FEATURES OF HYDRODYNAMICS WHEN USING AN OPEN TURBINE MIXER WITH A SPECIAL BLADE SURFACE

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Abstract
This article investigates a turbine mixer in a bioreactor with surface-modified dimples to enhance mixing efficiency. Computational simulations using ANSYS software examined the impact of these dimples on fluid dynamics. Results confirm improved efficiency, supported by experimental validation. A novel approach to optimize the turbine mixer design for increased mixing performance.
Keywords: *turbine mixer, dimples, hydrodynamics, mixing.*

Introduction. Mixing processes play a key role in various industrial processes, especially in the field of biotechnology, where precise control of hydrodynamics is crucial for optimal efficiency.

In recent years, advanced technologies involving bioreactors with mixing devices have been directed towards increasing efficiency and productivity through design element upgrades. One promising direction is the modification of the geometry of mixer blades to positively influence hydrodynamics.

Ammar Alkhalidi in his article explores the possibilities of enhancing the standard efficiency of oxygen transfer in aeration tanks using a turbine blade that generates energy for dispersing and saturating the liquid with oxygen. The integration of specially designed turbine blades increases efficiency by 25%, while an electric generator recuperates excess energy at high flows. The system demonstrated that it is possible to recover 11% of the used energy, making the process more efficient without additional energy costs [1].

Anka-Irina Galaction analyzes the impact of the size of biocatalysts and the type of mixers on the mixing efficiency in a bioreactor with immobilized *S. cerevisiae* cells in alginate. The study showed that increasing the size of biocatalysts improves mixing, thanks to more intense circulation in the upper part of the reactor with a pump mixer and a turbine with curved blades. It is noted that the pump mixer and Rushton turbine are the most effective for this type of bioreactor [2].

IgorKorobiichuk uses a new approach in computer modeling of bioreactor hydrodynamics using ANSYS software, comparing different designs of turbine mixers. In particular, the introduction of a new two-disk turbine mixer with blades oriented at different angles significantly reduces the risk of vortex formation during mixing. According to modeling results and experimental studies, the new design showed a low probability of vortex formation at different rotation speeds [3].

The studies considered used various mixer geometries, each with a new blade geometry. We propose a change in the geometry of the blade surface of the mixing device by adding dimples. This study is aimed at exploring a turbine mixer in a bioreactor, focusing on modifying the blade surface with dimples to enhance mixing efficiency.

The goal of the study is to intensify hydrodynamic processes during homogenization and dispersion of the liquid. This idea requires further research through computer modeling and actual experimentation, which is expected to intensify the mixing processes.

It is anticipated that using dimples applied to the blade surface with a few millimeters in diameter can influence the change in mixing efficiency and the power consumption of the mixer. In this study, computational simulations using ANSYS software are applied for a comprehensive analysis of the impact of dimples on the fluid motion in the bioreactor volume. This research was conducted using real mixers printed on a 3D printer.

Materials and Methods. The methodology of this study is based on a comparative analysis of computer modeling and laboratory experimentation.

Computer modeling was conducted using ANSYS CAD software, which ensured a high level of consistency between the experimental conditions and laboratory studies. The CFX module was chosen for solving hydrodynamic problems. A cylindrical volume measuring 246 mm in height and 242 mm in diameter, filled to 75% of its total volume with water, was created and used as a model fluid to represent the nutrient medium.

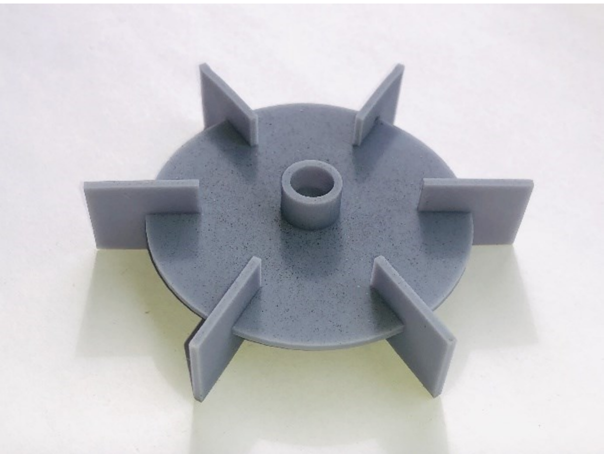

Fig. 1. Standard turbine mixer.

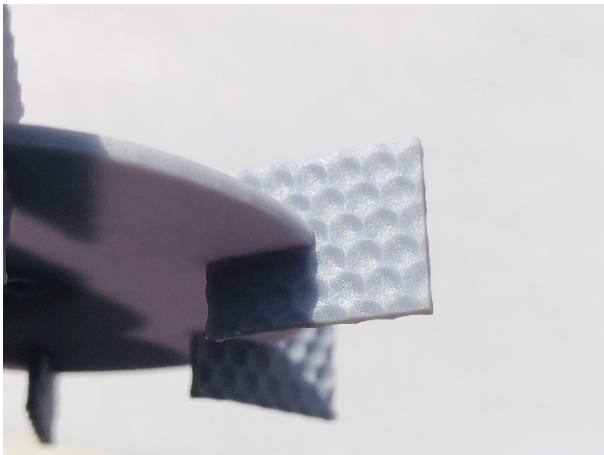

Fig. 2. Turbine mixer with dimples.

In the study, two types of mixers were used: a standard open-type turbine mixer (Fig. 1) and an open-type turbine mixer with dimples (Fig. 2). Both mixers had a diameter of 80 mm and were submerged 50 mm from the bottom. The rotation speed of the mixers was set at 300 rpm, and the duration of the simulation was 30 seconds. All parameters were adjusted to simulate real conditions of laboratory experiments.

The experiment was conducted in the laboratory of the Department of Biotechnology and Engineering at Igor Sikorsky Kyiv Polytechnic Institute. Polymer models printed on a 3D printer were mounted on a shaft in a laboratory stand designed to study mixing processes, allowing the investigation of the hydrodynamic properties of the system across a wide range of rotation speeds from 35 to 800 rpm. The efficiency of mixing was evaluated using photometric analysis of the vortex formed in the liquid. The input data for the experiment corresponded to those used in the modeling.

Results and Discussion. The study revealed that using a turbine mixer with dimples on the blades (Fig. 5) affects the reduction of the flow shear speed and results in the formation of a less deep vortex compared to the standard turbine mixer (Fig. 4) under the same initial conditions.

The most significant difference was observed at rotation speeds ranging from 200 to 300 rpm, which is the optimal speed range for many biotechnological processes. Such results can have a significant impact on the efficiency of biotechnological production, as they allow for a more uniform distribution of components in the liquid phase, which is critically important for the quality of the final product.

The simulation yielded arrays of data regarding velocity fields, temperatures, pressures, shear stresses, and volume fraction contours, with one such contour (velocity) shown in (Fig. 3). Analysis of the obtained data confirms that the computer models adequately describe the conditions of the real experiment and validate the hydrodynamic features of fluid motion.

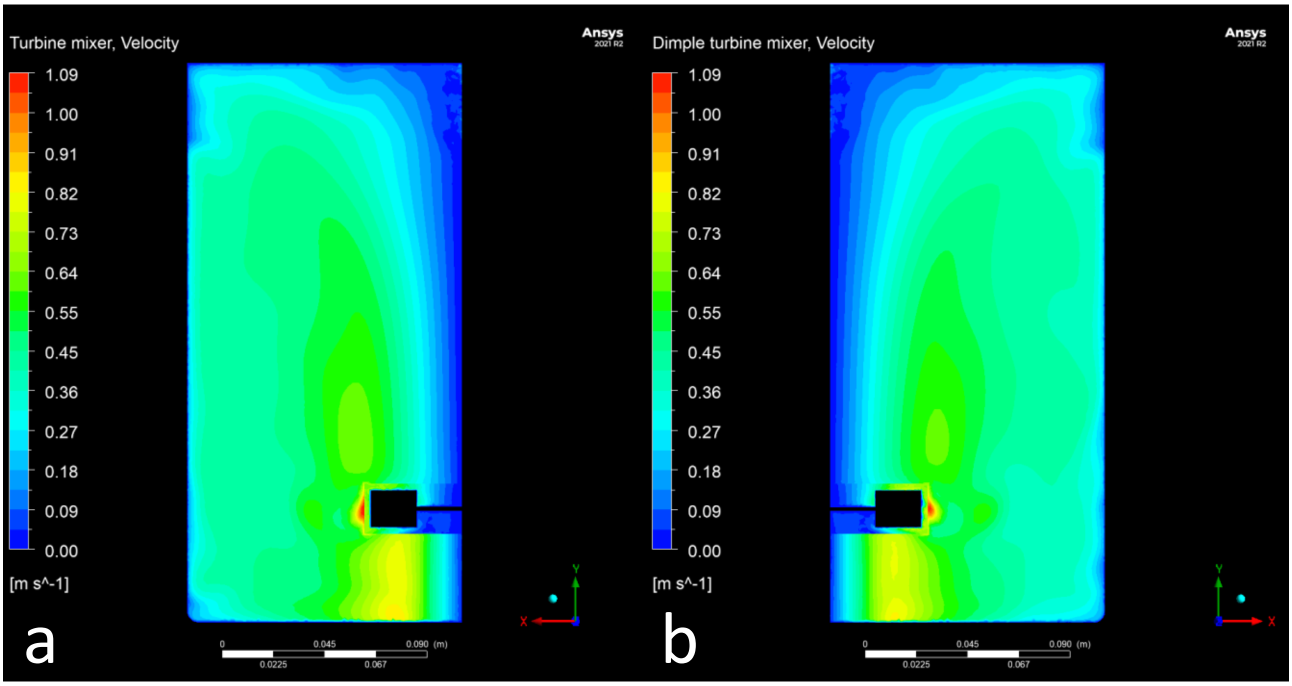

Fig. 3. Velocity contours at 300 rpm obtained from CFX ANSYS: a - turbine mixer, b - turbine mixer with dimples.

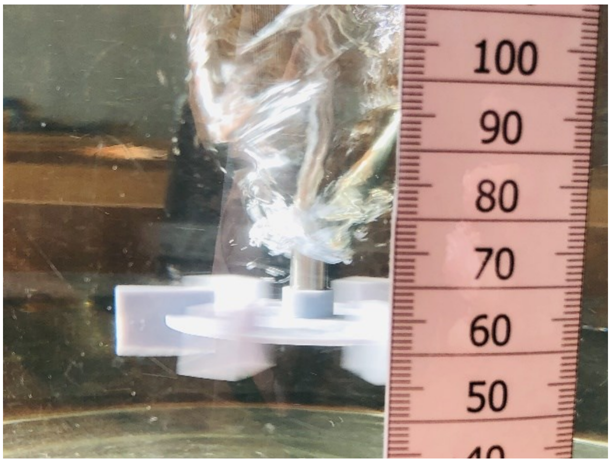

Fig. 4. Standard turbine mixer, vortex at 300 rpm.

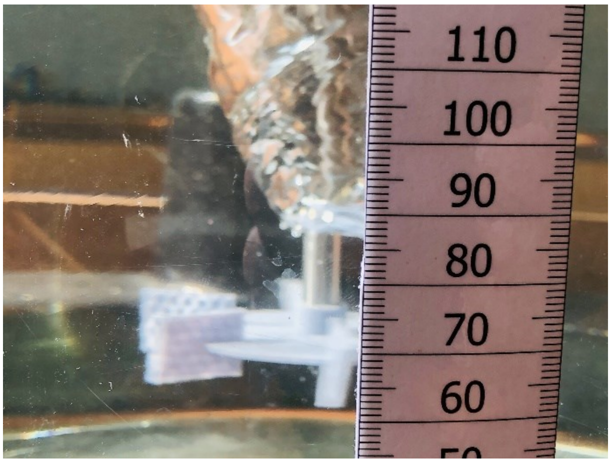

Fig. 5. Turbine mixer with dimples, vortex at 300 rpm.

Conclusions. This study explored the hydrodynamic features using a homogenizer with a specially designed blade surface featuring dimples. The use of a turbine mixer with dimples on the blade surfaces allowed for the investigation of the hydrodynamic conditions within the device, confirmed by computational simulations and experimental studies.

The results indicate an improvement in mixing efficiency, particularly at rotation speeds of 200-300 rpm. Additionally, it was found that using a mixer with dimples results in the formation of a shallower vortex. Such an improvement can contribute to a more uniform distribution of components in the liquid phase, which is critical for the quality of the final product.

Given the results described, there is a need for further research on homogenizers with different geometries and blade surfaces, which will be the focus of future studies.

Overall, this research proposes a new approach to enhancing the design of turbine mixers, potentially opening up new opportunities for improving biotechnological cultivation processes.

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