STUDY OF ULTRASONIC DESTRUCTION OF MICROALGAE USING A CASCADE EMISSION PLANT

Kolisnichenko O.O., Shybetskyi V.Y.
Igor Sikorsky Kyiv Polytechnic Institute, kolisnichenko.kpi@gmail.com

Abstract
This article investigates the ultrasonic disintegration of microalgae using a cascade emission system. Simulations confirmed effective acoustic pressure and deformation levels for cavitation. Experiments with Chlorella showed that ultrasound power, treatment time, and suspension concentration significantly affect cell destruction. The most intense breakdown occurred within the first minutes at high power and concentration, supporting ultrasound's application in biofuel production.

Keywords: *biofuel, microalgae, ultrasound, Chlorella, cavitation*

Introduction. The use of microalgae for biofuel production has attracted growing interest due to their rapid biomass accumulation and high lipid content [1-3]. Among various cell disruption methods, ultrasonic treatment stands out for its efficiency and ability to be scaled industrially. Cavitation and mechanical stresses generated by ultrasound enhance the release of intracellular compounds, including lipids, making microalgae an attractive feedstock for renewable energy technologies [3-6].

The aim of this study was to evaluate the effectiveness of a cascade ultrasonic emission system for microalgae treatment. Computer modeling using the Finite Element Method (FEM) was carried out to determine the acoustic pressure distribution inside the apparatus and to analyze the potential for cavitation formation. Experimental investigations were conducted to verify the modeling results and assess the impact of ultrasonic treatment parameters on Chlorella cell disintegration [1,7,8].

Materials and Methods. The study combined computer simulation and laboratory experiments.

For the simulation part, a 3D model of the cascade ultrasonic emitter and surrounding fluid domain was developed in SolidWorks. The modeling was performed in ANSYS software [9], focusing on two domains: a mechanical domain (emitter) and an acoustic domain (liquid medium). The emitter was modeled using structural steel properties, while the fluid was approximated as water.

Boundary conditions included a fixed support at the emitter top, a fluid-solid interface at the boundary with the liquid, rigid walls for the device casing, and radiation boundaries at the open pipe ends [9]. A harmonic pressure of 40 kPa was applied to the emitter surface at an operating frequency of 25.7 kHz [10]. As shown in Fig. 1 a fine computational mesh (~600,000 elements) was used to ensure accurate resolution of ultrasonic wave propagation [9]. Modeling outputs included the displacement of the emitter surface and the pressure distribution within the liquid, enabling the analysis of areas where cavitation could potentially occur.

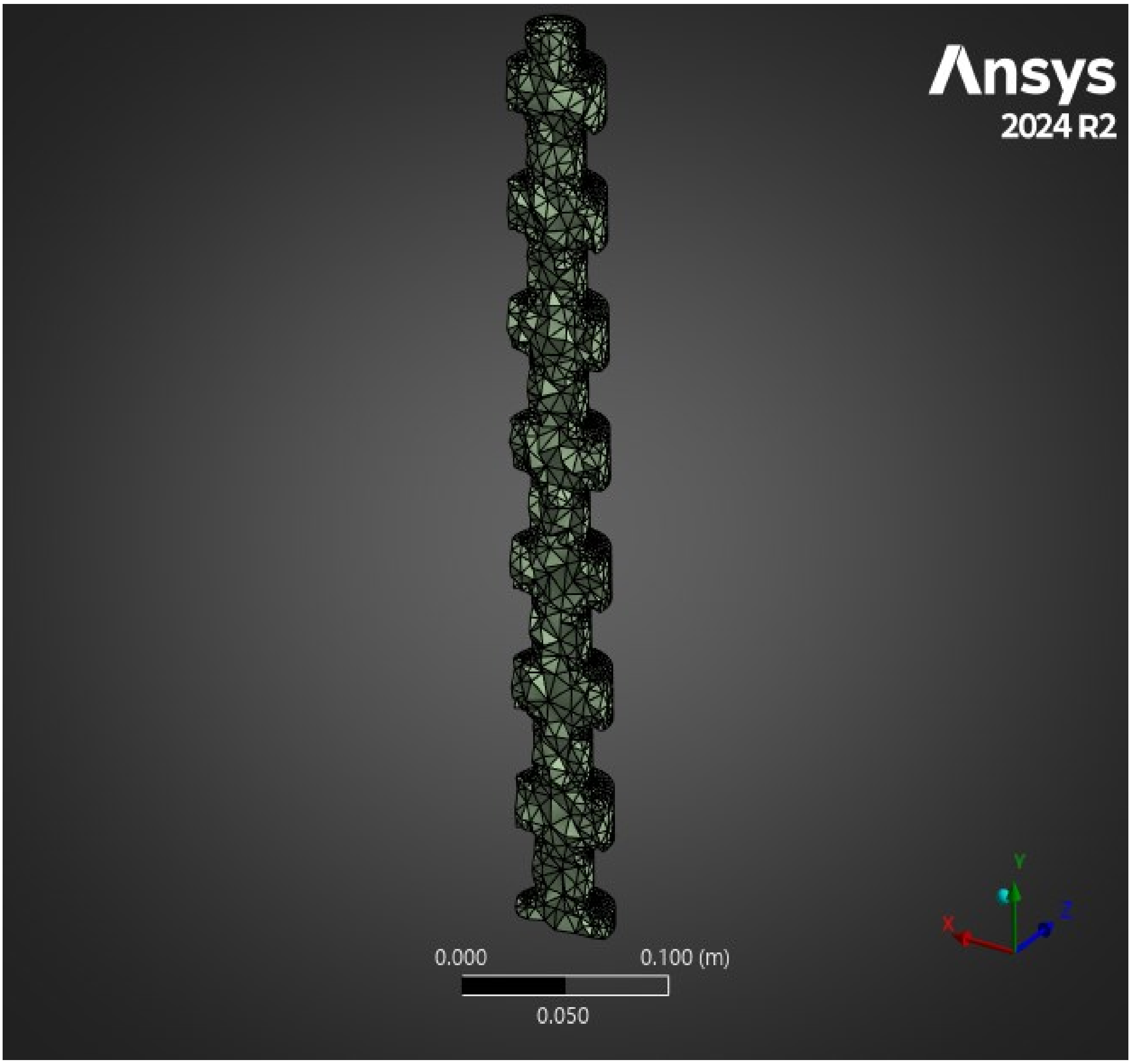

Fig. 1. Grid for calculations in Modal.

In the experimental phase, a laboratory setup equipped with a cascade-type ultrasonic emitter was used [11]. Suspensions of Chlorella were prepared at two concentrations (1:1 and 1:3) and subjected to ultrasonic treatment at different power levels and exposure durations (3, 5, 10, and 20 minutes). After each treatment, samples were stained with methylene blue to differentiate live and dead cells and were analyzed microscopically to determine cell viability and the degree of disintegration.

Results and Discussion. The computer simulations revealed that the maximum deformation of the emitter surface occurred along the Y-axis, reaching approximately 2.86×10^{-9} meters [9]. The deformations along the X and Z axes were symmetrical and significantly smaller, indicating stable oscillation of the emitter without torsional distortions.

The pressure distribution analysis showed regions of maximum pressure under the lower end of the emitter and near the structural protrusions, with peak values exceeding 3400 Pa [9], [10]. These pressure patterns suggested areas where cavitation phenomena could potentially occur, providing favorable conditions for effective cell disruption. We can see this in Figure 2.

The experimental studies conducted by the authors confirmed the tendencies observed in the modeling. The most significant reduction in the number of live Chlorella cells was recorded within the first 3–5 minutes of exposure at maximum ultrasound power [11]. The greatest efficiency of cell disintegration was observed at a 1:1 suspension concentration, which corresponded to the regions of maximum acoustic intensity identified in the simulation results.

The agreement between the computer simulations and experimental outcomes highlights the effectiveness of numerical modeling for predicting and optimizing ultrasonic treatment processes in microalgae biotechnologies.

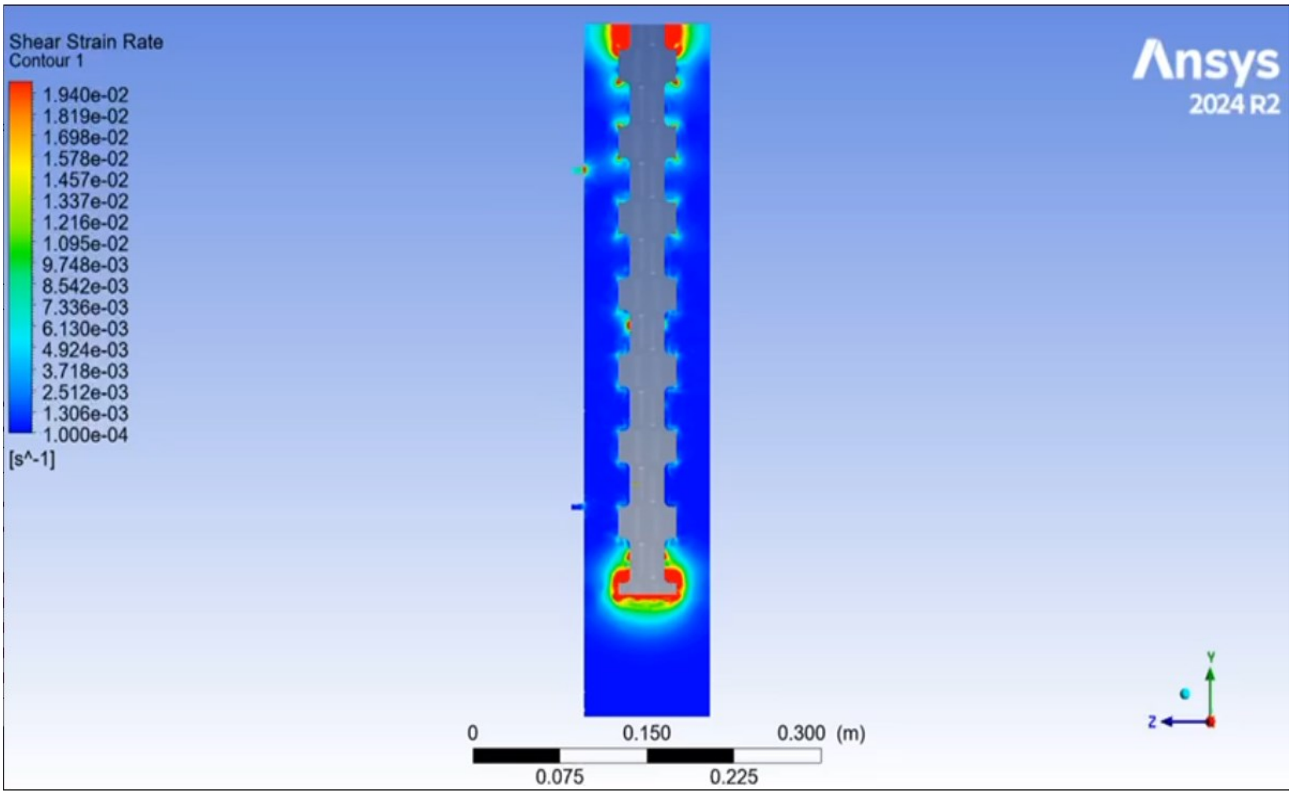

Fig. 2. Distribution of acoustic pressure in an acoustic environment.

Conclusions. The research confirmed the effectiveness of ultrasonic treatment for microalgae cell disruption. Computer simulation successfully determined the pressure distribution within the apparatus, identifying areas with high potential for cavitation. Experimental studies verified that the most efficient disintegration occurred at maximum ultrasound power and higher suspension concentration (1:1), with significant cell destruction observed after just a few minutes of treatment.

The results can be applied to the design and optimization of industrial ultrasonic systems for biofuel production and lipid extraction. Future work should focus on detailed experimental identification of cavitation zones, optimization of emitter geometries for enhanced efficiency, and integration of ultrasonic treatment with complementary cell disruption methods to further improve process performance.

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