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RESEARCH ARTICLE

Validation of Ultrasound Cavitation at Different Frequency in an Ultrasound Bath using the Aluminium Foil Corrosion Test

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ABSTRACT

Ultrasound baths are one of the beneficial applications of ultrasonic cavitation, and they are widely utilized in various industries. The study aims to validate the effects of frequency and number of piezoelectric transducers in an ultrasound bath by measuring cavitation intensity using the aluminium foil corrosion test through the graphical method. The experimental variables include 20 kHz of two piezoelectric transducers, 40 kHz of two piezoelectric transducers, 20 kHz of four piezoelectric transducers, and 40 kHz of four piezoelectric transducers. A standard piece of aluminium foil was placed horizontally in the bath for five minutes. Tests were conducted at various liquid depths, ranging from 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5 litres. The results indicate that the cavitation intensity and the corroded area increased with greater liquid depth. Each configuration demonstrated a high level of significance. The study concludes that the 40 kHz of four piezoelectric transducers generates the highest cavitation intensity, resulting in the most intensive corroded area on the aluminium foil.

Keywords: Ultrasound, 20 kHz, 40 kHz, Piezoelectric transducer, Cavitation.

INTRODUCTION

Sound is a complex phenomenon is involving fluctuations in pressure and vibrations that travel through its surroundings, whether in the air or any other medium. It is typically caused by mechanical actions that create pressure variations. These vibrations are utilized in sono processing to induce both physical and chemical effects (Kentish, 2017).

Ultrasound is the use of high-frequency pressure waves that are above the range of human hearing, typically exceeding 20kHz (Evrendilek, 2014 & Arvanitoyannis *et al.,* 2017). The vibration produced by the ultrasound is generated by a piezoelectric transducer, which consists of two ceramic pieces that change size precisely and consistently change in size in response to an electric field. Therefore, when an alternating electric field is applied, the ceramic elements move up and down in a highly repeatable manner. The frequency of the electric field applied controls the frequency of the acoustic wave produced. Frequencies ranging from 20kHz and 40kHz are commonly used in food processing applications (Mason, 1998), such as emulsifications

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and microbiological inactivation. These frequencies exceed the thresholds of human hearing (20 Hz to 20 kHz). This technique is called "power ultrasound" because it generates strong sound waves that can create significant shear stresses in the surrounding fluid (Kentish, 2017). The ultrasonic frequency used must be below 2.5 MHz, as cavitation will not occur at frequencies exceeding this threshold (Jan *et al.,* 2017). Piezoelectric transducers convert alternating electrical energy into ultrasonic acoustic waves within the steel tank of an ultrasound bath (Elahi *et al.,* 2021).

The ultrasound technique is driven by acoustic cavitation (Scudino *et al.,* 2020), which is caused by the propagation of ultrasonic waves through a liquid medium (Neokleous *et al.,* 2022). This phenomenon results in cavities that increase in size with each cycle, ultimately leading to the creation of acoustic bubbles. These bubbles also produce a high temperature and pressure (Jan *et al.,* 2017). These bubbles rapidly form and collapse quickly, intensifying the attractive forces between molecules in the medium (Chandrajith *et al.,* 2018). During the negative phase of the waves, small bubbles emerge, during the positive phase, these bubbles burst, resulting in high local pressure and temperature. The high amplitude acoustic waves create variations in pressure within the liquid medium leading to cavitation. This process involves the formation of small bubbles that expand and eventually collapse (Nishida *et al.,* 2022).

Ultrasonic cleaners have been utilized for decades in various industries, including metallurgy, industrial manufacturing, textiles, automotive and chemical laboratories. These powerful cleaners have a wide range of applications, such as cleaning glassware, jewellery, surgical instruments, automotive components and even teeth. They are also known for enhancing chemical reactivity (Khan *et al.,* 2023). Currently, ultrasound-based methods and equipment are employed to detect organs, monitor motion, identify tumour masses, and assess pre/post-natal conditions. Additionally, they are used for kidney stone removal, physiotherapy, and aesthetic treatments. Ultrasound has a wide range of applications in many other fields (Gallo *et al.,* 2018). However, the food industry has been slow to adopt ultrasound technology. In the past decade, scientists have shown renewed interest in this technology as it has quickly established itself as a mild non thermal processing tool that can replace or enhance a variety of conventional food processing methods. These methods include emulsification, homogenization, mixing, milling, extraction, pasteurization, filtration, moisture removal for drying and crystallization, as well as equipment cleaning (Zisu & Chandrapala, 2015). Recently, there has been a growing interest in using ultrasound for food processing and interacting with liquid foods, particularly in the dairy and fruit juice industries (Paniwnyk, 2017).

Globally, ultrasound (US) technology is one of the most commonly used non-thermal processing techniques owing to its environmentally friendly, non-toxic, and benign nature. Furthermore, it has a diverse array of applications in the food industry (Shanmugam *et al.,* 2012). This technology has been employed in the food industry because of its ability to enhance the functional, physical and chemical properties of a wide range of food products (Higuera-barraza *et al.,* 2016).

Ultrasound produces mechanical, chemical, and biochemical effects in liquids by creating and then collapsing cavitation bubbles (Paniwnyk, 2017). To ensure its efficiency, ultrasound is validated by various phenomena such as the aluminium foil corrosion test, SonoCheck and cavimeter test (Zwahlen *et al.,* 2014). The aluminium foil corrosion test is a commonly used indicator of ultrasonic cavitation (Tangsopha *et al.,* 2017) and serves as a tool for studying cavitation activity. Historically, the standard home aluminium foil (0.0006 inches thickness) has been used for this test. This test is widely used as an indicator of ultrasonic cavitation (Kanegsberg & Kanegsberg, 2016) and serves as a tool for studying cavitation activity. The distribution and activity of cavitation, which are essential factors impacting cleaning efficiency, and many studies have utilized the aluminium foil erosion method to evaluate cavitation activity (Juschke & Koch 2012, Xu *et al.,* 2016,). When ultrasound causes cavitation, the foil becomes dimpled, resembling an orange peel pattern. Prolonged exposure to ultrasonics can cause the foil to tear and eventually disintegrate (Kanegsberg & Kanegsberg, 2016).

In this study, the cavitation activity of 20 kHz and 40 kHz ultrasonic bath was validated using an aluminium foil corrosion test by the graphical method.

MATERIAL AND METHODS

The study, aimed to validate the effectiveness of different frequencies and numbers of piezoelectric transducers by configuring the transducers under an

Figure 1. Ultrasound bath with two Transducer

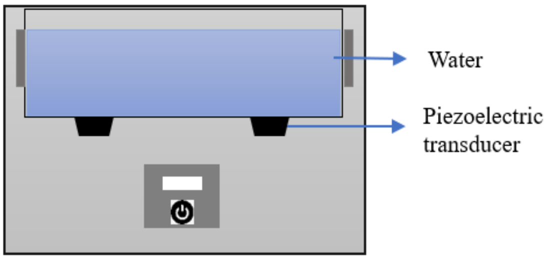


Figure 2. Ultrasound bath with four Transducer

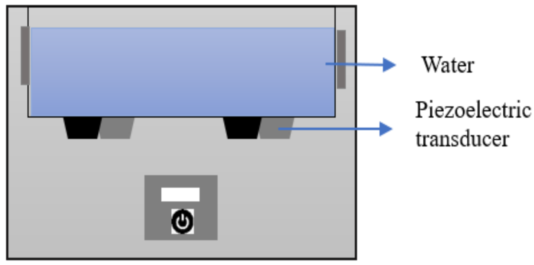


Table 1. The experimental design for the optimization of piezoelectric transducer

Independent variables	Levels	Dependent variables
Frequency	2 levels (20KHz and 40KHz)	Aluminium foil corrosion test
Number of transducers	2 levels (2 nos. and 4 nos.)	
Depth of liquid	10 levels (0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5)	

ultrasonic bath and securing them with Araldite glue. The ultrasonic bath had a chamber size of 300 × 200 × 100 cm with a maximum capacity of 5 liters. The schematic representation of the ultrasound bath with two transducers and four transducers is shown in the Fig.1 and Fig.2 respectively. The experimental design used in the study to optimize the frequency and number of piezoelectric transducers were demonstrated in the Table.1

Validation

We performed the cavitation test with the aluminium foil with a thickness of 11 microns. The foil was cut into uniform pieces of dimension 25 mm × 15 mm and positioned horizontally of the ultrasound bath (Tangsopha *et al.,* 2017).

Aluminium foil corrosion test

The ultrasonic bath was filled with water to various levels, ranging from 0.5 liters to 5 liters, in increments of 0.5 liters (i.e., 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, and 5 liters). The aluminium foil samples were positioned horizontally in the center of the ultrasonic tank to ensure accurate exposure to ultrasonic waves. The ultrasound bath was operated at each specified frequency and transducer configuration (2 or 4 transducers) for a duration of five minutes per test. After the tests, the foils were perforated and the total corroded/pitted area was calculated using a graphical method.

Figure 3. Corroded aluminium foil

Statistical analysis

The average corroded area for each configuration was calculated; the data were statistically analyzed using IBM SPSS statistics Version 20 to assess the significance of differences between the two frequencies (20 kHz and 40 kHz) and the number of transducers (two and four).

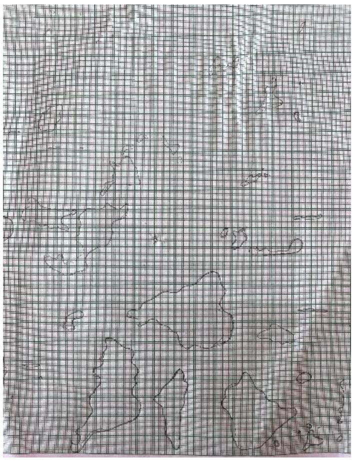
RESULT AND DISCUSSION

The validation results of the aluminium foil corrosion test are presented as an indicator of ultrasonic cavitation intensity. The evaluation focuses on the effect of ultrasonic cavitation on the surface of aluminium foil samples under varying frequencies, number of transducers, and liquid depths. Figure 3 shows the impact of acoustic cavitation on the surface of the aluminium foil. And the deformation, pitting, and perforation were observed similar to Tangsopha *et al.,* (2017) and Kanegsberg & Kanegsberg (2016).

Table 2. Effect of frequency and number of piezoelectric transducer on aluminium foil corrosion test

Transducer /depth of liquid	20 kHz (2 transducer)	40 kHz (2 transducer)	20 kHz (4 transducer)	40 kHz (4 transducer)	F Value
0.5	135.17^{aA} ± 0.601	285.83^{aB} ± 0.428	482.50^{aC} ± 0.477	530.83^{aD} ± 0.563	291476.675**
1	485.50^{bA} ± 0.563	589.50^{bB} ± 0.563	845.00^{bC} ± 0.365	1175.50^{bD} ± 0.764	1814089.568**
1.5	585.83^{cA} ± 0.477	789.50^{cB} ± 0.764	1588.33^{cC} ± 0.628	1647.00^{cD} ± 0.365	64272.713**
2	650.83^{dA} ± 0.601	965.83^{dB} ± 0.477	1876.83^{dC} ± 0.601	2043.17^{dD} ± 0.477	2531640.000**
2.5	786.83^{eA} ± 0.601	1122.00^{eB} ± 0.577	2195.00^{eC} ± 0.577	2690.17^{eD} ± 0.601	2297667.253**
3	911.83^{fA} ± 0.477	1303.00^{fB} ± 0.365	2228.00^{fC} ± 0.577	2775.00^{fD} ± 0.577	2814588.351**
3.5	1074.83^{gA} ± 0.477	1524.67^{gB} ± 0.494	2497.50^{gC} ± 0.428	2932.83^{gD} ± 0.601	2884376.275**
4	1290.83^{hA} ± 0.601	1780.00^{hB} ± 0.577	2690.17^{hC} ± 0.601	3075.17^{hD} ± 0.477	2087103.456**
4.5	1403.17^{iA} ± 0.703	1930.50^{iB} ± 0.428	2799.67^{iC} ± 0.494	3198.00^{iD} ± 0.577	2116034.277**
5	1521.50^{jA} ± 0.428	2200.17^{jB} ± 0.601	2933.50^{jC} ± 0.428	3265.00^{jD} ± 0.577	2285549.136**
F value	459106.730**	981082.035**	95768.926**	442113.868**	

Figure 4. Graphical representation of corroded area



The degree of cavitation damage increased with higher ultrasonic frequency and a greater number of transducers, indicating a more intense cavitation effect. Figure 4, depicts the quantitative analysis of the corroded area, with a graphical representation of the pitted areas, while Table 2. provides the corresponding data. The results show a significant increase in the corroded area as the frequency increased from 20 kHz to 40 kHz, with the higher frequency resulting in intensive cavitation and perforations. Additionally, the use of four transducers instead of two transducers significantly enhanced the cavitation effect, resulting in a larger corroded area on the aluminium foil. There was a significant increase in cavitation-induced corrosion as the liquid depth increased from 0.5 to 5 litres. The maximum depth of five litres increased corrosion. This data suggests that the volume of the liquid medium directly impacts cavitation intensity.

CONCLUSION

The study has shown that both the frequency and number of piezoelectric transducers have a significant impact on the intensity of cavitation in an ultrasonic bath. The results of the aluminium foil corrosion test indicate that increasing the frequency from 20 kHz and 40kHz and four transducers instead of two results in a stronger cavitation was found to increase with greater liquid depth, with the highest effect observed at a depth of five litres. The optimal configuration for maximum cavitation was determined to be 40 kHz with four transducers, suggesting that higher frequency and more transducers are effective in intensifying ultrasound cavitation for industrial applications.

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