CHAPTER 1: INTRODUCTION

Background of Study

The application of ultrasonic wave in various fields including separation process has increased predominantly; including the cavitations cleaning. The ultrasonic cavitations cleaning technique could be defined as a contaminants removal process from an object by using blast energy of cavities. These cavities or bubbles are formed in a chamber contains an aqueous solution by applying a high frequency sound wave, i.e., ultrasonic wave. The wave is electrically activated by an ultrasonic transducer. This transducer is built into the chamber provides sufficient amount of energy needed to generate cavities to scrub the surface of the object to be cleaned.

The binary mixture that will be utilized is methanol-water. The effects of ultrasonic waves; ultrasonic intensities and ultrasonic frequencies will be resulting different relative volatility for different composition of methanol and water in the mixture. Thus, an experimental procedure should be conducted to obtain the most suitable composition of the mixtures with the optimum ultrasonic frequency.

Problem Statement

Ultrasonic Cavitations

Nowadays, ultrasonic cavitations technique as alternative of cleaning is used in different kind of industries. The exact measurement to standardize the cavitation cleaning ranges has not developed yet. Furthermore, the most suitable aqueous solution use as the medium of cavitations event has never been brought up into further development. One of the measurements proposed is by using aluminum foil. Cavitations activity caused formation of dents on the surface of the foil. The number and sizes of the dents can be used to quantify the cavitations activity applied.

Image Processing Toolbox - MATLAB

The Image Processing Toolbox provides a comprehensive set of reference-standard algorithms and graphical tools for image processing, analysis, visualization, and algorithm development. It is used to restore noisy or degraded images, enhance images for improved intelligibility, extract features, analyze shapes and textures, and register two images. Most toolbox functions are written in the open MATLAB language. This means that it is capable to inspect the algorithms, modify the source code, and create custom functions. It includes:

- Deblurring
- Enhancement
- Image Arithmetic
- Image Registration

- Image Segmentation
- Spatial Transformation
- Measuring Image Features
- Transform

Objective and Scope of Study

The objective of this project is to construct an algorithm of image-processing by using MATLAB. This algorithm is to relate the properties of cavitations due to changes of material as the medium for cavitations take place. The scope of the study:

- To conduct a literature review on image-processing and measurement of ultrasonic cavitation
- To develop an algorithm to identify the exact number of dents on a specimen due to cavitation
- To relate the properties of cavitation (dents on specimen) with the properties of aqueous solution as the medium of cavitation event.

CHAPTER 2: LITERATURE REVIEW

2.1   Sound Wave

In order to understand the mechanics of ultrasonic, it is necessary to first have a basic understanding of sound waves, how they are generated and how they travel through a conducting medium.

A sound wave is produced when a solitary or repeating displacement is generated in a sound conducting medium, such as by a "shock" event or "oscillatory" movement. The displacement of air by the cone of a radio speaker is a good example of "oscillatory" sound waves generated by mechanical movement. As the speaker cone moves back and forth, the air in front of cone is alternately compressed and rarefied to produce sound waves, which travel through the air until they are finally dissipated.

We are probably most familiar with sound waves generated by alternating mechanical motion. There are also sound waves which are created by a single "shock" event. An example is thunder which is generated as air instantaneously changes volume as a result of an electrical discharge (lightning). Another example of a shock event might be the sound created as a wooden board falls with its face against a cement floor. Shock events are sources of a single compression wave which radiates from the source.

2.2   Ultrasonic

Ultrasonic wave is the frequency band above 20 kHz. It may be extended up to 1 GHz, goes over into conventionally called the hypersonic regime. The standard human receptor is in audio spectrum which is between 20 Hz and 20 kHz.
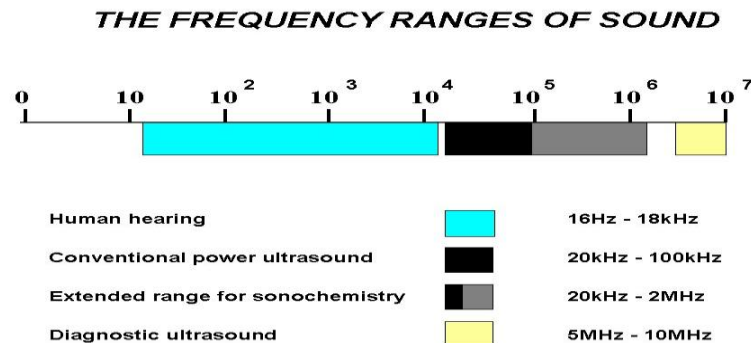
THE FREQUENCY RANGES OF SOUND

Human hearing	16Hz – 18kHz
Conventional power ultrasound	20kHz – 100kHz
Extended range for sonochemistry	20kHz – 2MHz
Diagnostic ultrasound	5MHz – 10MHz

Figure 2.1: Frequency Ranges of Sounds

The sound wave is produced when a solitary or repeating displacement is generated in a sound conducting medium, such as by a "shock" event or "vibratory" movement. This movement can produce "bubbles" due to non-elastic media for sound wave medium. Most liquids are considered as non-elastic media.

To introduce ultrasonic energy into a cleaning system requires an ultrasonic transducer and an ultrasonic power supply or "generator." The generator supplies electrical energy at the desired ultrasonic frequency. The ultrasonic transducer converts the electrical energy from the ultrasonic generator into mechanical vibrations.

2.3 Ultrasonic Transducers

The commonly-used ultrasonic transducers nowadays are ***piezoelectric*** and ***magnetostrictive***. These transducers are used to convert electrical energy into mechanical energy (as is vibration).
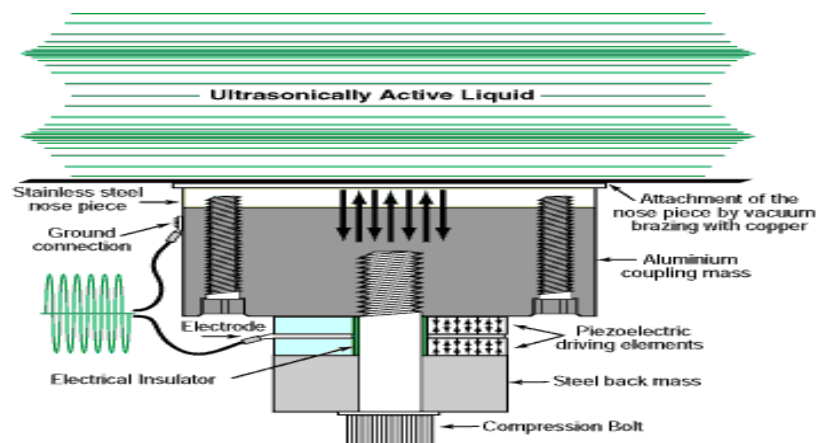
2.3.1 Piezoelectric Transducer

Figure 2.2: Piezoelectric Transducer

Piezoelectric transducers convert alternating electrical energy directly to mechanical energy through use of the piezoelectric effect in which certain materials change dimension when an electrical charge is applied to them.

Electrical energy at the ultrasonic frequency is supplied to the transducer by the ultrasonic generator. This electrical energy is applied to piezoelectric element(s) in the transducer which vibrate. These vibrations are amplified by the resonant

masses of the transducer and directed into the liquid through the radiating plate. Early piezoelectric transducers utilized such piezoelectric materials as naturally occurring quartz crystals and barium titanate which were fragile and unstable. Early piezoelectric transducers were, therefore, unreliable. Today's transducers incorporate stronger, more efficient and highly stable ceramic piezoelectric materials which were developed as a result of the efforts of the US Navy and its research to develop advanced sonar transponders in the 1940's. The vast majority of transducers used today for ultrasonic cleaning utilize the piezoelectric effect.

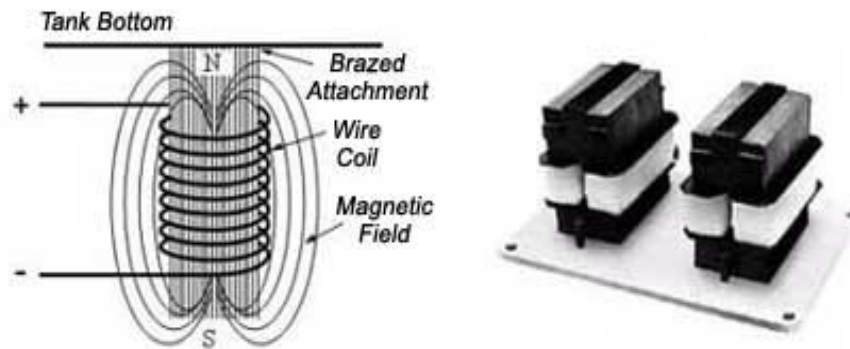### 2.3.2 Magnetostrictive Transducer

Figure 2.3: Magnetostrictive Transducer

Magnetostrictive transducers utilize the principle of magnetostriction in which certain materials expand and contract when placed in an alternating magnetic field.

Alternating electrical energy from the ultrasonic generator is first converted into an alternating magnetic field through the use of a coil of wire. The alternating magnetic field is then used to induce mechanical vibrations at the ultrasonic frequency in resonant strips of nickel or other magnetostrictive material which are attached to the surface to be vibrated. Because magnetostrictive materials behave identically to a magnetic field of either polarity, the frequency of the electrical energy applied to the transducer is 1/2 of the desired output frequency. Magnetostrictive transducers were first to supply a robust source of ultrasonic vibrations for high power applications such as ultrasonic cleaning.

Because of inherent mechanical constraints on the physical size of the hardware as well as electrical and magnetic complications, high power magnetostrictive transducers seldom operate at frequencies much above 20 kilohertz. Piezoelectric transducers, on the other hand, can easily operate well into the megahertz range.

Magnetostrictive transducers are generally less efficient than their piezoelectric counterparts. This is due primarily to the fact that the magnetostrictive transducer requires a dual energy conversion from electrical to magnetic and then from magnetic to mechanical. Some efficiency is lost in each conversion. Magnetic hysteresis effects also detract from the efficiency of the magnetostrictive transducer.

2.4   Ultrasonic Generator

The ultrasonic generator converts electrical energy from the line which is typically alternating current at 50 or 60Hz to electrical energy at the ultrasonic frequency. This is accomplished in a number of ways by various equipment manufacturers. Current ultrasonic generators nearly all use solid state technology.
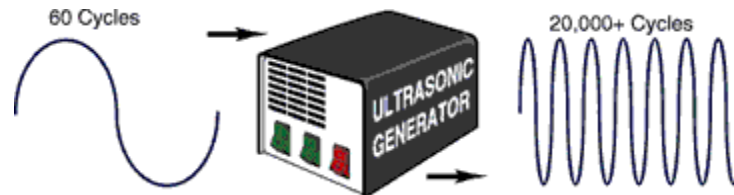

Figure 2.4: Ultrasonic Generator

There have been several relatively recent innovations in ultrasonic generator technology which may enhance the effectiveness of ultrasonic cleaning equipment. These include square wave outputs, slowly or rapidly pulsing the ultrasonic energy on and off and modulating or "sweeping" the frequency of the generator output around the central operating frequency. The most advanced ultrasonic generators have provisions for adjusting a variety of output parameters to customize the ultrasonic energy output for the task.

2.5   Cavitations

According to Young (1999), cavitationt is defined as the formation and activity of bubbles (or cavities) in a liquid. The word 'formation' refers, in a general way, both to the creation of a new cavity or to the expansion of pre-existing one to a size where macroscopic effects can be observed. These bubbles may be suspended in

the liquid or may be trapped in tiny cracks either in the liquid's boundary surface or in solid particles suspended in the liquid.

In the Journal Ultrasonics Sonochemistry, Niemczewski (2007) noted that cavitation is a physical phenomenon consisting of the creation of very small vacuum bubbles in a liquid media, filled to a certain degree of vapor, gas or a mixture thereof, which under certain conditions implode. These bubbles are not visible to the naked eye.

Joroen Cornel (2004-2005) classified cavitation into four (4) categories; based on how it is produced:

- Hydrodynamic cavitation: by pressure variation in a flowing liquid due to the geometry of the system;
- Acoustic cavitation: by sound waves in a liquid due to pressure variations;
- Optic cavitation: by photons of high intensity (laser) light rupturing in a liquid;
- Particle cavitation: by any other type of elementary particles; e.g. a proton, rupturing a liquid, as in a bubble chamber.

Since the cavitation effect in this project is produced by ultrasonic waves (which is a type of sound wave), thus it falls under the acoustic cavitation category.

In elastic media such as air and most solids, there is a continuous transition as a sound wave is transmitted. On the other hand, in non-elastic media such as water and most liquids, there is continuous transition as long as the amplitude of the sound is relatively low. As amplitude increased, the magnitude of the negative

pressure in the areas of rarefaction eventually becomes sufficient to cause the liquid to fracture. This phenomenon is known as cavitation.

Cavitation bubbles are created at sites of rarefaction as the liquid fractures or tears because of the negative pressure of the sound wave in the liquid. as the wave fronts pass, the cavitation bubbles oscillate under the influence of positive pressure, eventually growing to an unstable size. Finally, the violent collapse of the cavitation bubbles results in implosions, which cause shock waves to be radiated from the sites of the collapse. This process is presented in Figure 2.5.
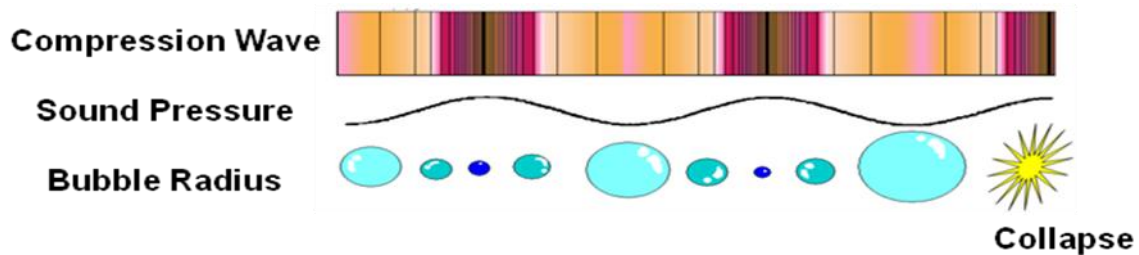

Figure 2.5: Implosion of Bubbles Due to Ultrasonic Cavitations

The collapse and implosion of countless cavitation bubbles throughout an ultrasonically activated liquid result in the effect commonly associated with ultrasonics. It has been calculated that temperatures in excess of 10 000°F and pressures in excess of 10 000psi are generated at the implosion sites of cavitation bubbles.

The formation of cavitation by ultrasonic is due to the declining of pressure in the liquid body. Whenever pressure is reduced, the boiling point temperature of a liquid

is also lowered. If the pressure is reduced far enough until the boiling point is reduced to below room temperature, then the liquid will begin to boil without needing to be heated. When this happens on a small scale, due to localized pressure reduction, small bubbles of vapor are formed – this is called cavitation. It can happen in a liquid subjected to ultrasonic vibrations or in other circumstances where movement creates areas of low pressure (e.g. ship's propellers).

Most of the effects are caused not by the formation of vapor bubbles, but by their destruction. The bubbles can exist only when the pressure is low. The low-pressure areas are highly localized and changing all the time. For an ultrasonic standing wave, the time between lowest and highest pressure is typically 10 to 25 microseconds. They are extremely unstable when the pressure is high so they collapse violently, momentarily creating immense temperatures and pressures. The collapse of each bubble happens in a microscopically small volume. However, given a strong and uniform ultrasonic field, millions of them throughout the liquid will be formed and destroyed thousands of times per second, so they can affect the bulk properties of the liquid. The effect us exploited in sonochemistry and ultrasonic cleaning.

2.6   Ultrasonic Cleaning

An important application of ultrasonic cavitations is in ultrasonic cleaning field. An ultrasonic cleaner is a cleaning equipment that uses ultrasound to clean delicate items. It was one of the earliest industrial applications of ultrasonics as shown in Figure 2.6. Objects to be cleaned are placed in a bath of fluid which is violently agitated by a number of ultrasonic transducers.

Figure 2.6: Ultrasonic Cavitations Cleaning Equipment
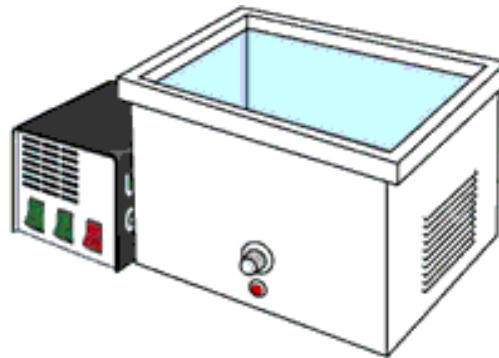
Some contaminants are comprised of insoluble particles loosely attached and held in place by ionic or cohesive forces. These particles need only be displaced sufficiently to break the attractive forces to be removed. The ionic force of the media could break the bonds between the contaminant and the surface.
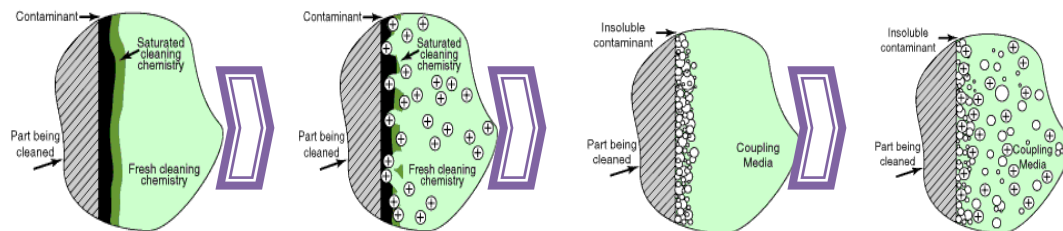
Figure 2.7: Ultrasonic Cavitation Cleaning Activity

CHAPTER 3: METHODOLOGY

Gather information regarding ultrasonic cavitations (literature review)
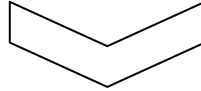
Perform an experiment by using methanol-water mixture as medium for cavitations event. Use aluminum foil as specimens.
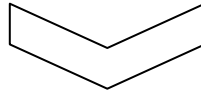
Use the existing algorithm to calculate the cavitations intensity (includes number of cavities and their diameter)
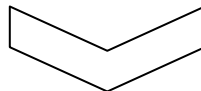
Gain the appropriate statistics and details to relates cavitations intensity with properties of medium
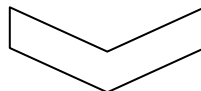
Study and observe the information gained and make conclusions based on experimental data.

3.1 Literature Review and Planning

The scope of literature review includes the basic principles of ultrasonic cavitations, ultrasonic intensity measurement automation using MATLAB, and planning the appropriate experimental procedures. This literature study enforces more accurate process estimation and the feasibility of the project.

3.2 Performing the Experiment

Experiment was conducted by using ultrasonic bath and aluminum foil as the specimen. Dents formed on the specimen will be calculated using MATLAB algorithm. This step will be further reviewed on the Chapter 4.

3.3 Usage of Existing MATLAB Algorithm

MATLAB algorithm has been developed to provide appropriate measurement on cavitation intensity. It includes measurement on dent's diameter and area.

3.4 Statistics and Correlations

After the appropriate data obtained from both laboratory experiment and MATLAB program, statistics regarding this matter is studied. Correlation between the properties of the ultrasonic media and the cavitation intensity is to be observed. Other parameters such as frequency and temperature are been studied too.

3.5 Conclusions and Recommendations

Discussion on the statistics obtained in previous step is conducted. Conclusions made based on the experimental data. Recommendation on improving the project is also proposed.

CHAPTER 4: EXPERIMENTAL PROCEDURES

Experimental procedures are to be conducted by using these manipulated variables:

5 ultrasonic media (as shown in Figure 4.1):

o A; 0%vol methanol – 100%vol water

o B; 25%vol methanol – 75%vol water

o C; 50%vol methanol – 50%vol water

o D; 75%vol methanol – 25%vol water

o E; 100%vol methanol – 0%vol water

Figure 4.1: 5 different methanol-water mixtures

- 2 operating frequencies:

  o 28kHz

  o 45kHz

- 2 operating temperatures:

  (should be higher than 35°C since the apparatus is not equipped with cooler)

  o 40°C

  o 50°C

- Constant variables:

  o Operating power = 100%

  o Immersion time for each sample = 1 minute

The ultrasonic media is classified according to the composition of methanol in the mixture. The properties of the mixtures that are taken into account are density and viscosity.

The experimental setup is shown in Figure 4.2.

Figure 4.2: Experimental setup

Properties of the Mixtures

1. Density in g/cm^3

$$Density = \frac{mass(g)}{volume(cm^3)}$$

Mixture A: $Density = \dfrac{200g}{200cm^3} = 1.00 g/cm^3$

Mixture B: $Density = \dfrac{189.6g}{200cm^3} = 0.948 g/cm^3$

Mixture C: $Density = \dfrac{179.2g}{200cm^3} = 0.896 g/cm^3$

Mixture D: $Density = \dfrac{168.8g}{200cm^3} = 0.844 g/cm^3$

Mixture E: $Density = \dfrac{158.4g}{200cm^3} = 0.792 g/cm^3$

2. Viscosity in centipoises (cP)

To calculate the viscosity of a mixture, viscosity blending index (VBI) for each component in the mixture need to be obtained first using this equation:

$$VBI = 14.534 \times ln[ln(v + 0.8)] + 10.975$$

The VBI of the mixture is calculated as below:

$$VBI_{AB} = [w_A \times VBI_A] + [w_B \times VBI_B]$$

Where; v = viscosity in centipoise at particular temperature.

At 40°C, v_{water} = 0.655688cP; v_{MeOH} = 0.417934cP

At 50°C, v_{water} = 0.548981cP; v_{MeOH} = 0.36171cP

w = weight fraction of each component of the blend.

At 40°C

VBI_{water} $= 14.534 \times ln[ln(0.655688 + 0.8)] + 10.975 = -3.262$

VBI_{MeOH} $= 14.534 \times ln[ln(0.417934 + 0.8)] + 10.975 = -12.625$

At 50°C

VBI_{water} $= 14.534 \times ln[ln(0.548981 + 0.8)] + 10.975 = -6.555$

VBI_{MeOH} $= 14.534 \times ln[ln(0.36171 + 0.8)] + 10.975 = -16.608$

At 40°C

Mixture A: 1.00 water – 0.00 methanol

$VBI_{AB} = [1.00 \times -3.262] + [0.00 \times -12.625] = -3.262$

$v_A \quad = 0.656cP$

Mixture B: 0.79 water – 0.21 methanol

$VBI_{AB} = [0.79 \times -3.262] + [0.21 \times -12.625] = -5.228$

$v_B \quad = 0.588cP$

Mixture C: 0.56 water – 0.44 methanol

$VBI_{AB} = [0.56 \times -3.262] + [0.44 \times -12.625] = -7.382$

$v_C \quad = 0.527cP$

Mixture D: 0.79 water – 0.21 methanol

$VBI_{AB} = [0.3 \times -3.262] + [0.7 \times -12.625] = -9.816$

$v_D \quad = 0.470cP$

Mixture E: 0.56 water – 0.44 methanol

$VBI_{AB} = [0.00 \times -3.262] + [1.00 \times -12.625] = -7.382$

$v_E \quad = 0.418cP$

At 50°C

Mixture A: 1.00 water – 0.00 methanol

$VBI_{AB} = [1.00 \times -6.555] + [0.00 \times -16.608] = -6.555$

$v_A \quad = 0.549cP$

Mixture B: 0.79 water – 0.21 methanol

$VBI_{AB} = [0.79 \times -6.555] + [0.21 \times -16.608] = -8.666$

$v_B \quad = 0.495cP$

Mixture C: 0.56 water – 0.44 methanol

$VBI_{AB} = [0.56 \times -6.555] + [0.44 \times -16.608] = -10.978$

$v_C \quad = 0.447cP$

Mixture D: 0.79 water – 0.21 methanol

$VBI_{AB} = [0.3 \times -6.555] + [0.7 \times -16.608] = -13.592$

$v_D \quad = 0.403cP$

Mixture E: 0.56 water – 0.44 methanol

$VBI_{AB} = [0.00 \times -6.555] + [1.00 \times -16.608] = -16.608$

$v_E \quad = 0.362cP$

Summary of Mixtures Properties:

Table 4.1: Properties Table of Methanol-Water Mixture

MIXTURE	COMPOSITION (wt%)	DENSITY (g/cm^3)	VISCOSITY (Cp)	
			40°C	50°C
A	100wt% H_2O – 0wt% MeOH	1.000	0.656	0.549
B	79wt% H_2O – 21wt% MeOH	0.948	0.588	0.495
C	56wt% H_2O – 44wt% MeOH	0.896	0.527	0.447
D	30wt% H_2O – 70wt% MeOH	0.844	0.470	0.403
E	0wt% H_2O – 100wt% MeOH	0.792	0.418	0.362

Image examples of specimens using water as media are shown in Figure 4.3:
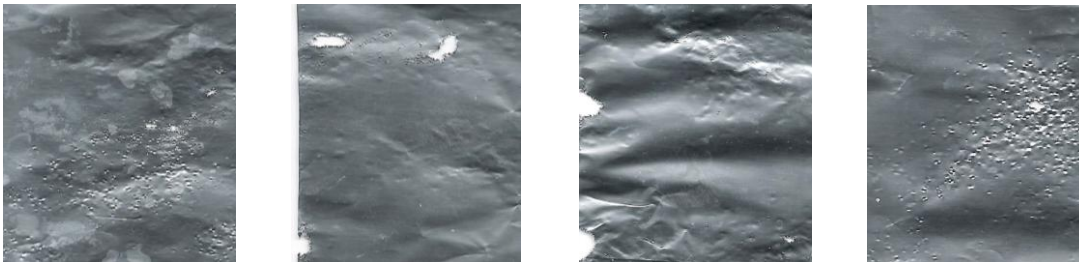
Figure 4.3: Dents formed on the surface of specimens (aluminum foil)

These images need to be cropped into much smaller sizes in order to identify the dents formed onto the specimens. Cropped images can be obtained from MATLAB algorithm. The dents formed will be more visible in cropped image by the program.

The results will then be organized in table form. Example for frequency 28kHz at 40°C is as shown in Table 4.1

Table 4.2: Example of Table for frequency 28 kHz at 40°C

Mixture	Sample No	Cropped Area (in^2)	No. of Dents	Dents Density (Dents/in^2)	Dents Diameter (mm)	Dents Area (mm^2)
A	1					
	2					
	3					
	4					
	AVG					
B	1					
	2					
	3					
	4					
	AVG					
C	1					
	2					
	3					
	4					
	AVG					
D	1					
	2					
	3					
	4					
	AVG					
E	1					
	2					
	3					
	4					
	AVG					

The results are then to be presented in graphical form for final conclusion.

CHAPTER 5: MATLAB PROGRAMMING (IMAGE PROCESSING)

In this project, the program used to quantify the dents formed onto the aluminum foil surfaces already been developed. There are three (3) M-files that is used to develop the algorithm. These files already have the function of image-processing technique using image segmentation in order to identify the dents.

M-File 1 (newstat.m)

```matlab
a=input('Input image: ', 's');
a=imread(a);

figure
a1=imcrop(a);
a1=imresize(a1,2);

[m n]=size(a1);        %measuring size of cropped image

m1=m/600;              %converting to inch, for 600dpi resolution
n1=n/600;              %converting to inch, for 600dpi resolution
cropped_area=m1*n1  %cropped image area in inch

%converting to bw image
thresh=0.95;            %Threshold limit to preserve white areas (dents
detail). The value attained from histogram
bw=im2bw(a1,thresh);

yudo_cmap               %go to function yudo_cmap to create contour map

%labelling image to get the features
[label_op,num_op]=bwlabel(op);
[label_isi2,num_isi2]=bwlabel(isi2);

pixel = regionprops(label_isi2,'Area');
allArea = [pixel.Area];            %area of each dents
diameter = (allArea*4/pi).^0.5;    %diameter of each dents

%return dents density
num_of_dents= num_isi2             %num of dents
density=num_isi2/cropped_area      %num of dents per inch square

%average measurement of the dents
average_area=(sum(allArea)/num_isi2)*25.4/600        %area in milimeter
square
```

```
average_diameter=(sum(diameter)/num_isi2)*25.4/600    %diameter in
millimeter
```

M-File 1 is used to specify the parameters that will be obtained by the program. The parameters are:

- Cropped_area (the area cropped from the scanned images of aluminum foil)

- AllArea (area of each dents formed onto the cropped area)

- Diameter (diameter of each dents)

- Num_of_dents (quantity of dents formed in the specified cropped area)

- Density (number of dents per square inch of the cropped area)

- Average_area (average area of the dents in millimeter square)

- Average_diameter (average diameter of the dents in millimeter)

M-File 2 (yudo_cmap.m)

```
figure, imshow(a1)
title ('Cropped image')

cl=imclose(bw,strel('disk',2));
open=cl;
op = imclearborder(open);
op=imresize(op,2);

%figure, imshow(op)
%title ('bw and cleaned')

i = 0;
bw4=0.07*op;

while (1)
    i = i + 1;
    bw2=imerode(op,strel('disk',i));    %figure, imshow(bw2)
    bw3=bw2*0.07;                        %figure, imshow(bw3)
    bw4=bw4+bw3;                         %figure, imshow(bw4)
        if sum(sum(bw2))== 0
            break
```

```matlab
        end
end

%figure, imshow(bw4)
%title ('contour map')

%to find perimeter of dents
op2=op;
bw_perim = bwperim(op2);
overlay1 = imoverlay(bw4, bw_perim, [.3 1 .3]);

%to find local maximum of each dents
mask = imregionalmax(bw4);
overlay2 = imoverlay(bw4, bw_perim | mask, [.3 1 .3]);
%%figure, imshow(overlay2)
%%title ('Overlaid images')

bw4_c = imcomplement(bw4);
bw4_mod = imimposemin(bw4_c, ~bw4 | mask);

%watershed operation
w = watershed(bw4_mod);

%%figure, imshow(label2rgb(w))
%%figure, imshow(w)
%%title ('watershed image')

isi=imfill(~w,'holes');
isi2=isi-~w;
figure, imshow(isi2)
title ('final separated dents')

isi2=imresize(isi2,0.5);
op=imresize(op,0.5);
```

M-File 3 (imoverlay.m)

```matlab
function out = imoverlay(in, mask, color)
%IMOVERLAY Create a mask-based image overlay.
%   OUT = IMOVERLAY(IN, MASK, COLOR) takes an input image, IN, and a
binary
%   image, MASK, and produces an output image whose pixels in the MASK
%   locations have the specified COLOR.
%
%   IN should be a grayscale or an RGB image of class uint8, uint16,
int16,
```

```
%   logical, double, or single.  If IN is double or single, it should be
in
%   the range [0, 1].  If it is not in that range, you might want to use
%   mat2gray to scale it into that range.
%
%   MASK should be a two-dimensional logical matrix.
%
%   COLOR should be a 1-by-3 vector of values in the range [0, 1].  [0 0
0]
%   is black, and [1 1 1] is white.
%
%   OUT is a uint8 RGB image.
%
%   Examples
%   --------
%   Overlay edge detection result in green over the original image.
%
%       I = imread('cameraman.tif');
%       bw = edge(I, 'canny');
%       rgb = imoverlay(I, bw, [0 1 0]);
%       imshow(rgb)
%
%   Treating the output of peaks as an image, overlay the values greater
than
%   7 in red.  The output of peaks is not in the usual grayscale image
range
%   of [0, 1], so use mat2gray to scale it.
%
%       I = peaks;
%       mask = I > 7;
%       rgb = imoverlay(mat2gray(I), mask, [1 0 0]);
%       imshow(rgb, 'InitialMagnification', 'fit')

%   Steven L. Eddins, The MathWorks, Inc.
%   $Revision: 1.2 $  $Date: 2007/08/15 13:18:08 $

% If the user doesn't specify the color, use white.
DEFAULT_COLOR = [0 1 0];
if nargin < 3
    color = DEFAULT_COLOR;
end

% Make the uint8 the working data class.  The output is also uint8.
in_uint8 = im2uint8(in);
color_uint8 = im2uint8(color);

% Initialize the red, green, and blue output channels.
if ndims(in_uint8) == 2
    % Input is grayscale.  Initialize all output channels the same.
    out_red   = in_uint8;
```

```
    out_green = in_uint8;
    out_blue  = in_uint8;
else
    % Input is RGB truecolor.
    out_red   = in_uint8(:,:,1);
    out_green = in_uint8(:,:,2);
    out_blue  = in_uint8(:,:,3);
end

% Replace output channel values in the mask locations with the appropriate
% color value.
out_red(mask)   = color_uint8(1);
out_green(mask) = color_uint8(2);
out_blue(mask)  = color_uint8(3);

% Form an RGB truecolor image by concatenating the channel matrices along
% the third dimension.
out = cat(3, out_red, out_green, out_blue);
```

Whereas for both M-File 2 (yudo_cmap.m) and M-File 3 (imoverlay.m) are used to create contour map of the scanned images of aluminum foil and create mask-based image overlay respectively. These are the programs where the image-processing technique takes place.

Images shown in MATLAB program:

In MATLAB program, a small area will be cropped from the original scanned image. The program will show the details in MATLAB script:

Figure 5.1: Area Cropped from the Specimen

```
cropped_area =
    0.3804 (in inch²)

num_of_dents =
    10

density =
    26.2858 (in dents/inch²)

average_area =
    7.8740 (average area of dents in mm²)

average_diameter =
    0.6359 (average diameter of dents in mm)
```

Figure 5.2: Cropped image

The cropped image allows the dents to be more visible as shown in Figure 5.2. This is due to a very small area is selected. From the program, it is known that the area selected is **0.3804 inch^2**.

Figure 5.3: Final separated dents

Figure 5.3 shows the final separated and clear image of dents. In this image, the dents are countable. However, the quantity of dents from the cropped image is already shown in the program and the value is **10 dents**.

CHAPTER 6: RESULTS AND DISCUSSION

Based on the experimental procedures that had been conducted, the results obtained for each frequency at each temperature are shown in Tables 5.1 to 5.4.

Table 6.1: Results for frequency 28kHz at 40°C

Mixture	Sample No	Cropped Area (in^2)	No. of Dents	Dents Density (Dents/in^2)	Dents Diameter (mm)	Dents Area (mm^2)
A	1	0.2457	27	109.8901	0.4416	5.6230
	2	0.0360	9	250.0000	0.3924	3.9887
	3	0.0473	9	190.2748	0.4580	4.5250
	4	0.0631	4	63.3914	0.6591	7.3237
	AVG	**0.0980**	**12**	**153.3891**	**0.4878**	**5.3651**
B	1	0.1078	21	194.8052	0.4496	4.9775
	2	0.0507	9	177.5148	0.4329	4.5219
	3	0.0320	5	156.2500	0.3878	3.9531
	4	0.1257	6	47.7327	0.4443	4.3080
	AVG	**0.0791**	**10**	**144.0757**	**0.4287**	**4.4401**
C	1	0.0828	15	181.1594	0.5277	4.6512
	2	0.0767	9	117.3403	0.4899	5.2644
	3	0.1501	15	99.9334	0.3811	4.3957
	4	0.2030	21	103.4483	0.4180	3.9874
	AVG	**0.1282**	**15**	**125.4703**	**0.4542**	**4.5747**
D	1	0.1008	11	109.1270	0.5954	8.2050
	2	0.5021	26	51.7825	0.4524	3.5461
	3	0.0572	8	139.8601	0.4282	3.8153
	4	0.0898	13	144.7661	0.4712	4.9042
	AVG	**0.1875**	**15**	**111.3839**	**0.4868**	**5.1177**
E	1	0.0406	2	49.2611	0.4362	3.5348
	2	0.0747	4	53.5475	0.5902	6.8792
	3	0.0752	9	119.6809	0.4245	3.7253
	4	0.0924	17	183.9827	0.5426	4.1238
	AVG	**0.0707**	**8**	**101.6180**	**0.4984**	**4.5658**

Table 6.2: Results for frequency 28kHz at 50°C

Mixture	Sample No	Cropped Area (in²)	No. of Dents	Dents Density (Dents/in²)	Dents Diameter (mm)	Dents Area (mm²)
A	1	0.0807	16	198.2652	0.3996	3.6830
	2	0.0905	11	121.5470	0.4085	3.5582
	3	0.0797	5	62.7353	0.4322	3.7253
	4	0.1077	19	176.4160	0.6511	5.9478
	AVG	**0.0897**	**13**	**139.7408**	**0.4729**	**4.2286**
B	1	0.1101	25	227.0663	0.4174	3.6288
	2	0.1207	15	124.2751	0.4504	4.2474
	3	0.0460	4	86.9565	0.3674	3.7411
	4	0.0533	6	112.5704	0.4399	3.2093
	AVG	**0.0825**	**13**	**137.7171**	**0.4188**	**3.7067**
C	1	0.1307	19	145.3711	0.4065	3.7016
	2	0.1040	8	76.9231	0.4362	4.0217
	3	0.2176	45	206.8015	0.6328	4.1039
	4	0.0813	5	61.5006	0.4382	3.4183
	AVG	**0.1334**	**19**	**122.6491**	**0.4784**	**3.8114**
D	1	0.0867	15	173.0104	0.4514	3.6512
	2	0.0598	4	66.8896	0.4205	4.1910
	3	0.1078	8	74.2115	0.5116	5.9214
	4	0.1302	12	92.1659	0.3234	3.0689
	AVG	**0.0961**	**10**	**101.5694**	**0.4267**	**4.2081**
E	1	0.2137	25	116.9864	0.3449	2.4655
	2	0.0363	4	110.1928	0.5272	7.1120
	3	0.1429	11	76.9769	0.3784	2.9402
	4	0.0433	3	69.2841	0.4653	4.6567
	AVG	**0.1091**	**11**	**93.3601**	**0.4290**	**4.2936**

Table 6.3: Results for frequency 45kHz at 40°C

Mixture	Sample No	Cropped Area (in²)	No. of Dents	Dents Density (Dents/in²)	Dents Diameter (mm)	Dents Area (mm²)
A	1	0.0395	7	177.2152	0.3859	3.7979
	2	0.1963	24	122.2618	0.3094	2.9873
	3	0.3321	38	114.4234	0.4094	3.8860
	4	0.2521	28	111.0670	0.3058	2.1454
	AVG	**0.2050**	**24**	**131.2419**	**0.3526**	**3.2042**
B	1	0.1633	26	159.2162	0.3227	2.7490
	2	0.3509	39	111.1428	0.3499	3.8328
	3	0.1541	21	136.2751	0.3050	2.5380
	4	0.2929	32	109.2523	0.3453	3.1962
	AVG	**0.2403**	**30**	**128.9716**	**0.3307**	**3.0790**
C	1	0.2882	29	100.6246	0.3402	2.8115
	2	0.5163	78	151.0750	0.3775	3.4697
	3	0.3300	39	118.1818	0.3723	3.2293
	4	0.3223	34	105.4918	0.3322	2.6617
	AVG	**0.3642**	**45**	**118.8433**	**0.3556**	**3.0431**
D	1	0.4251	45	105.8574	0.3574	3.0038
	2	0.7204	91	126.3187	0.3120	3.1328
	3	0.6080	63	103.6184	0.2873	1.7232
	4	0.5510	48	87.1143	0.3341	2.5123
	AVG	**0.5761**	**62**	**105.7272**	**0.3227**	**2.5930**
E	1	0.2493	17	68.1909	0.3779	3.3145
	2	0.2990	25	83.6120	0.3366	2.7940
	3	0.1764	16	90.7029	0.3252	3.4846
	4	0.1237	13	105.0930	0.2964	1.7845
	AVG	**0.2121**	**18**	**86.8997**	**0.3340**	**2.8444**

Table 6.4: Results for frequency 45kHz at 50°C

Mixture	Sample No	Cropped Area (in²)	No. of Dents	Dents Density (Dents/in²)	Dents Diameter (mm)	Dents Area (mm²)
A	1	0.1823	22	120.6802	0.3416	2.7921
	2	0.2372	32	134.9073	0.3710	3.3139
	3	0.4189	47	112.1986	0.3137	2.4265
	4	0.2305	25	108.4599	0.2782	1.5867
	AVG	0.2672	32	119.0615	0.3261	2.5298
B	1	0.1003	8	79.7607	0.2901	1.6351
	2	0.1259	9	71.4853	0.2527	1.3123
	3	0.1974	25	126.6464	0.4851	6.6565
	4	0.1078	17	157.6994	0.2872	1.6012
	AVG	0.1329	15	108.8980	0.3288	2.8013
C	1	0.1794	23	128.2051	0.2807	1.5884
	2	0.1607	11	68.4505	0.4213	4.8812
	3	0.1133	19	167.6964	0.3474	2.9722
	4	0.1452	5	34.4353	0.2526	3.3716
	AVG	0.1497	15	99.6968	0.3255	3.2034
D	1	0.1007	5	49.6524	0.3276	3.0226
	2	0.0384	1	26.0417	0.3059	1.7357
	3	0.0583	6	102.9160	0.2973	3.5392
	4	0.0333	3	90.0901	0.3419	2.2578
	AVG	0.0577	4	67.1750	0.3182	2.6388
E	1	0.0843	6	71.1744	0.2743	2.2419
	2	0.0573	4	69.8080	0.3187	3.0873
	3	0.0313	1	31.9489	0.2866	1.5240
	4	0.0214	1	46.7290	0.3326	2.8130
	AVG	0.0486	3	54.9151	0.3031	2.4166

Table 6.5: Mixture Properties Table with Average Dents Density

COMPOSITION (wt%)		DENSITY (g/cm³)	VISCOSITY (Cp)		DENTS DENSITY (per inch²)			
			40°C	50°C	28kHz@ 40C	28kHz@ 50C	45kHz@ 40C	45kHz@ 50C
A	100wt% H_2O – 0wt% MeOH	1	0.656	0.549	153.3891	139.7408	131.2419	119.0615
B	79wt% H_2O – 21wt% MeOH	0.948	0.588	0.495	144.0757	137.7171	128.9716	108.898
C	56wt% H_2O – 44wt% MeOH	0.896	0.527	0.447	125.4703	122.6491	118.8433	99.6968
D	30wt% H_2O – 70wt% MeOH	0.844	0.47	0.403	111.3839	101.5694	105.7272	67.175
E	0wt% H_2O – 100wt% MeOH	0.792	0.418	0.362	101.618	93.3601	86.8997	54.9151

Table 6.6: Mixture Properties Table with Average Dents Diameter

COMPOSITION (wt%)		DENSITY (g/cm³)	VISCOSITY (Cp)		DENTS DIAMETER (mm)			
			40°C	50°C	28kHz@ 40C	28kHz@ 50C	45kHz@ 40C	45kHz@ 50C
A	100wt% H_2O – 0wt% MeOH	1	0.656	0.549	0.4878	0.4729	0.3526	0.3261
B	79wt% H_2O – 21wt% MeOH	0.948	0.588	0.495	0.4287	0.4188	0.3307	0.3288
C	56wt% H_2O – 44wt% MeOH	0.896	0.527	0.447	0.4542	0.4784	0.3556	0.3255
D	30wt% H_2O – 70wt% MeOH	0.844	0.47	0.403	0.4868	0.4267	0.3227	0.3182
E	0wt% H_2O – 100wt% MeOH	0.792	0.418	0.362	0.4984	0.429	0.334	0.3031

Table 6.7: Mixture Properties Table with Average Dents Area

COMPOSITION (wt%)		DENSITY (g/cm³)	VISCOSITY (Cp)		DENTS AVERAGE AREA (mm²)			
			40°C	50°C	28kHz@ 40C	28kHz@ 50C	45kHz@ 40C	45kHz@ 50C
A	100wt% H_2O – 0wt% MeOH	1	0.656	0.549	5.3651	4.2286	3.2042	2.5298
B	79wt% H_2O – 21wt% MeOH	0.948	0.588	0.495	4.4401	3.7067	3.079	2.8013
C	56wt% H_2O – 44wt% MeOH	0.896	0.527	0.447	4.5747	3.8114	3.0431	3.2034
D	30wt% H_2O – 70wt% MeOH	0.844	0.47	0.403	5.1177	4.2081	2.593	2.6388
E	0wt% H_2O – 100wt% MeOH	0.792	0.418	0.362	4.5658	4.2936	2.8444	2.4166

From the data obtained in the tables, these graphs were constructed;
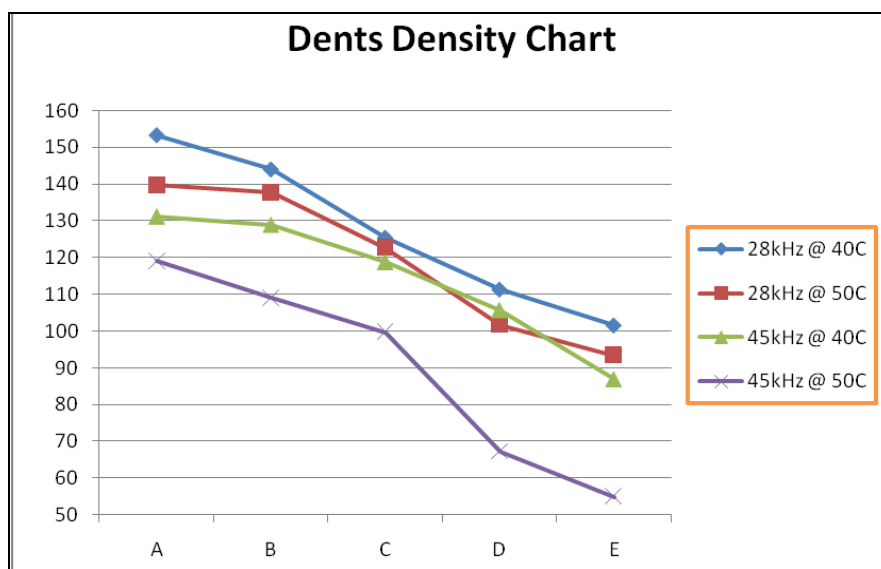
Figure 6.1: Dents Density Chart

- Based on Figure 5.1, it is shown that the more methanol composition in the mixture will cause less formation of dents.
- It is also shown that the formation of dents will decreased when the frequency and temperature are increased.

- At condition of frequency 28kHz at 40°C, the density of dents formed on the specimen is clearly shown as decreased from mixture A (0% methanol) to mixture E (100% methanol)

- From the chart, it is also shown that the lower the frequency, the more intense cavitation will happened. However, this does not mean that cavitation does not happen at high frequency. In this case, the cavities formed may be too small to give sufficient forced in order to form dents onto the specimen. This will be further discussed in the Chart 6.2 and Chart 6.3.

- It is also shown that at the same frequency, cavitation intensity is higher at lower temperature. This may be due to more bubbles formed in relatively low pressure as well as temperature.

- On the other hand, for frequency 45kHz at 40°C, formation of dents is slightly more in mixture D (75% methanol) than frequency 28kHz at 40°C. This may be due to damage caused by the bubbles (cavities) activity inside the mixture. At lower frequency (28kHz) the cavitation intensity is high enough to cause damage to the specimen – cause the result to be less accurate.
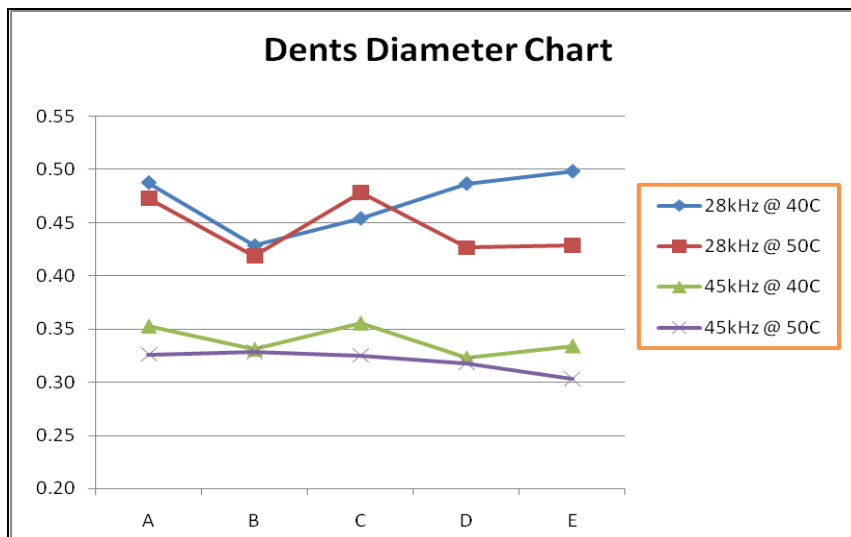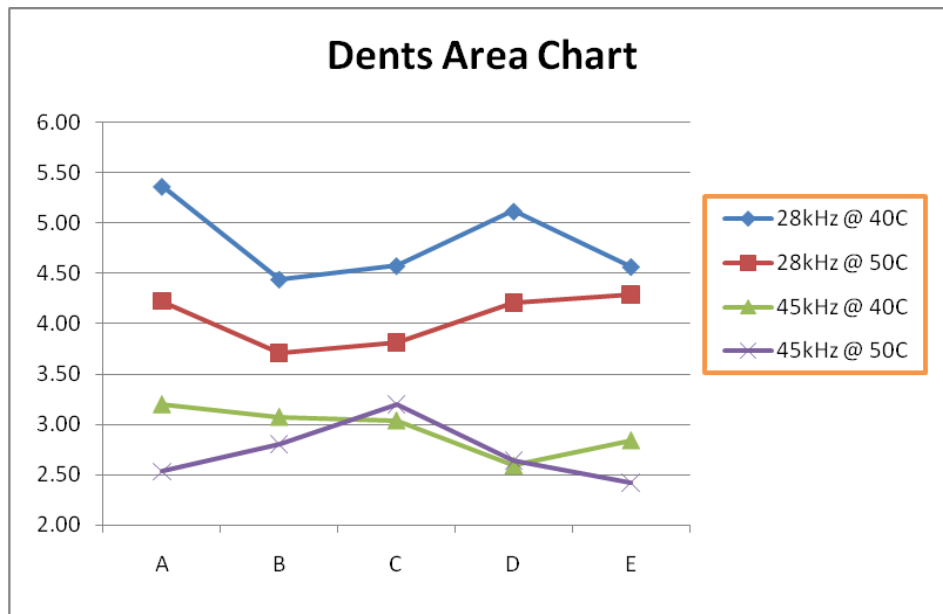

Figure 6.2: Dents Diameter Chart

Figure 6.3: Dents Area Chart

- For both dents diameter and area charts, it is shown that higher frequency formed smaller bubbles. This may also be true for temperature.

- Based on the result, it is as known theoretically that higher frequency should gives smaller bubbles (cavities) and eventually smaller dents formed onto the specimens. However, these bubbles may be too small to create a significant force in order to form dents. However, from the trend obtained by the results, it is acceptable to conclude that the lower frequency and temperature will result in bigger cavities formed.

PROPERTIES OF MIXTURE CHARTS – DENSITY AND VISCOSITY
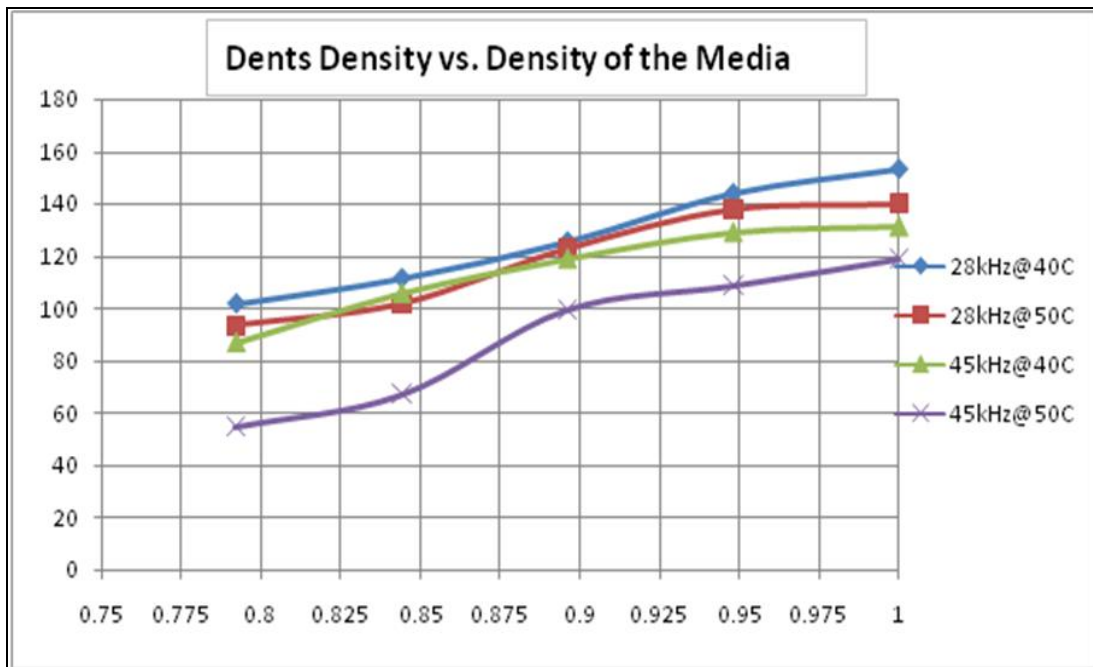
Figure 6.4: Dents Density versus Density of the Media

- In Figure 6.4, it is shown that by increasing the density, the formation of the dents also increased; which is that the cavitation intensity is increased.

- This is due to the differences in density of the component used in the mixture. The density of methanol is lower than density of water. The more composition of methanol will results lower density of the mixture; which eventually the formation of dents onto the aluminum foil will be less.

- Same as Figure 6.1, the effects of frequency and temperature is more or less the same on the cavitation intensity.
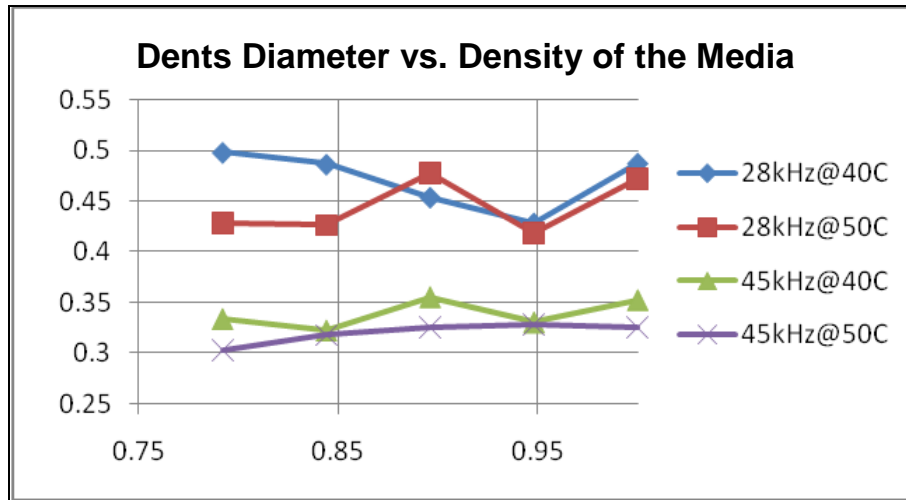
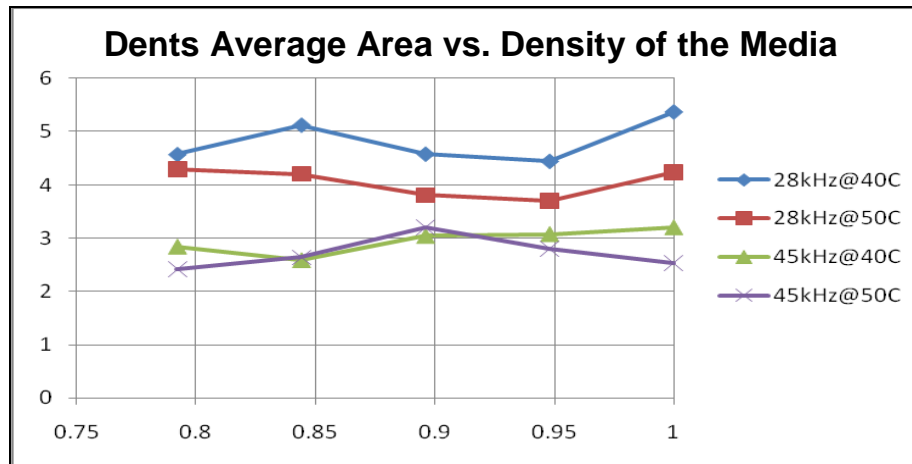**Figure 6.5: Dents Diameter versus Density of the Media**

Figure 6.6: Dents Average Area versus Density of the Media

- In both Figure 6.5 and 6.6, the pattern of each graph cannot be easily concluded according to the density of the media. However, as for temperature, higher temperature tends to form smaller bubbles. This also applicable for frequency; higher frequency formed smaller bubbles.

- In some cases,it is clearly seen that higher density formed smaller bubbles, but as the density increased to some point, the bubble size is decreased; and vice versa.
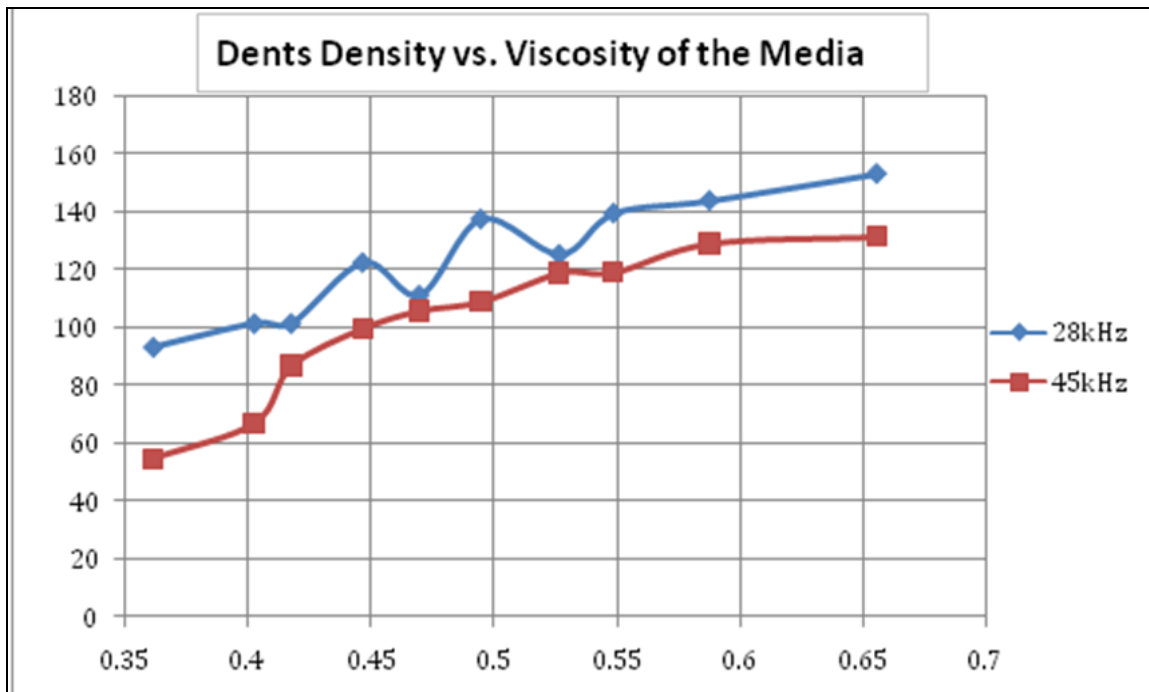
Figure 6.7: Dents Density versus Viscosity of the Media

- According to Figure 6.7, the dents density increased when the viscosity of the liquid media is increased; so is the cavitation intensity. This is especially clearly seen for frequency 45kHz.

- However, there are some points (at 28kHz), the dents density decreased at higher viscosity but eventually increasing again towards the highest viscosity.

- The viscosity of water is higher than methanol. More composition of methanol lowered the viscosity of the mixture.

- Viscosity is also highly affected by the temperature. At higher temperature, the liquid will be less viscous.
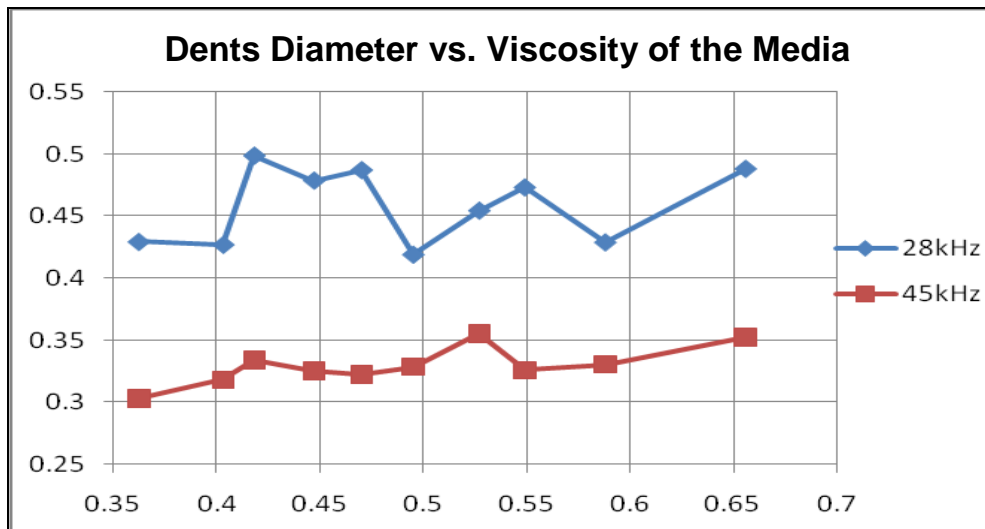
Dents Diameter vs. Viscosity of the Media

Figure 6.8: Dents Diameter versus Viscosity of the Media

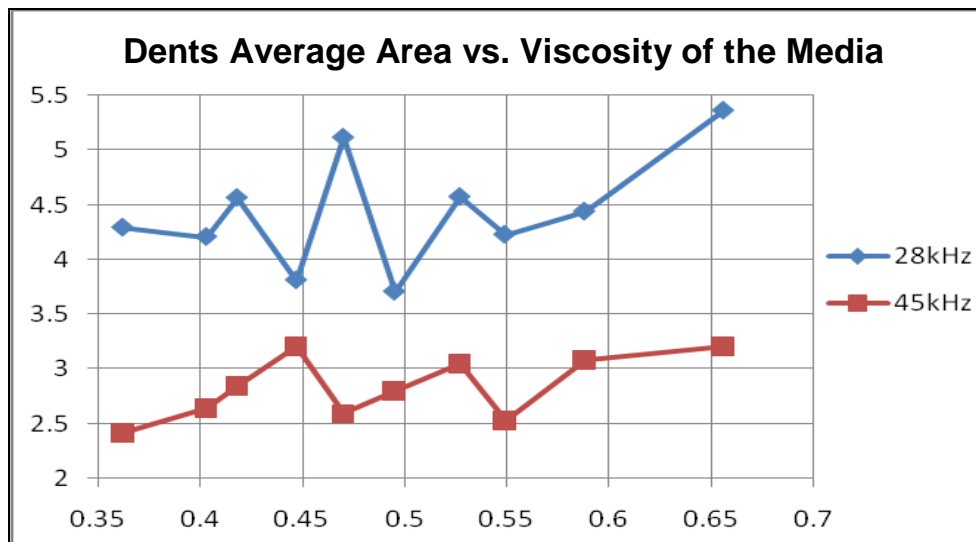**Dents Average Area vs. Viscosity of the Media**

Figure 6.9: Dents Average Area versus Viscosity of the Media

- There is no specific pattern of dents average area and diameter according to the viscosity of the ultrasonic media as shown in both Figure 6.8 and 6.9.

- However, bigger bubble tends to be formed in more viscous liquid than the less viscous liquid. Although at some points, this statement cannot be proven as true, but most of the points show that more viscous liquid produces bigger cavities.

CHAPTER 6: CONCLUSION

It is known that the difference composition of a mixture can give significant effect onto bubbles formation. This is due to the differences in the mixture density; as well as its viscosity. While bubble formations can also be related with the cavitations intensities. Consequently, compositions of methanol-water mixture could affect the cavitations intensities.

As for the frequency, small bubbles (cavities) will formed by higher ultrasonic frequency. These bubbles are too small to provide sufficient force to form dents onto aluminum foil surface. This is also true for the temperature; which is why less dents formed at higher frequency and temperature.

A literature review on ultrasonic cavitation has been correlated. The addition of alcohol (methanol) in water will disrupt the cavitation intensity; however it is needed to ensure the samples are safe from any damage due to rapid cavities formation.

REFERENCES

1. Young F.R., *Cavitation,* 1999.

2. Adnan R. et al., 2008, Effects of Ultrasonic Waves on Enhancement of Relative Volatilities in Methanol-Water Mixtures. *Jurnal Teknologi, 48(F) 61 – 73.*

3. Fuchs F. J., 2002, Ultrasonic Cleaning Fundamental Theory and Application. *Blackstone~Ney Ultrasonics.*

4. Ivan, Soltec S. R. L., 2004, The Principles of Ultrasonic Cleaning. *Soltec ® Soluzioni Tecnologiche.*

5. Tri Yudo Harisasono; 2008, Quantification of Ultrasonic Cavitation Event. *Universiti Teknologi PETRONAS.*

6. Tech Paper: Fundamental of Ultrasonic Cleaning (Page 12 of 19)
    http://www.blackstone-ney.com/04.TP_fundamentals_12.php

7. Sonochemistry Centre – Research
    http://www.sonochemistry.info/Research.htm

8. Tech Paper: Magnetostrictive Versus Piezoelectric Transducers
    http://www.blackstone-ney.com/04.TP_mag_vs_piezo.php

9. Liquid Dynamic Viscosity Calculation by Vogel Equation
    http://ddbonline.ddbst.de/VogelCalculation/VogelCalculationCGI.exe

10. How to Calculate Viscosity of Liquid Mixture?
    http://profmaster.blogspot.com/2007/12/how-to-calculate-viscosity-of-liquid.html

APPENDICES