Comparison of the cavitation activity of ethanol and acetic acid as ultrasonic cleaning solution

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Abstract

Ethanol and acetic acid are chemicals recommended for industrial cleaning purposes, yet a knowledge gap exists on the cavitation activity of either chemicals, which indicates ultrasonic cleaning efficiency. The study compared the cavitation activity of ethanol and acetic acid using Foil Test Method of Crawford (1964). The objective measured and compared the eroded area of the foil after being subjected to ultrasonic cleaning under the respective chemical solution for certain time intervals. The foil, 10 cm x 8cm, were exposed to different time intervals - 60, 90, 120, 150, and 180 seconds with three trials for each interval. The foil was then photographed. The eroded area of the foil was measured using ImageJ™ software. The mean area per trial were analyzed. The data yielded p=0.0351 > 0.05 and t=3.224 > critical value=2.776, indicating a significant difference between the area of foil erosion caused by the two chemicals.

Keywords: cavitation, ultrasound, ultrasonic cleaning, ethanol, acetic acid

Introduction. Vibration is the periodic back and forth oscillation of a material or particle transmitting mechanical energy across a material through a medium, creating mechanical waves. Particles vibrate as a response to transfer of mechanical energy. When an ultrasound travels in liquid, the vibrations of the waves produce pressurized, bubble-like voids in the liquid in a process called cavitation [1].

The cavitation produced by ultrasound transmits mechanical energy in its cavitation bubbles, thus making it suitable for removing contaminants in a process called ultrasonic cleaning. Ultrasonic cleaners are composed of an ultrasonic generator, an ultrasonic transducer, and a cleaning tank [2]. The transducer converts the electrical signal into an ultrasonic wave, which then transfers to the solution contained in the cleaning tank. The material to be cleaned is then submerged in the tank in which the pressurized cavitation bubbles clean the surface of the material.

Ethanol is a simple alcohol with the formula C_2H_5OH. Ethanol solution is an azeotrope, which means the chemical boils in the same temperature with it water content, making it impossible to distill the ethanol as a liquid in its purest form [3]. The chemical has shown to have distinct physical manifestations, such as production of mist [4] when exposed to ultrasound and other additional thermochemical factors. Ethanol has been recommended in ultrasonic cleaning for its alcoholic properties [5]

Acetic Acid is a monocarboxylic acid with the formula CH_3COOH, commonly used as solvent in dyes, manufacturing, blood testing, pesticides, and as food additive in the form of vinegar [6] Ultrasonic irradiation of acetic acid has also shown to indicate weakening of intensity of cavitations via perturbation of molecular equilibrium [7,8] and lowering the pH levels in transport of anchovies [9]. Acetic acid is

recommended for ultrasonic cleaning due to its acidic and solvent properties [4].

The knowledge gap exists in the cavitation strength produced by either of the chemicals, which indicates efficiency in ultrasonic cleaning.

This study aims to determine the difference between the ultrasonic cavitation produced by acetic acid and by ethanol using the Foil Test Method [10]. It specifically aims to:

(i) determine the eroded area of foil in respective setups for (a) ethanol and (b) acetic acid;

(ii) determine the relation of the eroded area of the foil and time of irradiation in ethanol;

(iii) determine the relation of the eroded area of the foil and time of irradiation in acetic acid; and

(iv) determine if there is a significant difference between the eroded area of foil under ethanol and acetic acid using paired t-test.

Methods. The study utilized the Foil Test method of Crawford [10] to measure the cavitation. The basic comparison for cavitation is expressed in the subsequent equation:

$$Cavitation = \frac{Eroded\ area * Foil\ thickness\ constant}{time\ of\ immersion}$$

The unit of cavitation is expressed in terms of erosion. All materials and variables were kept constant; thus, for convenience in comparing the cavitation activity between the use of acetic acid and the use of ethanol as ultrasonic solution, the average eroded foil area per time interval of the two solution was measured.

Preparation of chemicals. The concentration of acetic acid at 36%, called dilute acetic acid, is the

commercially used concentration for industrial and cleaning purposes, as opposed to lower concentrations used for gastronomical purposes [11]. The concentration of ethanol, 95%, used was the concentration used for commercial purposes as it was the highest possible distilled concentration of ethanol, in which the only substance present in the solution is water and ethanol [12]. For all the trials, the volume of the solution is 1000mL, measured using a 1000mL graduated cylinder. Respective chemicals were then transferred to a 1000mL beaker for degassing.

Degassing. Before being used to irradiate the foil, each solution was degassed by irradiating it to the ultrasonic cleaner for 30 minutes, to remove dissolved gasses present and inhibit the implosion of cavitation bubbles.

Experimentation. For each setup, a 0.10 m x 0.08 m aluminum foil attached to a metal frame was submerged at the bottom of the tank and irradiated with 40 kHz ultrasound at different time periods - 60, 90, 120, 150, and 180 seconds. There were three trials for each time of immersion. After the irradiation, the foil was then photographed against a white light background, 20 cm away from a 13 megapixel smartphone camera set at 3200 ISO and 720 pixels of vertical resolution. The brightness of the laptop screen and the lighting in the laboratory room were constant and controlled in all samples. The photographs were analyzed by ImageJ™ which then measured the area of perforations for each trial. The area of perforations in a foil sample equates to the respective eroded area.

Data Analysis. Paired sample t-test was used to determine the significant difference between the eroded areas of foil samples of the two solutions. The method was repeated for all the three trials for each of the five time durations. The mean of each trial were then used for paired sample t-test. The alpha value was set to $\alpha=0.05$. If the p value is less than α and the t value is less than the critical value, then there is no significant difference between the eroded areas of foil using acetic acid and using ethanol as ultrasonic cleaning solution.

Safety Procedure. During experimentation for each set-up, the irradiation of the chemical solution were contained in the fume hood of the laboratory, to contain the possible fumes released by the chemicals and to minimize the possibility of combustion of ethanol. Gloves, masks, and laboratory gowns were worn throughout each step of chemical irradiation. Additionally, goggles were worn during the measurement and transfer of chemicals. After the data gathering, the chemical solutions were disposed in the sink of the laboratory.

Results and Discussion. The results shown in Table 1 & 2 and Figure 1 revealed that the eroded area for both chemicals of the foil increased along with time. Neither were linear, as the marginal difference per 30 second interval varied across time samples. For each of the chemical, the marginal difference in mean area increased with time except in between 150 and 180 seconds and the highest increase in mean area occurred between 120 and 150 seconds.

Table 1. Mean eroded area of three trials for each time of immersion and marginal mean area of foil erosion of ethanol

Time (seconds)	Mean area (cm^2)	Marginal Mean Area[1]
60	0.001	N/A[2]
90	0.063	0.061
120	0.065	0.002
150	0.145	0.080
180	0.157	0.0118

[1] Marginal mean area refers to the change in mean area.
[2] not applicable.

Table 2. Mean eroded area of three trials for each time of immersion and marginal mean area of foil erosion of acetic acid

Time (seconds)	Mean area (cm^2)	Marginal Mean Area[1]
60	0.230	N/A*
90	0.298	0.068
120	0.519	0.221
150	1.166	0.647
180	1.224	0.058

[1] Marginal mean area refers to the change in mean area.
[2] not applicable.
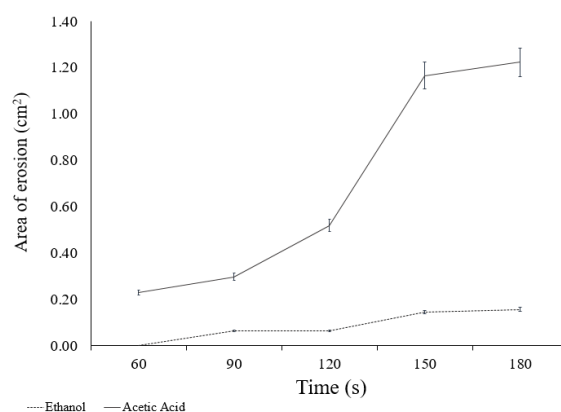
Figure 1. Mean area of erosion versus time of immersion graph for ethanol and acetic acid

The results shown in Table 3 yielded the t value of 3.244, which exceeds the critical value, 2.776. The p values generated by the data was 0.0351, which is less than 0.05. Thus, there is a significant difference between the area of foil erosion using acetic acid and ethanol as ultrasonic solution, in favor of acetic acid producing larger area of foil erosion.

Table 3. Paired sample t-test results.

	Ethanol area of erosion	Acetic Acid area of erosion
Mean $\pm$ S.D.	0.086 ± 0.064	0.688 ± 0.476
S.E.M.	0.029	0.213
critical value	3.244	
t-value	2.766	
p-value	0.0351	

The mean area of erosion under ethanol was lesser than all of the corresponding mean area under

acetic acid for the same time interval. Moreover, the mean area of erosion under acetic acid for any time interval was larger than the mean area of erosion under ethanol of all time intervals.

In the study of Vatandas et al. [13], ethanol solutions showed decrease in temperature as the ultrasonic velocity increases. Since for mechanical waves, velocity is directly proportional to frequency under constant wavelength, it can be inferred that the study implied decrease in temperature of the ethanol solutions as the ultrasound frequency increased. This could be a factor that affected negatively the solvent property of ethanol. Lower temperature indicates lower average kinetic energy in the molecules of ethanol. The decrease in kinetic energy prevents the solvent molecules to effectively break apart the solute molecules that are held together by intermolecular attractions. Ethanol also has a fairly neutral pH level of 7.33, compared to 4.76 for dilute acetic acid [6], which could inhibit the solubility of the solution [14].

$$velocity = wavelength * frequency$$

Foils subjected to ultrasonic irradiation using acetic acid as solution produced greater area of erosion consistently compared to ethanol for the same time interval. This can be inferred as due to the solvent properties of the acid, including its strong acidity of pH level of around 4.76 (dilute), depending on its concentration. The increase in mean area were comparable to ethanol for the 60 second time interval. The increase in marginal difference of mean area were also steeper than that of ethanol, except for in between 150 and 180 seconds. It is also worth noting that the highest increase in mean area occurred between 150 and 180 seconds, the same time interval in which the highest increase in mean area occurred in ethanol. This time interval could be a point of interest for future studies using Foil Test Method to describe cavitation.

Generally, the properties of ethanol shared with the other alcohol chemicals inhibit the solvent properties of ethanol, as opposed to the acidic properties of acetic acid. For definitive description of cavitation production, comparison with chemicals of similar alcoholic or acidic properties can be done.

Error Analysis. Possible errors which arose during the conduct of the study may be attributed to the performance of the ultrasonic cleaner, in which the frequency released by the transducer was not measured by another instrument. The temperature and pressure of the laboratory, both of which were not controlled throughout the set-ups, may affect the discrepancy of the data. In the photography stage, the pixilation and lighting settings of the phone camera may have affected the actual area perforated from the foil.

Conclusion. In the study, the cavitation produced by ultrasonic cleaner using ethanol and using acetic acid were compared. This was done using the Foil Test Method in which a piece of foil was irradiated for certain time intervals for each chemical. For both chemicals, the mean area of erosion of the foil increased along with time, but the increase in mean area diminished in the last time interval. Acetic

acid was shown to be more effective in producing perforations in the foil, thus indicating stronger cavitation activity.

Other properties of ethanol and acetic acid as cleaning solution, e.g. thermal, electrochemical, were not determined. The data gathering also involved image processing which can be affected by other uncontrollable environmental factor of image set-up.

Recommendations. For more accurate results, it is recommended to use higher resolution camera and more controlled environment of photography. It is recommended to include temperature as a control variable as it also affects the solubility of the foil in the solution [14]. The study, which used Foil Test Method, compared the cavitation produced by the two chemicals. More definitive methods to compare the effectiveness of each solution in stain removal using ultrasonic cleaning are also recommended to give a more definitive

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