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Piezo Pump Disruptor for Algae Cell Wall Ultrasonication

Abstract: It is well known that green algae cells are used for bio-fuel production. There are a few known ways of how to process algae cells for oil extraction – chemical and mechanical. Ultrasonic cavitation is one example of mechanical processing that is in use. Longitudinal ultrasonic systems are used for this purpose. In a proposed system the flow of an algae–liquid mixture is created by means of the ultrasonic capillary effect, thus the transducer is the only energy consumer which now acts as a homogenizer (disruptor) and a pump at the same time. What is important is that the capillary is located nearby the strong cavitation field which decreases the chance of unprocessed algae cells flowing into the secondary reservoir. Numerical and comparative tests are done and presented in this paper. The main results are presented in figures and tables, all advantages of the system are outlined in the conclusion section.

Keywords: ultrasonic, cavitation, algae, bio-fuel

DOI 10.1515/ehs-2014-0031

Introduction

The tests were conducted using the UIP 1000HD transducer. Standard tips were used to perform the tests. We would like to note that any ultrasonic transducer can be used, as long as the necessary amplitude for cavitation appearance can be provided. Under standard conditions, according to the manufacturer of the equipment, the algae ultrasonication process should be performed under a specific pressure within the range from 0.5 to 1 MPa, depending on the setup. Besides pressure, specific flow rates (up to 10 l/min), an amplitude of up to 170 μm, temperature up to 80°C and the viscosity of up to 100 Pa·s (http://www.hielscher.com/i1000_p.htm) should be maintained. The manufacturer declares that complete (100%) cell destruction occurs after 120 min (http://www.hielscher.com/algae-grow-lab.htm). Process characteristics are unknown; probably, they should be as mentioned above. The tests that were performed were made at an open pond, without pressure so a comparison between standard equipment and the proposed system cannot be done. However, fully comparable tests are planned to be performed in the future.

The ultrasonication method for algae cell processing is already widely applied in the industry, not only for oil extraction for bio-fuel (Demirbas 2010), but also for other applications (http://www.fao.org/docrep/012/i1704e/i1704e.pdf). Ultrasonication is a good method for extracting all other chemical materials from algae. The only few disadvantages are the possibility of a temperature rise after a long processing time and energy consumption. Thus in this paper we are trying to lower the energy costs of algae processing.

The value of research made in this field of study is very high because tremendous efforts are made to create a real opportunity to have an alternative fuel source. Bio-fuel production from crops, algae and other types of agricultural bioresources is already on the way. All of them require to be processed to get usable fuel (Furuki et al. 2003). But the fuel made at such facilities will arrive at gas stations as fast as the relative energy consumption for its production decreases. This research is dedicated to contribute to the achievement of such a goal. The transducer operating tip and capillary formation tools are presented in Figure 1.

Numerical Analysis

Despite the use of standard equipment a full scale research was done, including modeling. COMSOL multiphysics software was used to conduct the analysis. The

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Figure 1: Plastic tools that can form a circular capillary around a transducer's tip.

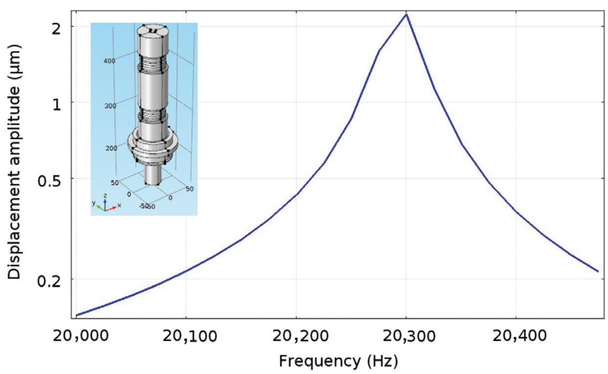

Figure 2: Frequency dependence of the transducer active side displacement amplitude along the *Z*-axis.

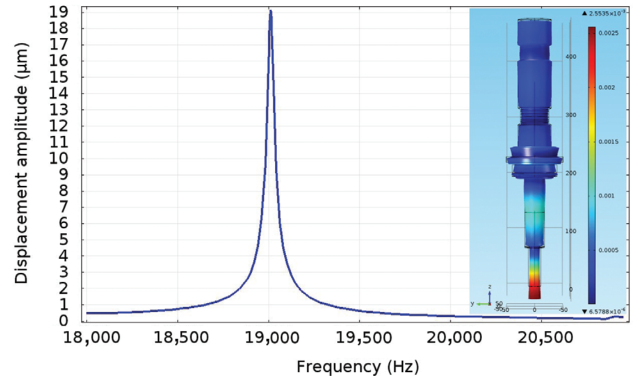

Figure 3: Calculated amplitude along *Z*-axis.

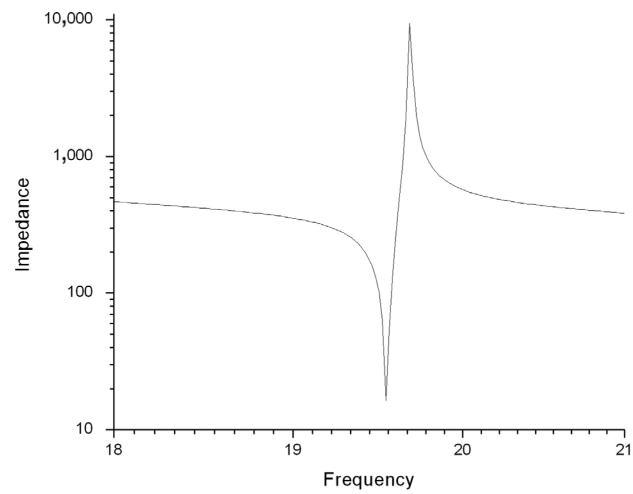

Figure 4: Impedance–frequency characteristic.

results of numerical analysis can slightly vary from real parameters due to the approximate selection of materials. The exact materials and their mechanical parameters are unknown, which is also the case with the piezoelements. However, modeling results seem to be accurate, according to experimental results. The modeling results of the core transducer, without any interchangeable tips, are presented in Figure 2.

The other analysis is done with a replaceable tip (working body); 20 V voltage was used for the excitation in both cases. The mechanical amplitude test was done using "Polytec vibrometer OFV-5000." Results are presented in Figure 3; 20 V modeling results presented in Figure 3 were obtained for the transducer mentioned with a ø22 tip. The amplitude is 2 µm because adding a tip increases the level of impedance and by applying the same voltage we cannot get the same power.

Measurements

Tests were performed to compare a virtual model and a real system. During all tests a 20 Hz scanning step was used. The impedance–frequency characteristic was made using "HP 4192A impedance analyzer." Results are presented in Figure 4.

The graph presented in Figure 4 is the impedance–frequency characteristic of the transducer with a replaceable tip. The obtained resonant frequency is 19.55 kHz. Generally, a transducer without any tips has a larger resonance–anti-resonance frequency width and a slightly higher frequency.

Mechanical amplitude tests were done using the "Polytec vibrometer OFV-5000," and results are presented in Figure 5.

Measurement results presented in Figure 5 were obtained for the transducer mentioned with a ø22 tip. Resonant frequency is 19.55 kHz and the maximum obtained amplitude was 14.3 nm at 5 V, the phase range at resonance was 178.8°. Generally, the measurement results are in good correlation with the modeling results. According to the manufacturer's manual, the maximum

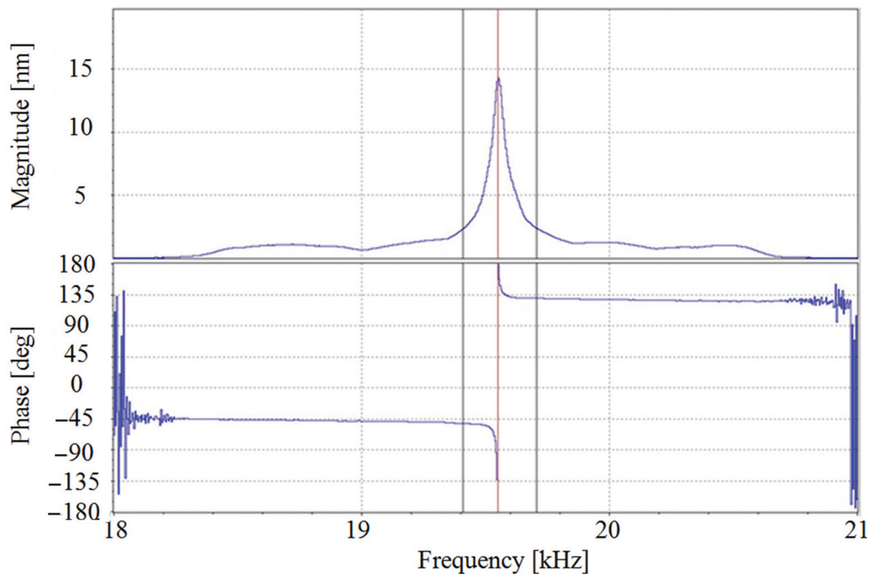

Figure 5: Mechanical amplitude and phase along *Z*-axis.

amplitude depends on the configuration and type of sonotrode and exceeds 150 µm. The difference between the modeling results and measurements is below 1 kHz.

Ultrasonic Capillary Effect

Ultrasonic capillary effect was discovered in 1961 by E. G. Konovalov. Ordinary liquid rises in a capillary to some specific height which is not very significant. However, in the presence of cavitation in the liquid the situation changes drastically. In our case we create cavitation by means of ultrasonic acoustic waves. The ultrasonic transducer is designed to vibrate at an ultrasonic frequency of about 20 kHz. A cavitation cluster forms around the transducer's active tip placed in the liquid. As the distance from the transducer increases, the number of cavitation bubbles per unit of volume decreases. If we put a capillary tube into a liquid we will observe the appearance of a cavitation cluster. If the cavitation cluster around the capillary end is strong enough then the liquid will rise. The stronger the cavitation cluster, the higher the liquid will rise (Prokhorenko et al. 1981). Based on this outlined principle we propose our PiezoMechanical (PM) system.

Experimental Setup

Usually the mention of a capillary brings the idea of some kind of a tube to one's mind, much like a thermometer. It is definitely possible to use such a capillary. However, we have used a rounded or circular capillary, formed by a circle. The tip of the transducer is primarily responsible for the production of vibrations and the capillary should be as close to the tip as possible to be most effective. A kind of a "T-shirt" for the tip of the transducer was made from plastic. The diameter of the tip was 22 mm, and the inner diameter of the "T-shirt" was 22.2 mm, 22.5 mm and 22.8 mm. Slice of the setup schematics is presented in Figure 6.

In Figure 6 the experimental setup of the pump disruptor is presented. The dashed zone represents an algae–liquid mixture; the red zone represents a cavitation cluster (approximately); ξ represents the tip of the transducer that generates longitudinal vibrations; the green zone is a 0.25 mm circular capillary; the blue zone is a tank for processed and pumped substances; and the last hatched zone is a "T-shirt" that forms a circular capillary around the transducer's tip and a reservoir for processed substances. The same schematics were used for 0.2 mm and 0.8 mm capillary tests. There were a number of reasons that were responsible for such differentiation of capillary sizes. Firstly, the algae water mixture has a specific viscosity and, probably (and practice has proven this to be true), the pump was unable to operate. The pressure generated by the cavitation field was not enough to pump the highly viscous liquid through the 0.2 mm round capillary. The same problem was observed with the 0.8 mm capillary; the other reason of the effect – the pressure generated was not enough to overcome the force of gravity. Thus we can only present results that

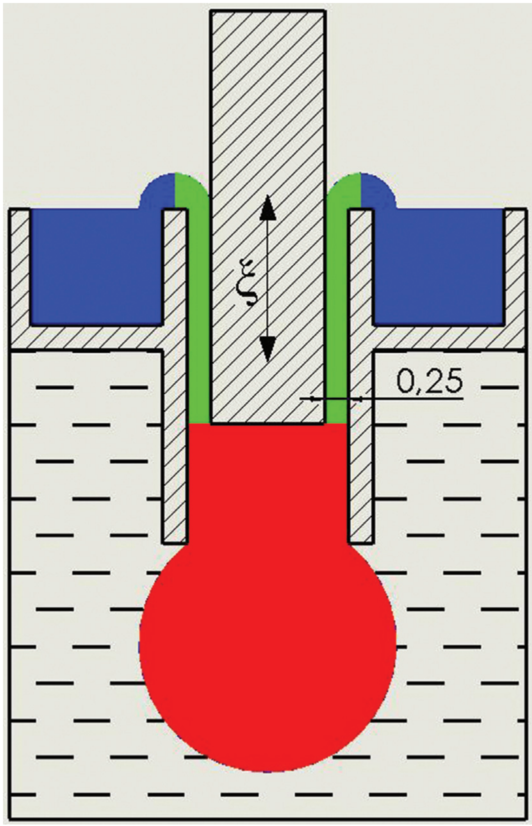

Figure 6: Experimental setup schematics.

were made using the 0.5 mm circular capillary. The average results are presented in Table 1.

Numerical results on algae cell ultrasonication are presented in Table 1. *Scenedesmus acutus Meyen* algae species was used for this experiment. The first line named (Before) represents the unaffected state of this species. Two types of tests were done: test I with 100 Ws and test II with 160 Ws of power. This information was obtained according to the data provided by the generator. Numerical results in Table 1 show how many cells or colonies have survived and the percentage shows how many were destroyed. As you can see, the power increment of $\times 1.6$ does not result in an increment of the same multiplication factor. We assume that such nonlinearity can be caused by dynamic water resistance, which increases with an increment in power. The time of affection in both cases was about 10 s. Processed samples were taken from the secondary reservoir. The pumping flow rate was about 67 ml/min. This data could be considered as a basic result for a standard system, except for the fact that there was no pressure.

Conclusion

The proposed system is proven to be capable to pump and process algae. However, the process is very slow even though the manufacturer suggests that for this particular system the flow rate should be in the range of 0.2–4 l/min, depending on the process. Such a flow rate should be generated by an external pump. The number of cycles for processing the algae–liquid mixture and the pressure is not mentioned either. The proposed system can be modified, by selecting the perfect capillary size for best performance. The proposed system can operate at multi-cycle algae processing, same as any standard system. The main goal of this system was to be able to operate without an external pump, which was achieved. Going further it can be modified to increase the flow rate and improve algae disruption quality. We are planning to improve this by increasing pressure which would make it easier to compare the results with a standard system.

Funding: The work was supported by the Lithuanian Science Council project (No. MIP-018/2014).

Table 1: Experimental results of algae processing.

Scenedesmus acutus Meyen	Units in colony (mln/ml)	Colonies (mln/ml)	Single cells (mln/ml)	Overall cells (mln/ml)
Before	31.6	14.9	473.6	495.3
After test I	20.6	8.6	360.4	378.6
% destroyed	34.8	42.3	23.9	23.6
After test II	16.8	6.2	334.0	348.0
% destroyed	46.8	58.4	29.5	29.7

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