Fig. 1. The design of a three-level closed turbine mixer:
a – general view; *b* – front view

Using the hydrodynamic modeling technique, based on the use of the finite element method using the k–ε turbulence model, modeling is performed in the ANSYS package in the CFX module [4]. Mixer rotation frequency is 3 rev/s.

2.2. The experimental procedure for establishing the efficiency of homogenization with stirring with a three-level closed turbine mixer. To test the efficiency of homogenization and visualization of flows arising during the operation of the proposed design of a three-level turbine, it is printed on a 3D printer. All overall dimensions correspond to those that are used in the simulation. To establish the homogenization rate, the method of equalizing the concentrations over the entire volume is used [8]. To do this, 1 ml of acetic acid is added to the model fluid to be mixed, and the pH level is constantly monitored. As is known [9], pH=7 is close to neutral in water; upon addition of acid, the pH level of the solution shifts to lower values (acidic medium). It is clear that after adding a few drops of acid to the volume of water, the pH equalization does not occur immediately, since it is necessary for diffuse processes to occur. The time taken to establish a new pH will depend on the design and mode of operation of the mixing device. By comparing the homogenization time of various types of mixers, it can be argued about their efficiency.

To visualize the flows, a method with the addition of a color tracer is used, gradually stains the liquid in accordance with the flow lines.

3. Research results and their discussion

3.1. Hydrodynamic simulation during the operation of the mixer. An analysis of the results allows one to observe the distribution of velocity fields in the axial, tangential, and radial directions. The maximum velocity of fluid flows is observed directly near the blades of a closed turbine and is 0.477 m/s (Fig. 2). The velocity modulus in the direction of the vector is the largest in the radial direction, and significantly less in the axial and tangential directions (Fig. 3). However, it should be noted that as a result of high radial velocities, a pressure drop is formed inside the turbine, which leads to the appearance of an ejection effect. As a result, the mixer absorbs fluid flows in the axial direction, and redistribution of the velocity vectors over the entire working volume occurs (Fig. 4).
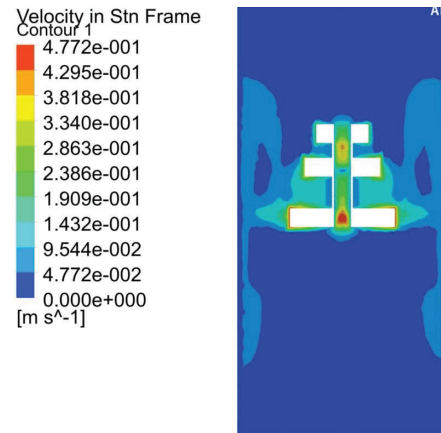

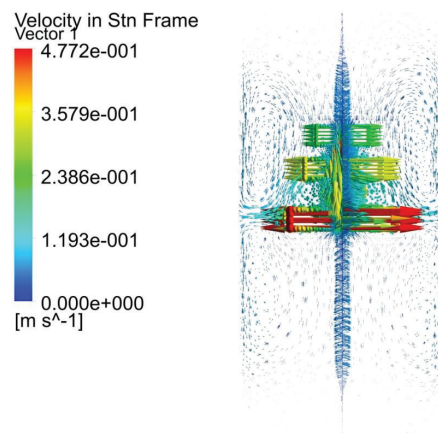**Fig. 2.** Velocity fields of a three-level closed turbine mixer obtained in ANSYS

Fig. 3. The module of the velocity vector of a three-level closed turbine mixer, obtained in the environment ANSYS
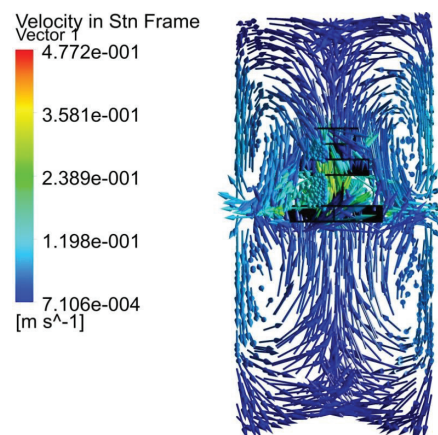

Fig. 4. Velocity vectors of a three-level closed turbine mixer obtained in ANSYS

It is found that the described phenomenon is significantly enhanced by the installation of several levels, which positively characterizes this design. The main property can be considered as the creation of lifting force, which can be useful when mixing dispersed systems, such as suspensions.

A feature is discovered specifically for the design of the three-level mixer that allows to state that the active working zone has a conditionally conical shape and occupies

a significantly larger volume compared to typical single-level structures (Fig. 4).

Separately, it should be noted that the resulting picture of shear stresses in the liquid, which must be taken into account during cultivation. Since the high turbulent flow zones can damage living microorganisms. However, the magnitude of these stresses is the largest in the boundary layer of the mixer near the turbine blades and lies within acceptable limits.

3.2. Experimental studies during the operation of the mixer. As a result of studies to establish the effectiveness of mixing according to the method described in paragraph 2.2, it is found that the proposed design shows the best results from the usual typical design of a closed turbine. The experimental setup is shown in (Fig. 5). The rate of concentration equalization by volume for a three-level closed turbine mixer is 8 seconds, while a typical design shows a time of 11 seconds.
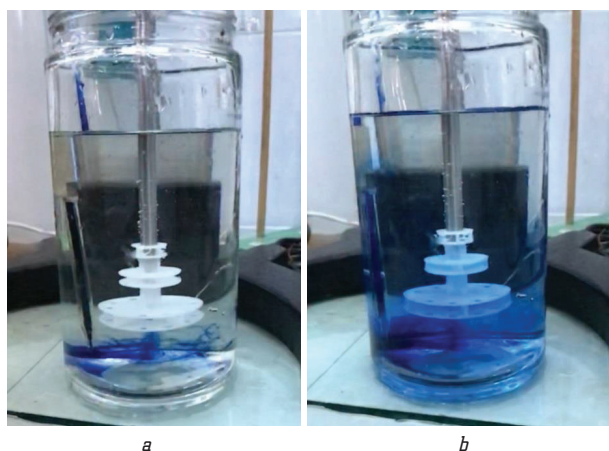

a   *b*

Fig. 5. Visualization of fluid flows using a color tracer:
a – the beginning of mixing; *b* – active mixing phase

To establish the reliability and adequacy of the proposed calculation models in the ANSYS environment, the flow is visualized, which is formed during the operation of the mixer. As a result, it is found that the radial component of the velocity and the ejection effect are clearly expressed, which is fully comparable with the results obtained in the simulation [10].

4. Conclusions

It has been found that a three-level closed turbine mixer shows better homogenization results than a typical closed turbine.

The proposed computational models in ANSYS make it possible to obtain velocity fields and establish the magnitude and direction of velocity vectors.

A similar technique for evaluating the effectiveness of homogenization can be used in the design of new designs of mechanical mixing devices.

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