Sensor as Tactile Techniques in Ultrasonic Cleaning Reactor

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***Abstract*— An "ideal sensor" which is robust enough to withstand bubble jetting is proposed. Such sensor could be used to investigate temperature of water, pressure of water and acoustic pressure which can be used to measure cavitation effects,generated by ultrasound. In this experiment, DS18B20 Digital Temperature Sensor, MAX4466 Hydrophone Amplifier and SKU 237585 Pressure Transducer Sensor were connected to Arduino Uno to form sensors systems tested at 3 different depths namely at the bottom (0 cm), at the middle (3.5 cm) and at the top of a beaker (7.5 cm), to determine the performance of sensors. Based on the result, DS18B20 Temperature Sensors provided the consistent reading as the standard deviation was between 0.08 to 0.38 which was less than 1% from average values. However, SKU237585 pressure transducer sensor gave inconsistent result as the standard deviation was more than 1% which was 0.01 to 0.56 from average data. The result also showed MAX4466 Hydrophone Amplifier was insufficient to detect the acoustic emission signal due to its' small bandwidth. In addition, the temperature and negative of pressure at the bottom of container produced the highest reading compared to top and middle of container similar to the study conducted by other researchers.**

***Keywords*— Acoustic emission signal, Negative pressure, Temperature of liquid medium, Ultrasonic cleaning reactor**

I. INTRODUCTION

Ultrasonic cleaning is an evolving research especially in the manufacturing industries. Ultrasonic cleaning research is booming due to application and the fact that it is shown as an effective method for critical cleaning and extraction of remaining oil [4]. Potential application of ultrasonic cleaning is due to the cavitation bubbles, which is induced by high frequency pressure waves of ultrasound horn. There are other countless methods to treat the produced sand involving land farming, pyrolysis, oxidate thermal treatment, centrifugation using cyclotrons and electrode emulsification [5]. Regardless of these treatments, it causes environmental pollution and soil contamination. Moreover, they also can be ineffective, time consuming and expensive [5].

The cavitation which is induced during the cleaning process can be detected by several method. The detection of cavitation is crucial to detect and quantify the degree of acoustic cavitation in order to establish the effectiveness of ultrasonic cleaning vessel throughout of its volume [6]. The first research about the cavitation bubbles by erosion is in 1917 by Rayleigh [6]. Example of cavitation detection is by using aluminium foils erosion test, as it will record the erosion that occur to the aluminium foil due to explosion of the cavitation [6]. Besides that, the detection of cavitation also can used by SonoCheckTM as it acts as an indicator based on the degradation of chloroform concentration by cavitation [7].

There are several ways to detect and quantifying parameters in the cavitation. Sound field measurement can be used to extract valuable parameters of cavitation due to the fact that sound field is driving force by cavitation [8]. This includes the influence of subharmonic amplitude and noise power in various frequency towards the cavitation effects [9]. Hydrophone is greatly providing an excellent signal-to-noise ratio to measure the time-dependent sound pressure. It has been an evolution from the bigger size and complicated design to underwater hydrophone and fibre optic technique that used small diameter and wide frequency response [10]. The measurement also can be done from negative pressure of liquid medium that influence the intensity of cavitation explosion. The change of energy to temperature of water also can be used to measure effectiveness of cavitation.

Arduino has been widely used as it easy-to-use, easy to understand and low cost thus attract interest for researchers to develop a sensor by using this microcontroller board [10]. The user also does not require to have basic in electrical engineering or programming. As the widely used of Arduino, the Arduino board has started to change in order to adapt to new challenges including the preferable of low cost yet effective sensors [11]. Many studies have been conducted related to the physical process and applications of acoustic cavitation. In order to measure the series of information related to cavitation, many companies came out with their creative ideas and invented new technologies in creating the best sensor in ultrasonic cleaning reactor [2]. This is important in order to determining the effectiveness of ultrasonic cleaning sensor to maximize the extraction of produced sand [4]. However, most of the sensor available in the market is expensive and only can extract only one information of cavitation parameters [7]. For example, CaviMeter only can be used to determine acoustic pressure without considering of temperature which also the important parameter on formation of cavitation. The sensor should be developed with low cost and reliable user friendly to allow more information of cavitation can be studied [10].

One of the reasons of the unavailability of measurement sensor is due to the difficulty to find the suitable material to overcome destructive process from cavitation as the material must be rocked to withstand with the impact of explosion and at the same time capable in extracting valuable measurement information [12]. Most of the sensors is limited to their application due to their vulnerability to mechanical damage and high maintenance cost [13]. Thus, the measurement devices need to be tough enough to endure hostile condition yet refined enough to extract useful measurement information.

In this research, electronic sensors were probe to test consistency of a series of information, which are pressure and temperature of liquid in the container. These electronic sensors consist of hydrophone, pressure transducer sensors and digital temperature sensor which connected with Arduino were placed in different depths liquid container to test the sensor near a rigid boundary. These electronic sensors are robust enough to overcome from damage due to explode of bubbles.

II. METHODOLOGY

A. *Experimental Set Up*

In this experiment, 60-watts piezoelectric and 100-watt power generator were used to generate ultrasonic on 7.5 cm diameter modified container. The piezoelectric transducer was mounted on the bottom of the modified container. For the safety purpose, thread seal tape was used to seal between the lid and body of the container to avoid any leakage that could lead to electrocute people around. 350 mL of water was poured into container and left in an open atmosphere for at least 24 hours for stabilizing the gas content and the entrained gas. The temperature of water was monitored in room temperature between 25^{0}C to 26^{o}C. In order to power up piezoelectric transducer, two-pin plug was plugged into socket plug to supply electricity to power generator. There were also two wire connected to power generator which is red and black. The red wire was then clipped to positive terminal of power transducer while the black wire was clipped to negative terminal of power transducer. It is important to running this experiment with water in the container to avoid any mechanical problem with the piezoelectric transducer.

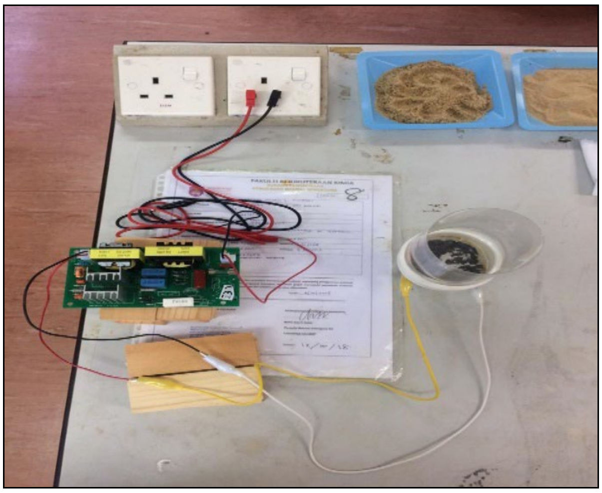

Fig. 1: The preparation of experimental apparatus

B. *Assembling the Hardware*

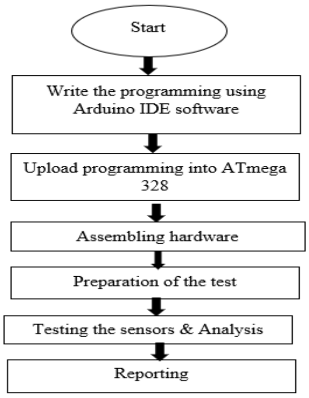

Fig. 2: The flow diagram of assembling the sensors

Based on Fig. 2, the process of conducting of this experiment consists of 6 elements. In first section, the software development was conducted by using Arduino IDE software. The purpose of this software development was used is to construct a series of command for sensors with an assembly language. Next, all the developed programming code were transferred into ATmega 328. In this process, first, the programming codes were interpreted and sent to PIC to declare input and output. To establish there were no error in theses code, the programming codes then were analysed and ran in the Arduino IDE. After the process completed, the programming code then were uploaded into ATmega328 by using universal serial bus (USB). The programming codes were analysed again to the electronic component to work.

In last section, Arduino Uno were assembled together with pressure amplifier, digital temperature and microphone. For the first test, three different colours of wires connected temperature sensor which is red (VCC), blue (data wire) and black (ground). These wires were connected into Arduino pin slot. The red colour wire was pinned to 5V slot, the black colour wire was pinned to GND slot and the blue wire was pinned to no 1 slot. After that, the USB were used to connect the computer to input jack of Arduino Uno to provide power supply to microcontroller board. The coding codes then was extracted into the Arduino Uno to provide instruction to the central processing unit in controlling this pressure sensor. The temperature sensor then was replaced with SKU 237585 Pressure Transducer Sensor and MAX 4466 Hydrophone Amplifier.

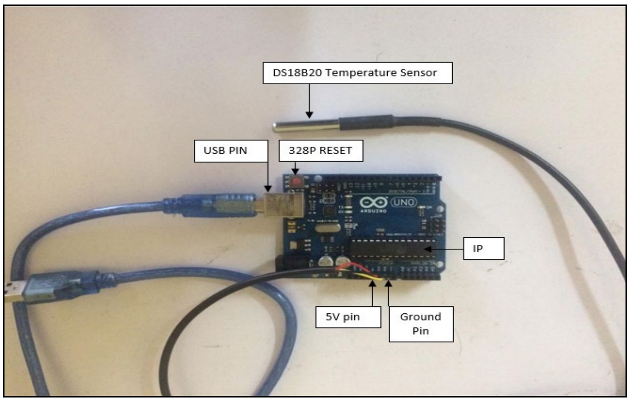

Fig. 3: The assembling of DS18B20 Temperature Sensor

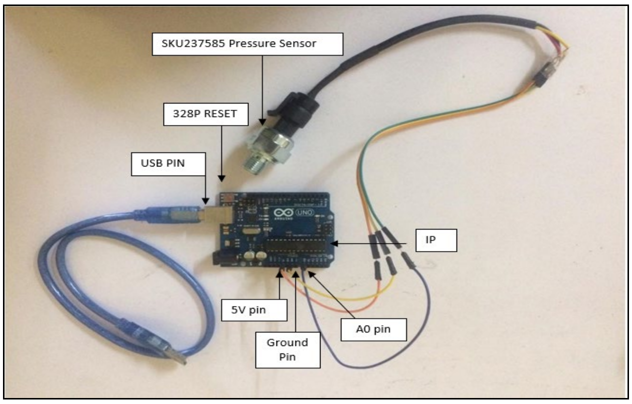

Fig. 4: The assembling of SKU237585 Pressure Transducer Sensor

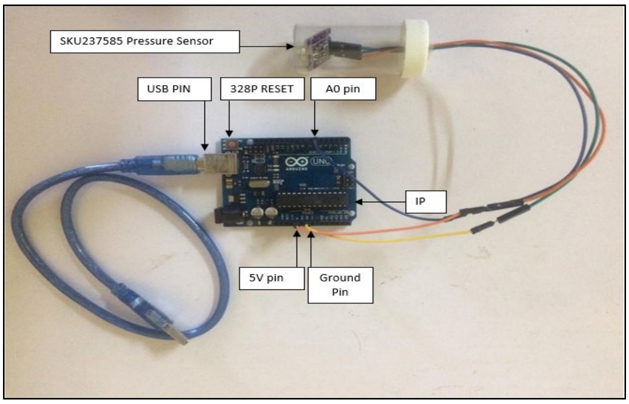

Fig. 5: The assembling of MAX 4466 Hydrophone Amplifier

C. *Testing the Sensors*

In this experiment, 50 g of sandy oil was placed inside the container. The temperature sensor was placed at the center of the container (4.5 cm). The data was taken for every 10 minutes for 90 minutes. The test was conducted for three times to estimate the average value for every temperature data collected to test consistency of the sensor. The experiment was repeated with placed the sensor at the top of the container (7.5 cm) and bottom of the beaker (0 cm). The experiment is then repeated with changed the temperature sensor with SKU 237585 and MAX 4466 Hydrophone Amplifiers and tested for 20 seconds.

III. RESULTS AND DISCUSSION

A. DS18B20 Temperature Sensors Analysis

In this experiment, DS18B20 temperature sensor was tested to determine the consistency of the sensor and near a rigid boundary. DS18B20 is used to determine the liquid temperature as it plays a dominant role in the dynamics of cavitation bubble. The temperature also influences the erosion rate as the erosion rate increases with the liquid temperature increase. In addition, the temperature of liquid also strongly influences bubbles dynamic as the maximum bubble radius and bubble life time are increased with the increased of temperature. Thus, it shows the important of liquid temperature in quantify the cavitation in liquid medium. The experiment is conducted three times at different depth of the location to determine the consistency of the sensors and to effect of temperature near to rigid boundary.

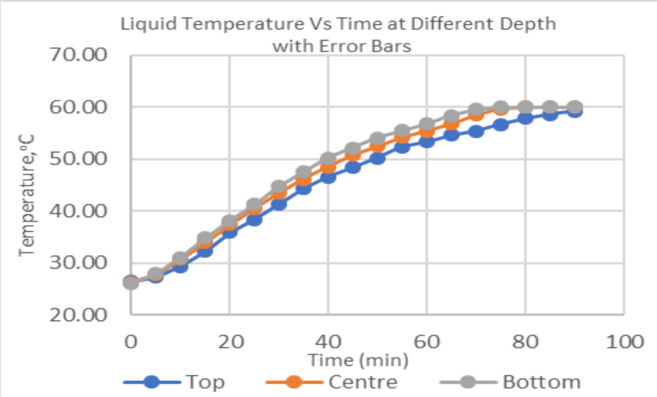

Fig. 6: Temperature of liquid medium at different depths with error bars

Based on figure 6, it demonstrates the temperature of the liquid at three different depths which is top, centre and bottom of the container throughout the 90 minutes. The relationship between the temperature and time as shown on figure above reveal that liquid temperature is linearly increasing with time until the end of this experiment. This is parallel with the study conducted by Ahmed that the liquid temperature is increases and reaches a peak followed by a decrease [3]. This is because the liquid has reached maximum energy absorption from sound wave thus also reached the ideal temperature for separation of sand and oil. However, in this experiment 90 minutes is insufficient to see the temperature drop after the plateau.

Moreover, temperature of bottom of container reach peaks which at 60°C first at 75 minutes followed by centre of container which is at 80 minutes while the top of container not reach peak of the temperature as the highest temperature at the bottom of container only reach 59.25°C. The reason the bottom of the temperature is higher compare to the temperature of centre and top of the container is because the liquid medium at the bottom of the container receive more energy transfer from absorption of sound wave [9]. The fact that the piezoelectric transducer mounted at the bottom of the container provide more energy to be received by the liquid medium at the bottom of the container. The temperature at the top of the container required more times to reach equilibrium stated consider it far to the piezoelectric transducer than other location [9].

In order to determine the consistency of the sensor, the graphs are plotted with error bars as it represents the uncertainty or variation of the corresponding coordinate of the point. This error bar can indicate the consistency of the data gained throughout in this experiment. For the temperature at the top of container, it only shows the slight difference between the sets of data as standard deviation values are between 0.05 to 0.38 which is low than 0.5. Same trend is shown by temperature at the centre and top of container as the standard deviation are below than 1% from the average data. Based on figure 6, the error bars cannot be seen on the graph as the variance is too small. As the small SD bar which shown in the graph, it shows data are clumped around the mean thus prove the data gained from DS18B20 temperature sensor gave consistent reading through 3 tests conducted.

B. SKU237585 Pressure Transducer Sensor Analysis

In this experiment, SKU 237585 was used as a pressure transducer sensor to determine the liquid negative pressure inside the modified container. Negative pressure measurement is considered as essential element in quantifying the cavitation that occurs in the ultrasonic cleaning system. This is because the explosion happens due to difference of pressure inside the bubble and negative pressure of liquid which also known as static pressure [11]. The increase of the static pressure that is over ambient temperature leads to an intense implosion of cavitation bubbles thus increase rate of separation of oil sand. Rarefactions comprise of the process pulling molecules from one another due to negative pressure is applied into liquid medium while compression involves the process of attracting molecules together as positive pressure is applied [13]. During this process, a bubble can grow as gas and vapor transported into the bubbles. Microbubbles is formed in this region as excessively large negative pressure is exerted [5]. In order to verify the consistency of this sensor, the experiment was conducted three times with three different depths. It is also essential to conduct the experiment with three different depths to verify the sensitivity of the sensor to near rigid boundary.

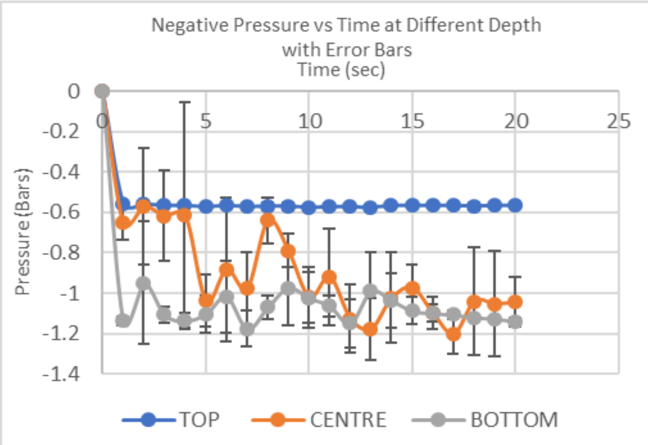

Fig. 7: Negative pressure of liquid medium at different depths with error bars

The relationship between negative pressure of liquid and time at different depths is shown in figure 7. Negative pressure, it shows that the negative pressure of liquid medium at the bottom of container is the highest followed by centre and bottom of the container. In addition, negative pressure at centre and bottom show fluctuation throughout of this experiment thus prove the formation and collapse of bubble happen at these depths. This is following the formation of cavitation due to rarefaction and compression of liquid in the medium. The cavitation continuous growing until it implodes due to pressure phase under high-pressure differentials. Based on the study by Mark Hodnett, rarefactions comprise of the process pulling molecules from one another due to negative pressure is applied into liquid medium while compression involves the process of attracting molecules together as positive pressure is applied [13]. During this process, a bubble can grow in successive cycles and reach an unstable diameter that collapse violently due to high-pressure differentials. Based on study by John Fuchs, the ultrasonic wave from the transducer will form negative pressure to liquid medium as ultrasonic wave causes lower surface tension to liquid medium Different trend is spotted on negative pressure at top of container as negative pressure graph is constant throughout of this experiment as negative pressure values maintain between -0.56 bars to -0.58 bars. Based on observation, there is no cavitation bubble formation on the top of container as occur on centre and bottom of container. This is due to negative pressure at top of container still insufficient received ultrasonic wave energy thus incapable to form bubble nucleate on the liquid medium [10]. On 10 seconds, it can clearly see that negative pressure of the centre of container lies with the negative pressure of bottom of container. It can be explained as the cavitation bubbles that form on bottom of container raised and exploded to the centre of the container. The reason the bottom of the negative pressure liquid medium of bottom of container is higher compare to the temperature of centre and top of liquid medium in the container is because activity of rarefaction and compaction the liquid medium at the bottom of the container is higher as piezoelectric transducer mounted at the bottom of the container provide more energy to be received by the liquid medium at the bottom of the container compare to others [9].

In order to determine the consistency of the sensor, the graphs are plotted with error bars as it represents the uncertainty or variation of the corresponding coordinate of the point. This error bar can indicate the consistency of the data gained throughout in this experiment. Based on figure 7, small SD bar for line negative pressure at top of container are displayed standard deviation for negative pressure at top of container are around 0.00 to 0.02 which is less than 1% of the average. As standard deviation is small enough, the error bars for negative pressure at top of container cannot been seen in the graph. Different trend shows in negative pressure line for centre and bottom of container as the error bars demonstrate large SD bar as data are more variable from the mean. This can be explained by the different volume of the dissolved gas contain in liquid that contain in three different test as dissolved gas contain also could affect the formation and collapse of the cavitation bubble [7]. The standard deviation for negative pressure at the centre of container is between 0.08 and 0.56 with the highest value is at 0.56 on 4seconds. Meanwhile, the standard deviation for negative pressure at the bottom of container is between 0.01 and 0.30 which the highest standard deviation happens at 2 seconds. The error bars in figure 7 may come from less relevant fluctuations in pressure and come from the noise on V_{rms} [9]. As the standard deviation are more than 1% from average, it can be concluded that SKU 237585 pressure transducer sensor is give inconsistent reading throughout the experiment.

C. MAX 4466 Hydrophone Sensor

In this experiment, MAX 4466 Hydrophone Amplifiers was tested to determine the acoustic spectrum of cavitation in the liquid medium with better spatial and sensitivity. Acoustic spectrum is defined as a short sample of a sound that represent the amount of vibration at each individual frequency. It is usually presented as a graph of either power or pressure as a function of frequency [10]. The power is usually measured in decibels and the frequency is measured in vibrations per second or hertz. By comparing to a reference measurement, a slight increase in high frequency signal is compared with using signal analysis to indicate the presence of cavitation [12]. In order to verify the consistency of this sensor, the experiment was conducted three times with three different depths. It is also essential to conduct the experiment with three different depths to verify the sensitivity of the sensor to near rigid boundary.

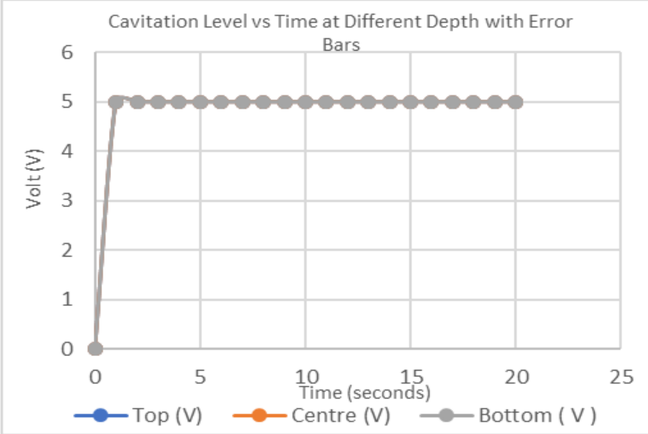

Fig. 8: Cavitation level of liquid medium at different depths

Figure 8 illustrates the relationship between cavitation level of liquid medium at different depths with error bars. It reveals that the cavitation level of top, centre and bottom at the container are constant 5 volts throughout of this experiment. It also shows the SD values are 0 for 20 seconds of this experiment. It is identified that the MAX 4466 hydrophone amplifier is insufficient enough to detect the acoustic frequency due to band width of this sensor only 600kHz. Based on the study conducted by Hodnett, measurement of the acoustic emission signal produced by bubble collapse covering frequency components between 1.5 and 5MHz. Thus, it required the sensor have gain bandwidth at least 1.5 MHz to detect acoustic frequency [13]. Eventhough MAX 4466 hydrophone give the consistent reading in this experiment, the data cannot be accepted due to the data gained is not accurate due to insufficient gain bandwidth of sensor.

IV. Conclusion

Based on this research, it can conclude that DS18B20 Temperature Sensor is suitable used in quantify the cavitation parameter in ultrasonic cleaning reactor. This is the fact that this sensor gave consistent reading as the standard deviation for both of sensors are less than 1% throughout three tests. However, SKU237585 pressure transducer sensor is unsuitable to use as it gave inconsistent reading as the variance between three tests is between 0.01 and 0.56 which is more than 1% from the average value. In addition, DS18B20 Temperature Sensor and SKU237585 Pressure Transducer Sensor also followed past studies of near rigid boundary as negative pressure and temperature of liquid medium are increased as increased in depths as receive more acoustic energy from power transducer. As DS18B20 have ran 270 minutes in this experiment, it can prove that this sensor is robust enough to apply in this ultrasonic field. However, the endurance of SKU237585 need further study eventhough it is made by carbon steel alloy as the experiment only conducted for 20 seconds. In this experiment also show that the MAX 4466 Hydrophone Amplifiers unable to collect the accurate data eventhough gave the consistent reading which is 5 volts. This is because sensor is insufficient to receive cavitation level as gain bandwidth is only 600kHz, while the normal cavitation level frequency is around 1MHz to 8.5 MHz.

Due to lack of resource, this experiment was conducted separately from one depth to another. It must be somehow affecting the result as the dissolve gas in liquid maybe different from the experiment before. Thus, it is suggested to conduct the test in these different depths in the same time. It is also suggested to test these three sensors in the same time to see the correlation between temperature of the liquid medium, the negative pressure of liquid medium and the acoustic emission signal. In order to study MAX 4466 hydrophone amplifier, the further study need to be conducted by using 10kHz to 20kHz as acoustic emission signal produced by bubble collapse is around 500kHz. However, it also suggested to use LM 321 could be used to replace the MAX 4466 Hydrophone

Amplifier in future as LM 321 have maximum bandwidth for 1 MHz for study the acoustic emission signal for 68kHz power transducer.

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