INTEGRATED ULTRASONIC-CAPACITANCE LIQUID LEVEL SENSOR

By

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

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Approved by,

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(Associate Professor Dr. Tang Tong Boon)

UNIVERSITY TECHNOLOGY OF PETRONAS

BANDAR SERI ISKANDAR, PERAK

January 2017

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

ABDUL FATAH FIKRI BIN ABD GHANI

ABSTRACT

Ultrasonic-Capacitance Integrated Liquid Level Sensors in oil storage using ultrasonic and capacitance primary objective is to propose combination of technique or system that is robust enough to measure the total liquid level and oil-water interface level in crude oil tank by assuming the clear separation between water and crude oil. In this case, a conventional capacitance oil-water interface level sensor is not robust enough to give accurate oil-water interface when the tank is not full. Plus, the conventional capacitance oil-water interface level sensor working principle ignores the capacitance of oil by assuming the total effective capacitance is equal to water level due to huge differences between oil and water dielectric permittivity. The risk of safety issue such as overflow of tank has not been considered. The aim of a capacitance probe is to measure the oil-water interface level in crude oil tank in real time and an ultrasonic level sensor to measure the total liquid level in crude oil tank. The outcome of the project is to proof the concept of the integrated liquid level sensors being reliable to detect the total liquid level and oil-water interface level in crude oil tank. First, the modelling of the capacitance sensor consist of the concentric probe, an insulator and a measuring probe using Finite Element Method based simulator, ANSYS Maxwell. The results of the capacitance reading indicating the interface level of water in crude oil tank was obtained and the result is compared to the formula of cylindrical probe. An experiment for the capacitance sensor was done to check the reliability of the design in real life condition. Then, ultrasonic level sensor was developed to detect the total liquid level in tank. However, due to cost and time restriction the experiment was scaled down in lab scale size and was done in a glass beaker instead of a tank. The experiment conducted and the ultrasonic level measurement shows reliable reading and linearity of the total liquid level. The data from both sensors was calculated to determine the total liquid level and water-oil interface level in the beaker.

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Furthermore, a very special note of thanks to my dedicated supervisor, Associate Professor Dr. Tang Tong Boon, who has always keep motivating me and been willing to spend his time in assisting me and provided good support since the start of the project to the end of the completion. Through the discussions with my supervisor, I have attained numerous share of insight and inspiration on the different aspects to be assessed for this project to become feasible. His excellent support, motivation, patience and effective guidance have brought a great impact to my project.

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Level measurement is very essential element in plant process control. Level is one of the element that always be monitored either for safety or inventory purpose other than flow, pressure and temperature. To guarantee the integrity and productivity of process, the key is to be furnished with instruments, giving dependable and exact estimations of level. At the fundamentals of level estimation, it is basically about deciding the position of a surface inside a tank, reactor or other vessel. All the more unequivocally, level estimation is the determination of the straight vertical separation between a reference point that more often than not is the base of a holding container and the surface of either a top of a solid, or the interface of two liquids. Exact control of the level of liquid in a tank, reactor, or the vessel is essential in numerous process applications.

Level measurement is regularly utilized for inventory management. To give great control, exact estimation is crucial and a few devices or systems are accessible for measuring liquid level. Each is intended to give an exact level measurement, in spite of the fact that measurement accuracy and standards of operation change among devices. Every single level measurement includes association between a detecting device, component, or framework and an item inside a holding compartment.

The level is additionally measured for safety reason. Filling vessels over their abilities can bring about security peril spills (flooding) in an open vessel. In the event that the vessels are holding acidic, responsive, hot, combustible, or unsafe materials, spills or overpressure could prompt cataclysmic results. Checking levels in tanks to ensure they are not spilling is exceptionally pivotal for the same sorts of perilous materials. Anticipating packs and break discovery is likewise imperative for meeting natural regulations [1].

In oil and gas industry, there are basically 3 types of liquid can be found which are water, heavy crude and light crude (condensate). Other than that it is only gas. Different liquid has its own characteristic and the most important point is different liquid have different dielectric constant. The dielectric constant is very crucial as few of instruments are using dielectric constant of the liquid to calibrate their instrument. One of the examples is capacitance type level sensor. For capacitance type level sensor, the design of the sensor itself is influenced by the liquid that the sensor need to tackled with. For example, if the capacitance type level sensor need to be used in a vessel containing water, the probe of the sensor need to be insulated. This is because the conductivity properties of water will form an electric short circuit from the tank to the measuring probe [2].

An example of level measurement application is in three phase separator vessel. The function of the three phase separator as shown in Figure 1 below is to separate the water and the condensate using weir [3]. The mixture of condensate and water will go into the vessels from the left. Due to the different density value, the water with higher density will settle to the bottom and condensate with lower density at the top forming the interface. The condensate at the top will flow over the weir to the right side of the vessel but the water will remain at the left side. Level sensor are used to monitor the water and to control the water from flowing over the weir and mix with the condensate.

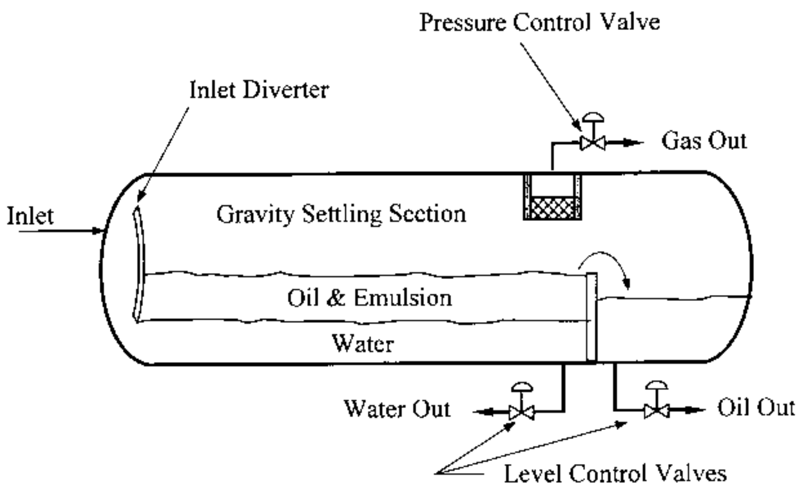

Figure 1 Three Phase Separator Vessel

The usual crude oil separators process is occurred in the large separator tanks with the objective to separate crude oil from all foreign substances that come together from the oil such as water, sand and gas. Most raw petroleum separators depend on gravity detachment and the partition procedure takes quite a while, contingent upon the extent of the vessel, type and amount of the oil. To make proficient utilization of the separators, it is critical to comprehend what is going on within the separator. As an example, it is vital to screen the separation procedure and to quantify the levels of multi-interfaces between various materials, for example, oil-water and water-sand.

One of the example is guided wave radar using microwave to detect oil-water interface and total liquid level. However, the method is limited when the emulsion of the liquid gets too thick and caused loss of signal in the emulsion and expensive [4]. Ultrasonic based level measurement on the other hand is proved to be a cheap method to detect the total liquid level but do not have the capability to pinpoint the interface level of the liquid in tank. This is due to loss of soundwave signal in liquid [5]. Another cheap method to detect interface level of liquid in tank is capacitive based level measurement. The method depends on the dielectric properties difference of the two liquid. This method is cheap and reliable though the method itself can only detect emulsion level but not the overall level of the liquid in tank.

1.2 PROBLEM STATEMENT

One of the common methods used for oil-water interface level detection is the capacitance based liquid level sensor. However, capacitance based liquid level sensor alone is not accurate enough to give accurate oil-water interface when the tank is not full. This is because capacitance liquid level sensors can only pinpoint the oil-water interface level and not the total liquid level in the tank. Thus, the capacitance based interface level sensor can only be calibrated when the tank is full. Moreover, the conventional capacitance oil-water interface level sensor working principle ignores the capacitance of oil by assuming the total effective capacitance is equal to water level due to huge differences of capacitance gain. This causes error in reading and increases the risk of safety issue such as overflow of tank. Hence, alternate or new technologies were evaluated to resolve this problem. This paper show an integrated version of ultrasonic and capacitance method level sensor to measure the total liquid and oil-water interface level in the tank [6].

1.3 OBJECTIVES

The objective of this project basically is to resolve the problem regarding capacitance based liquid level sensor in measuring the total liquid and oil-water interface level in a crude oil separator. Several experiments and simulation were conducted to check the functionality and adequacy of the technology "Integrated Level Measurement" in dealing with accurate level measurement in all process condition.

Below are the objectives that need to be achieved for the project in order to resolve the level measurement problem in tank:

1. To study the proposed ultrasonic-capacitance integrated level measurement in detecting and giving stable oil-water interface and total liquid level measurement.
2. To increase the accuracy of conventional capacitance oil-water interface level sensor by combining the level measurement by the principle of ultrasonic and capacitance.

1.4 SCOPE OF STUDY

The scope of the study is only limited to conventional ultrasonic and capacitance sensing system only. The other techniques will be considered as reference or guide to measure the overall and oil-water interface liquid level will also be studied in this project. The scope of study consists of scheduling planning for the work that needs to be done in executing the project successfully. This project needs to be completed using all available resources, time and knowledge that can be acquire within the 28 week time. Experimentation will took more time as a lot of steps need to be followed before the experiment can be executed. Thus, time management is a high priority in completing the project. Thus, analyzing of information and functionality of the existing technology will also be done. Information that has been analyzed is obtained within various sources. Direct level and indirect level indirect measurement method will be studied. Both direct and indirect level measurement methods advantages and disadvantages will be compared and tabulated. Moreover, analyzing of information and functionality of the integrated technology (capacitance and ultrasonic level measurement method) will be analyzed. The capacitive level measurement method will be first simulated using Finite Element Method based software, ANSYS Maxwell. This is to make sure the designed probe is capable of indicating the interface level of the process material. Next, the capacitance probe will be fabricated and undergo experiments to test reliability of the probe itself. After that, ultrasonic level sensor will be fabricated to test the reliability of the sensor to detect the overall level in the tank. Due to cost and time constraint, the experiments will be limited to non-metallic and lab size glass beaker.

CHAPTER 2 LITERATURE REVIEW AND THEORY

2.1 DIRECT AND INDIRECT LEVEL MEASUREMENT

Direct level measurement method measures the height above zero point and mainly used for small and slow process condition for an example sump tanks and Bulk storage tanks. Direct method is simple to use, reliable, low cost and suits well in hazardous area. Below are the examples of direct level measurement devices:

2.1.1 DIP-STICK AND DIP RODS

The rod will be dipped into the liquid inside the vessel and will be stopped either at the top of the vessel by a protruding flange on the rod, or at the bottom of the vessel when the tip of the rod touches the end of the vessel. When the rod is withdrawn, the wet or dry interface can be clearly seen and the level determined from a scale on the rod [7]. Figure 2 below shows few of the types of dipsticks and dip-rods.

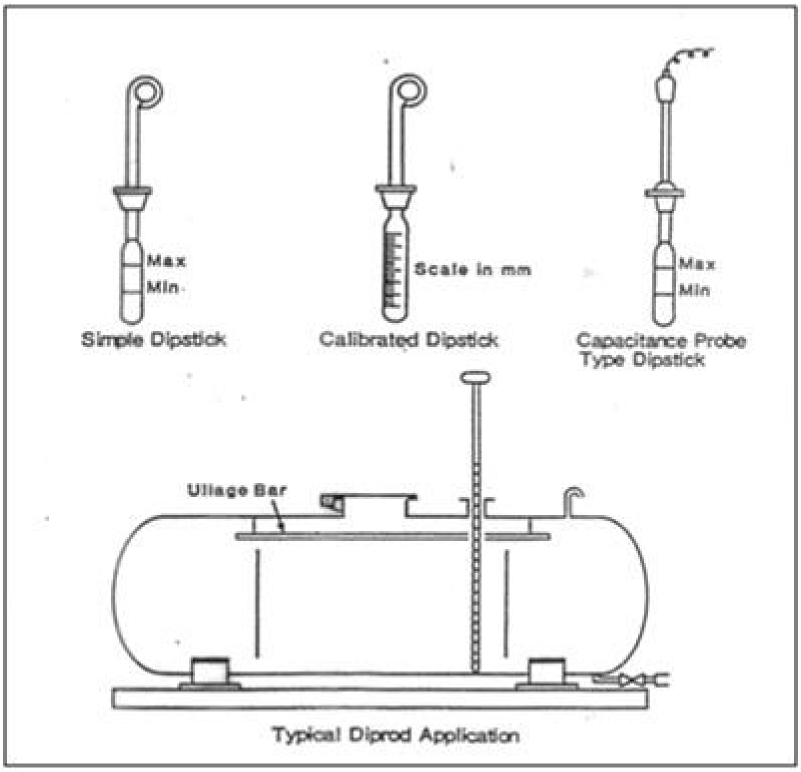

Figure 2 Dipsticks and Dip rods [8]

2.1.2 WEIGHTED GAUGE TAPE

Weighted gauge tape is similar with dipstick and dip-rods technology but the only different is weighted gauge tape will be used in on a deep vessels and tanks where a solid rod would not be appropriate. Figure 3 below shows the weighted gauge tape level measuring method.

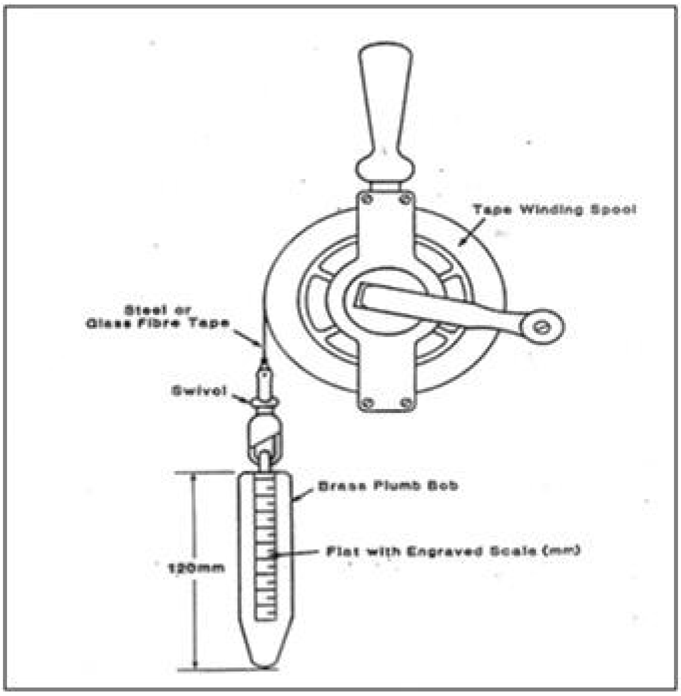

Figure 3 Weighted Gauge Tape [8]

2.1.3 SIGHT GLASS

There are various types of sight glass, the most common types being used are the flat glass tubular (or reflex).Reflex sight glasses, as illustrated in Figures 2.3 below, consists of a single glass with cut prisms. Light is deflected from the vapor portion of the column and is shown generally as white colour. Light is absorbed by the liquid portion in the column and is shown generally as a dark colour. They are used mainly for non- corrosive, non-toxic inert liquids at moderate temperatures and pressures. The tube is made of glass or transparent plastic and must be rated for the operating pressure of the vessel [9].

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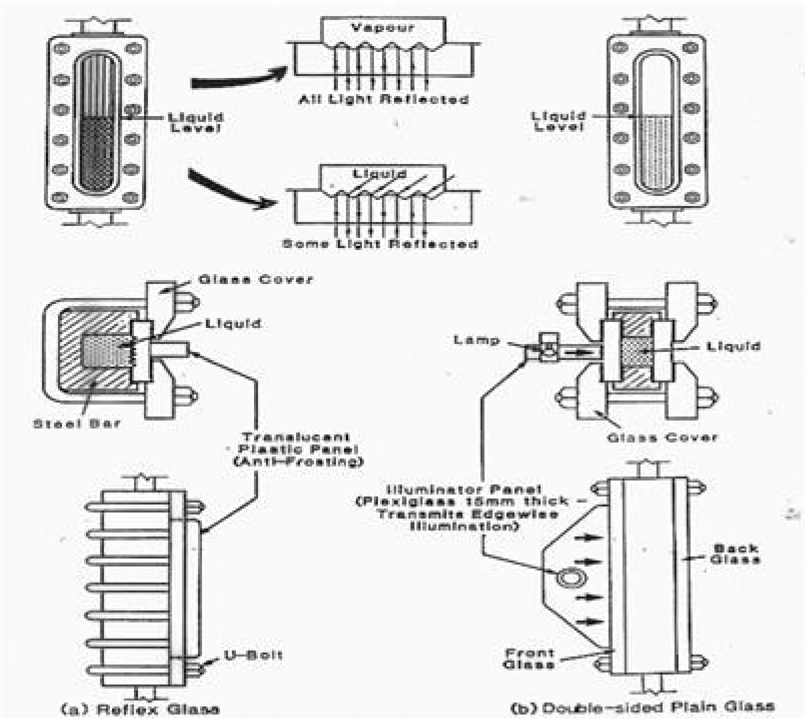


Figure 4 Reflex Sight Glass

2.1.4 FLOATS

Floats give a direct readout of liquid level when they are connected to an indicating instrument through a mechanical linkage. A simple example of this is the weighted tape tank gauge, as illustrated in Figure 5 in the following page [8].

The position of the weighted anchor against a gauge board gives an indication of the liquid level in the tank. The scale of the gauge board is in reverse order for an example the zero level indication is at the top and the maximum level indication is at the bottom of the gauge board. This is because whenever the liquid level rises, the float will move upward accordingly because of its buoyancy characteristic and this will cause the indicator at the gauge board will move downward. Hence, the zero level will be on the topside of the gauge board and maximum level will be of down side of the gauge board.

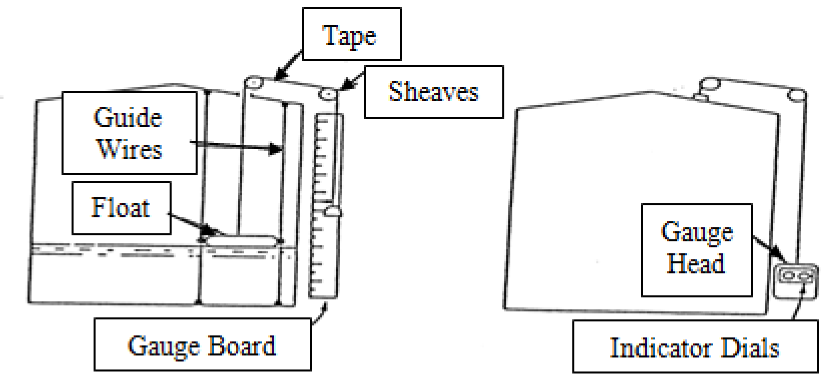


Figure 5 Weighted Tank Gauge using Float Type [8]

2.2 INDIRECT LEVEL MEASUREMENT

For the indirect level measurement the changes in the liquid surface position are used to determine the level with a reference line. It can be used for low and high levels measurement where the direct method is impracticable.

2.2.1 RADAR LEVEL MEASUREMENT

Radar level sensor measure the travelling time of radar wave from emitter to the targeted liquid and reflected back to the transceiver. This measured travelling time is then converted as distance indicator or liquid height. It is very similar to the working principle of ultrasonic sensor. The difference is the radar level sensor uses radar wave which is electromagnetic wave while ultrasonic level sensor uses sound wave which is a mechanical acoustic wave. Moreover, radar level sensor has higher frequency when compared to sound wave. Some radar level sensor use waveguide “probes” to guide the electromagnetic waves to and from the targeted liquid which capable of detecting interface of liquid-liquid interface level and overall liquid level. Figure 6 portrays the difference between guided-wave radar and non- contact radar [10].

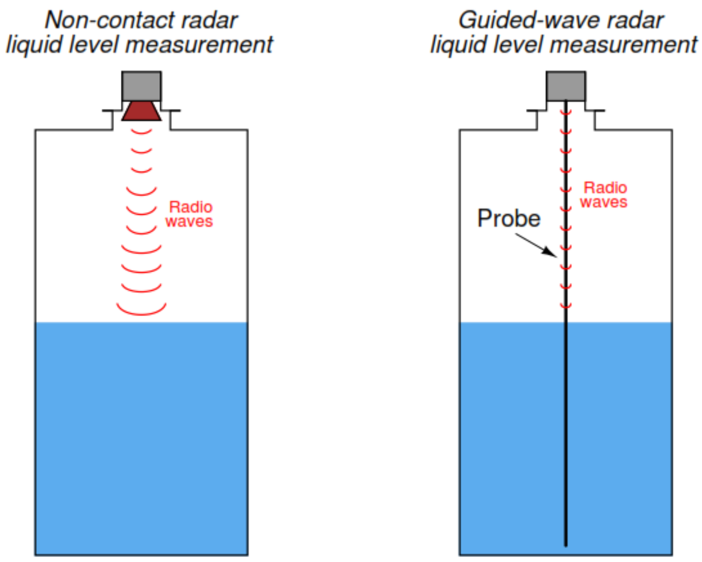


Figure 6 Radar Wave Level Measurement Sensor

2.2.2 CAPACITANCE LEVEL MEASUREMENT

The working principle of capacitance level measurement is assessing the capacitance of two electrical conductive material (metal rod and tank wall) in contact with the process material. The greater the amount of liquid in the tank, the higher the capacitance output of the sensor. Capacitive level probes can operate in conductive and nonconductive liquid depending on the designs. In capacitive level measurement, the design of the probes is classified as a crucial factor to operate in good accuracy. Formula 1 shows the calculation of capacitance [2]:

$$C = \varepsilon_0 \frac{A}{d} \quad (1)$$

Where,

C = Capacitance

ε_0= Permittivity of dielectric (insulating) material between electrodes

A = Overlapping area of electrodes

d = Distance between electrodes

Figure 7 below illustrates how capacitance probes system operates:

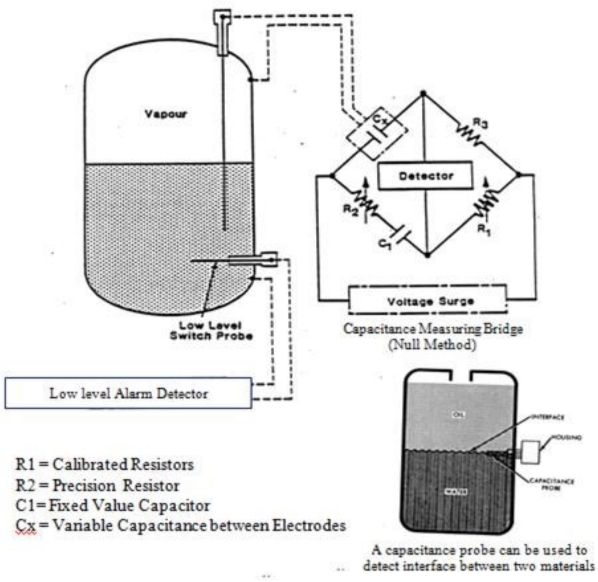


Figure 7 Capacitance Probes Systems

2.2.3 ULTRASONIC LEVEL DETECTION SYSTEM

Ultrasonic level sensor is a continuous-level measurement works on the principle of sending wave from a piezo-electric transducer to the contents of the vessel. The sensor will measures the time taken for the reflected sound wave (echo) to return to transducer and the distance is calculated as the product of one-half the flight time and the speed of sound. Successful measurement of the ultrasonic measurement depends on reflection from process material in a straight line back to transducer very similar method as radar sensors to measure level. Unlike the speed of light, the speed of sound is temperature dependent, so the temperature of the tank must also be measured and taken into account. Ultrasonic sensor can also be used to measure liquids, slurries, and granular solids. Process materials that produce a stronger sonic reflection are more applicable to this type of measurement [4].

Among the advantages of ultrasonic level sensor it is unaffected by product density, conductivity or dielectric constant. Furthermore, it does not consist of moving part and is a non-contact device with the process material. Plus, it is single top vessel entry thus leakage is less probable. However, ultrasonic level measurement has disadvantages which in applicable to vacuum and very –high pressure application approximately 45 psig and above. Moreover, return wave may be affected by heavy vapor, powder or particles, surface turbulence and ambience noise. Condensation, dust buildup, and presence of additional objects within the tank can all cause measurement inaccuracies [5].

Figure 8 below illustrates how ultrasonic level detection system operates:

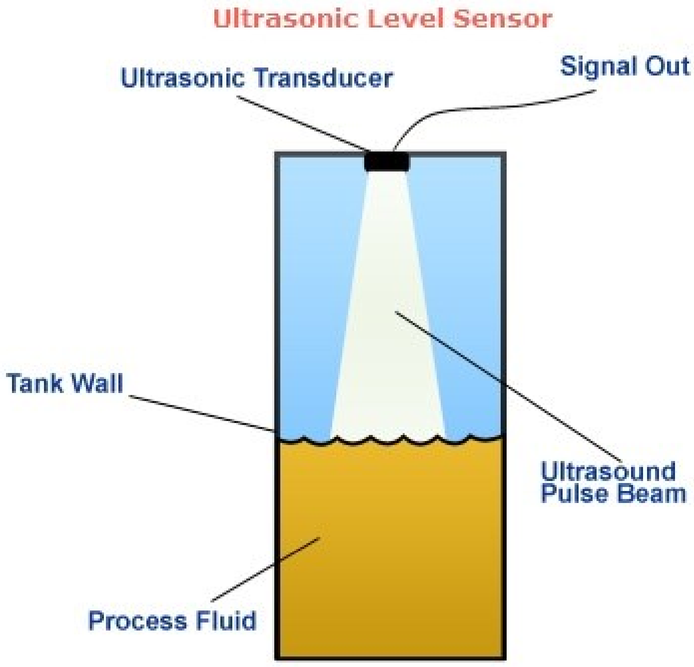


Figure 8 Ultrasonic Waves level detection system

Table 1 below shows the comparison in terms of advantages and disadvantages of all the level measuring methods mentioned above by referring [11-15]

Table 1 Advantages and Disadvantages of Level Measurements Method

Level Sensing Method	Advantages	Disadvantages
Floats	• Low Cost • Indicators easy to read from a distance. • Customizable for different applications. • Low cost. • Easy to install. • Simple to operate.	• Prone to corrosion if liquids and materials are not compatible. • Build-up of material on the float causes changes in weight displacement. • Can only be used with non-freezing fluids.
Dip Stick	• No moving parts to clog or wear. • No electronics to fail.	• Must be used properly to give accurate reading. • Each measurement requires person to perform time-consuming operation.
Sight-Glass	• Very simple for operator • Low cost	• Not suitable for automated control • Easily damaged • Need frequent maintenance for cleaning
Ultrasonic	• Under most conditions, the unit out of contact with process material, avoiding contamination and corrosion. • No moving parts • Low maintenance cost • Unaffected by different dielectric.	• Dense vapour, dust, and foam can affect the most advance devices. • Temperature must not exceed 150°C (300°F). • Pressure must not exceed 8 bar (116 psi).
Wave Radar	• Unaffected by temperature changes, dielectric constant changes of process material and vessel shape • Non- contact	• Expensive • Uses high input power sources • Danger to flammable liquid
Capacitance	• No moving parts. • Compatible with vast range of liquids, powders, and granular solids. • Compatible with vast range of vessel shapes. • Relatively low cost compared to other electronic measurement methods.	• Rely on uniform contact being maintained between liquids or solids and electrode. • Must be careful to select correct electrode for application

Based on Table 1 the most suitable and efficient methods to achieve the objective is capacitance and ultrasonic based liquid level sensors.

2.3 CAPACITANCE

In its basic form, a capacitor consists of two or more parallel conductive (metal) plates which are not connected or touching each other, but are electrically separated either by air or by some form of a good insulating material such as waxed paper, mica, ceramic, plastic or some form of a liquid gel as used in electrolytic capacitors. The insulating layer between a capacitors plates is commonly called dielectric.

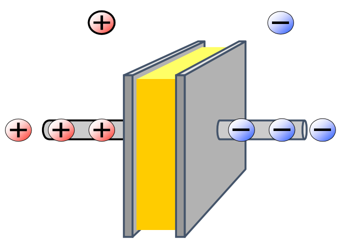


Figure 9 Basic Form of Capacitor

Due to this insulating layer, DC current cannot flow through the capacitor as it blocks it allowing instead a voltage to be present across the plates in the form of an electrical charge.

2.3.1 CAPACITANCE OF A PARALLEL PLATE CAPACITOR

The general equation for the capacitance of a parallel plate capacitor is as shown in formula 2.

$$C = \frac{\varepsilon_0 \times \varepsilon_r \times A}{d} \quad (2)$$

Where,

d =distance between the electrodes

A=dimensions of the electrodes

ε_r=dielectric between the electrodes

ε_0=electrical field constant, which is 8.84 x 10^{-12} Farads per meter

ε_r=permittivity, dielectric constant

Generally, the conductive plates of a capacitor are separated by some kind of insulating material or gel rather than a perfect vacuum. When calculating the capacitance of a capacitor, permittivity of air is considered the same as vacuum as both of the value are very close.

Based on the formula 2, there are three main factors influencing the capacitance which are the distance of electrodes, dimensions of electrodes and dielectric material between the electrodes. Figure

2.4 CAPACITANCE BASED LIQUID LEVEL SENSOR

2.4.1 TYPES OF LIQUIDS

In capacitive measurement electrically conductive liquid and non-conductive liquids are differentiated. Non-conductive and clean process material such as hydrocarbons can be measured by conventional and enhanced capacitance system given that these materials have stable dielectric constants. Figure 10 shows an example of capacitance measurement of a non-conductive liquid using measuring probe as the first electrode and tank wall as second electrode.

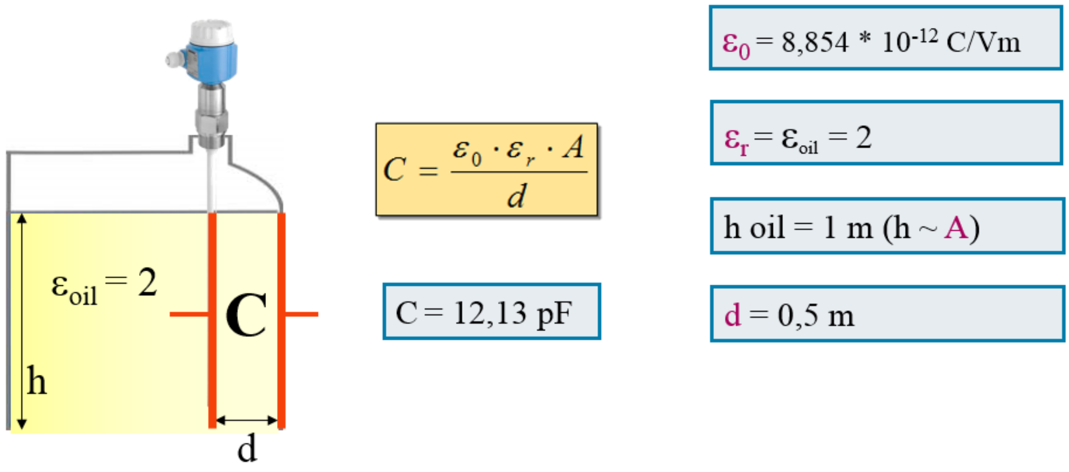


Figure 10 Example of capacitance measurement of a non-conductive liquid

Examples of non-conductive material is petrol, oil, solvents, hydrocarbon, pure alcohol and distilled water. Changing of the dielectric constant has proportional influence to the measurement value.

Next, measurement in conductive liquid which are normally water based liquids are carried out as follows. The medium form an electric short circuit from the tank to the probe insulation. Therefore, the measurement effect is only form by the probe insulation capacitance gain from the medium. This provide stable measurement which is independent of the tank geometry and the dielectric constant of the medium. If the level rises in the tank, the area of the capacitor increases proportionally. The measured capacitance change is used to determine the level. Moreover conventional capacitance functions admirably with conductive materials on the term of zero probability that a conductive covering may develop on the detecting probe. When we are managing conductive process materials, the detecting probe is constantly secured with an insulating sheath. The conductive procedure material couples the metal vessel wall (or other appropriate ground) specifically to the test sheath (Fig 2). Since the probe sheath is constant for a given installation, the system reacts indistinguishably to every conductive material. This makes capacitance a fabulous technique to measure the level of conductive process materials[16]. Figure 11 shows an example of capacitance measurement of a conductive liquid.

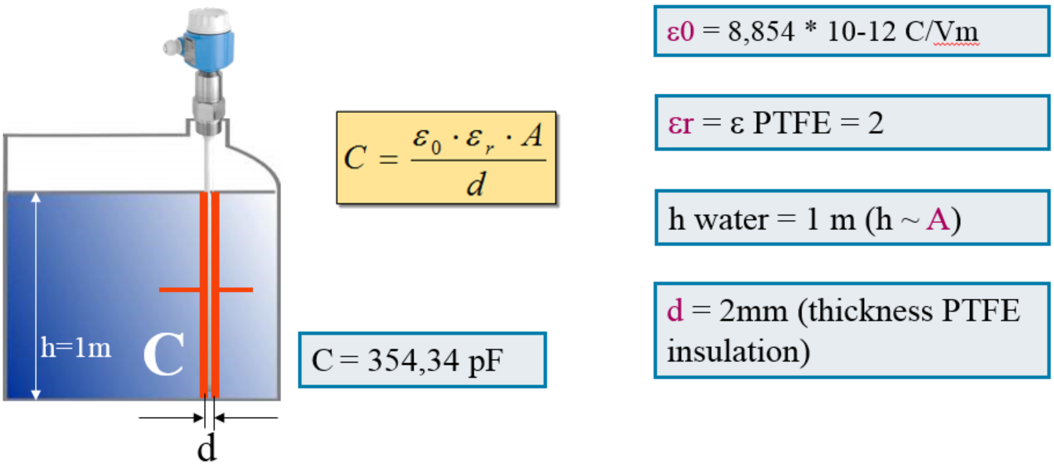


Figure 11 Example of capacitance measurement of a conductive liquid

Examples of conductive liquids are water base liquids, acids and lye, beverages and emulsion. Changing of the dielectric constant and conductivity of the liquid has no influence to the measurement value.

2.4.2 OIL-WATER INTERFACE LEVEL MEASUREMENT

As shown in Figure 10 and Figure 11, there is huge differences in capacitance reading of a conductive and non-conductive liquid. In multi-phases liquid tank consisting of water and oil, the capacitance reading is combined. Due to huge differences mentioned, the total capacitance is assumed equal to the interface position. Figure 12 shows an example of oil-water interface measurement using capacitance.

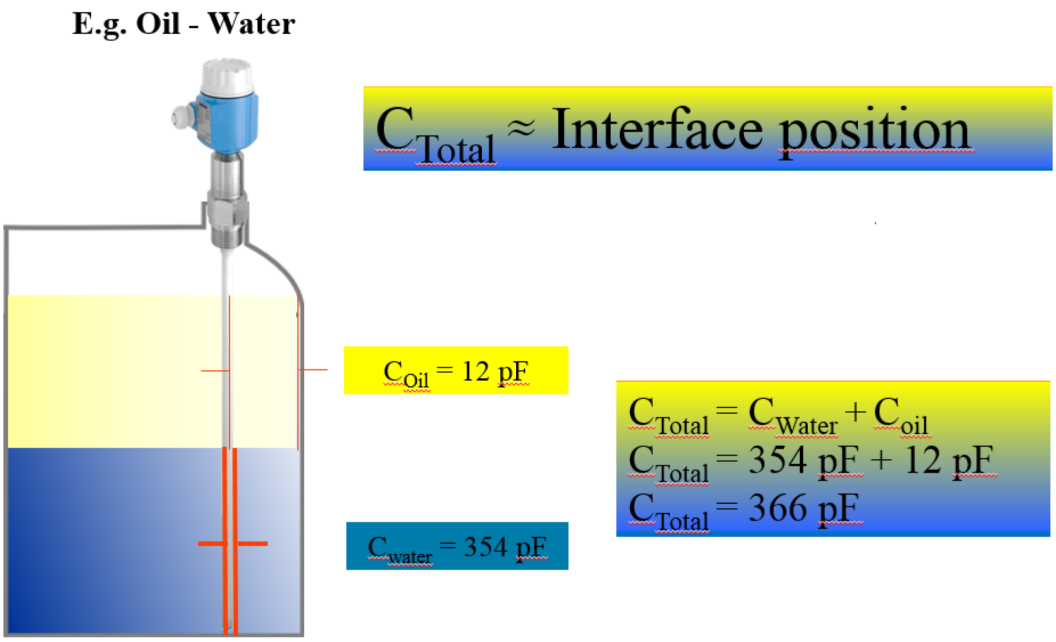


Figure 12 Oil-Water Interface Level Measurement

However, due to the assumption, insignificant measurement error for interface evaluation caused by varying oil layer on top of the water.Figure 13 illustrate the measurement error for interface evaluation.

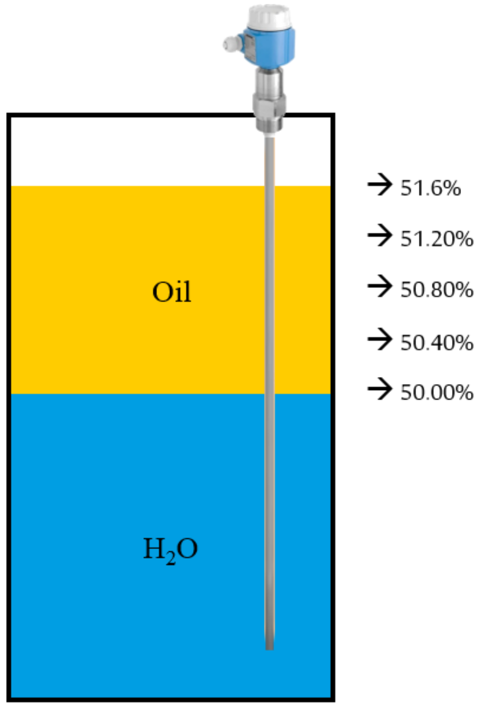


Figure 13 Error in Conventional Capacitance Oil-Water Interface Level Measurement

Thus, another sensor is needed to determine the total liquid level in the tank. Based on table 1 ultrasonic sensor is the best alternatives to integrate with the capacitance level sensor.

2.4.3 DESIGN OF CAPACITANCE ELECTRODES

The conductive metal plates of a capacitor can be either square, circular or rectangular, or they can be of a cylindrical or spherical shape with the general shape, size and construction of a parallel plate capacitor depending on its application and voltage rating.

For capacitance based liquid level sensor, a cylindrical shape is commonly used to measure the capacitance changes in tank. In theory, the value of capacitor for cylindrical conductor or probe can be determined by assessing the voltage difference between the conductors for a given charge on each conductor. Thus, from the definition of capacitance and including the case where the volume is filled by a dielectric of dielectric constant k, the capacitance per unit length is defined as shown in Equation 3 and Figure 14 [17].

$$\frac{C}{L} = \frac{2\pi k \epsilon_0}{\ln\left[\frac{b}{a}\right]} \tag{3}$$

Where,

C = capacitance of cylindrical

L= length

k = dielectric constant of liquid

ϵ_0= dielectric constant of air

b = outside diameter of probe

a = inside diameter of probe

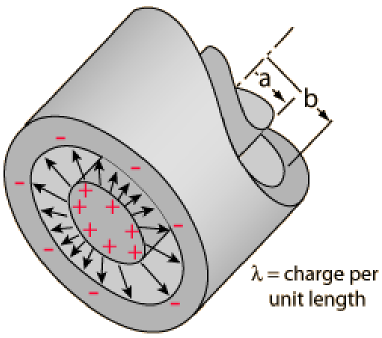


Figure 14 Cylindrical Capacitor

Concentric tube designs or outer probe are ideal for non-linear tank shapes such as spherical or horizontal (also apply to big container tanks). If the reference plane is not parallel to the primary capacitor plane an offset as shown in figure 15. In terms of tank geometry, the concentric tube are predominately used which represent a defined geometry and additionally it can increase the measurement affect by small plate distances.[18]

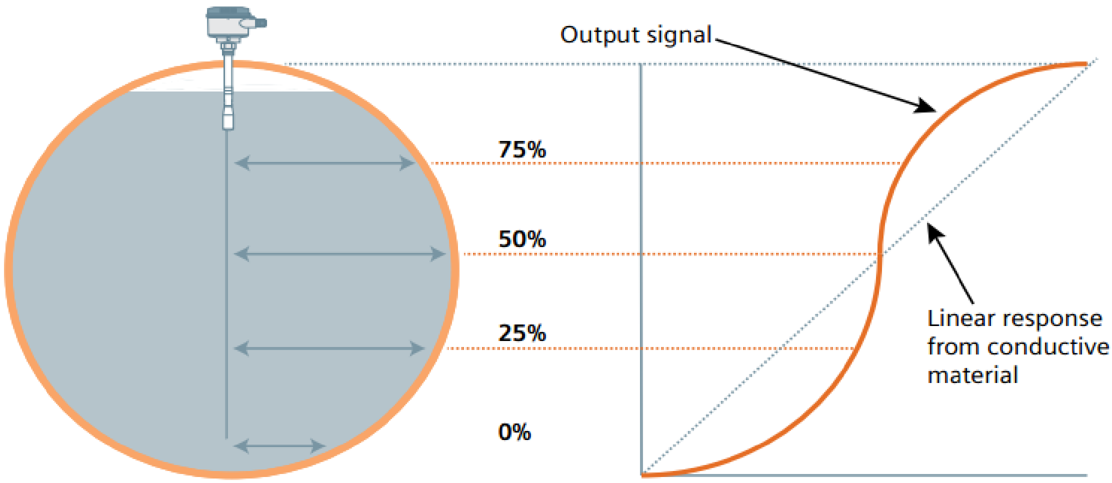


Figure 15 Concentric tube effect on capacitance measurement.

2.5 ULTRASONIC LEVEL MEASUREMENT

An alternative method of measuring liquid level in tank is to measure the travelling time of ultrasonic wave emitted and receive back by a transceiver. With the travelling time (time delay) is known, the data can be used to calculate the distance thus height of the liquid in a tank. Ultrasonic level sensors enjoys the merits of not affected by inconsistency of liquid density compared to hydrostatic and float level measurement. Ultrasonic level sensor principle is fundamentally the same when compared to echo meters which had been used for measuring the depth of wells.[19]

In terms of design, ultrasonic sensor varies in terms of the speaker (source of ultrasonic wave) and receiver (receive the reflection of the ultrasonic wave from the targeted liquid) being packaged separately and packaged as a single unit. While in terms of position, ultrasonic sensor being mounted varies either being mounted above or below targeted liquid and inside or outside the tank. These mounting locations have their perspective merits and verdicts. First, mounting the ultrasonic sensor above targeted liquid (inside tank), travelling through air space of tank enjoys merits of non-contact with the targeted liquid which means the reliability of ultrasonic level measurement is unaffected by inconsistency of electrical conductivity, density, moisture content and dielectric constant of the targeted liquid. However, the mounting position suffers from energy loss during travel time through air space of tank. Second, mounting the ultrasonic at the bottom of targeted (inside tank) enjoys merits of better accuracy liquid level measurement due to lower energy loss during travel time while suffers error if the targeted liquid is sticky and damaged if the liquid is corrosive. Third, mounting the ultrasonic sensor at the bottom of targeted liquid (outside tank) enjoys merits of non-intrusive level measurement. Figure 16 below shows some of the common designs and possible mounting location of the ultrasonic sensor [8].

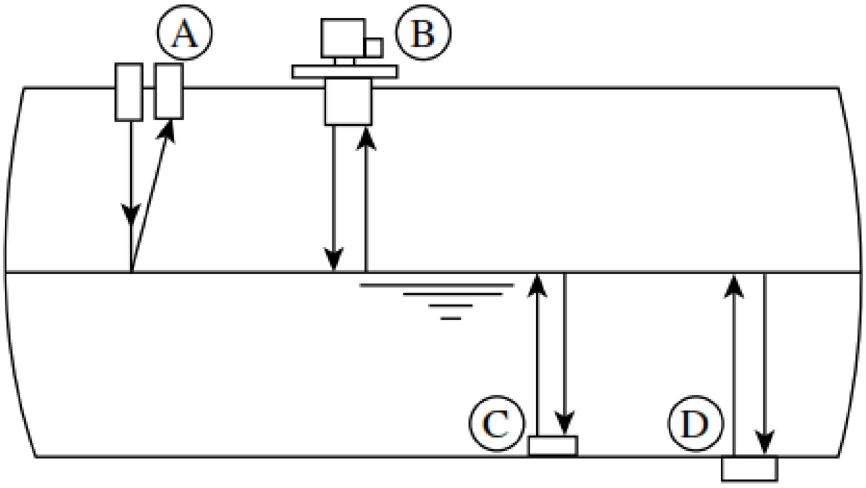


Figure 16 Common Designs and Possible Mounting Positions of Ultrasonic Sensor

When constructing an ultrasonic level sensor, there are three crucial factors that affects the accuracy of ultrasonic level sensor. The three factors are speed of ultrasonic wave, ultrasonic beam width and dispersion or absorption of ultrasonic wave. The first crucial factor is wave propagation speed emitted by the ultrasonic sensor traveling to the targeted liquid and back. Therefore, the consistency and stability of ultrasonic wave propagation speed is fundamental to the accuracy of ultrasonic level measurement. By using formula 4 the distance of ultrasonic sensor and liquid surface is known thus can be converted into level measurement based on the measured distance.

$$Distance = \frac{Speed\ of\ Sound\ In\ Air\ \times Time\ Delay}{2} \tag{4}$$

Moreover, the speed of sound through any medium is a function of density and bulk modulus (the “compressibility” of the medium), with density generally being the more variable of the two. For gases and vapours, this means the speed of sound is strongly affected by changes in gas pressure and/or gas temperature. For liquids, this means the speed of sound is strongly affected by temperature. Thus temperature compensation and automatic self-calibration are needed to increase accuracy of ultrasonic level measurement [20].

Second crucial factor affecting accuracy of ultrasonic level measurement is the beam width of ultrasonic sensor. Tank or container with too small of diameter and irregular structure inside the tank such as mixer paddles can cause the signal to bounce of tank's walls or the irregular structure could cause false readings for the ultrasonic sensor. Ultrasonic beam are naturally diverge when emitted. Two methods to reduce the divergence of ultrasonic wave is having a higher frequency emitter and a large element diameter. Figure 17 shows the illustration of ultrasonic beam angle. The beam spread is measured from the axis of the transducer to a point where the sound pressure drops to -6dB or 50%. Figure portrays a sound beam view of a flat transducer [21].

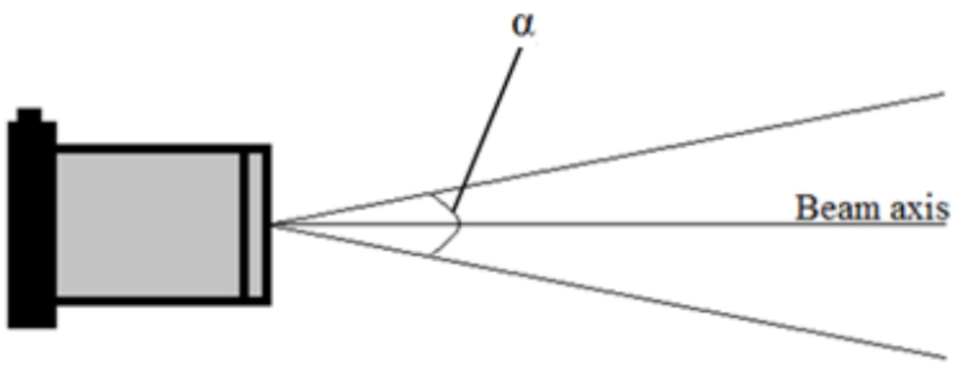


Figure 17 Beam Spread Angle of a Flat Ultrasonic Sensor

The third crucial factor affecting ultrasonic level sensing is the dispersion or absorption of the ultrasonic wave itself. Sound intensity is reduces by the square of distance which causes the dispersion of ultrasonic wave while absorption of ultrasonic wave caused by surrounding such as dry air, vapour, mist and emulsion. This is the limitation of ultrasonic sensor that needed to be consider when applying in level sensing [22].

2.6 SUMMARY OF CHAPTER 2

In brief, chapter 2 gives information about comparative study of level measurement. All commonly use level measurement methods are presented in terms of their advantage and disadvantage. However, in terms of performance and cost, capacitance and ultrasonic based level sensors proved to be the best choice. Then capacitance based level sensor working principle was studied. Starting from the basic of capacitance, effects of types of measured liquid (conductive and non-conductive) towards capacitance based sensor, capacitance based oil-water interface level measurement and the best design of probe for best accuracy and linearity. Lastly, the ultrasonic level sensors was studied. Starting from the basic of ultrasonic distance formula 4, then towards factors which affects the ultrasonic level measurement itself such as absorption of sound signal, possible mounting position of ultrasonic sensors in a tank, beam width of ultrasonic sensors, effects of temperature and air humidity to ultrasonic level measurement.

CHAPTER 3 METHODOLOGY

3.1 PROJECT FLOW CHART

Figure 18 below illustrate the flow of the project in the forms of flow chart. The flow chart is very important for the student to truly organize the plan of project to get optimum results in a very restricted time.

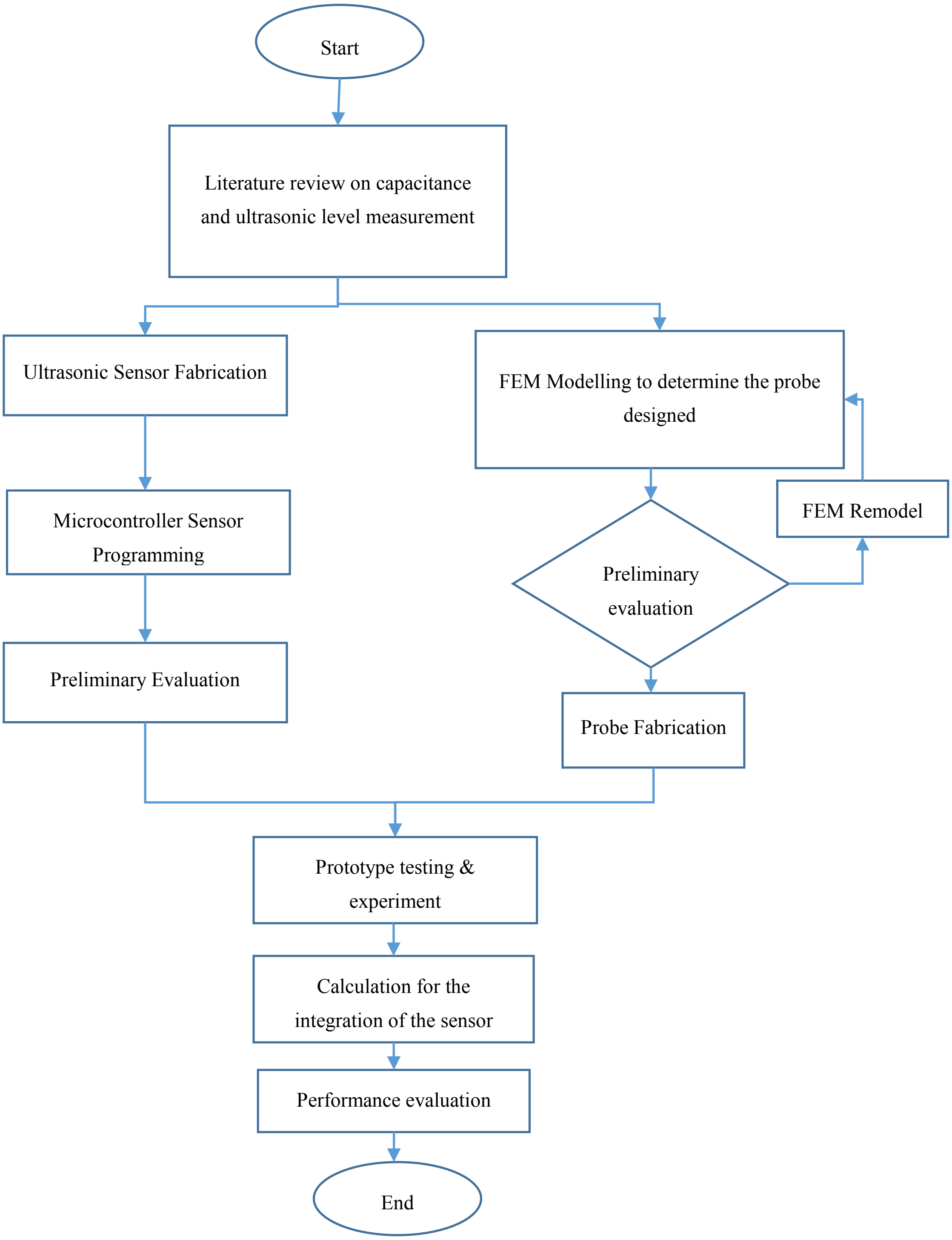


Figure 18 Flow Chart of Project

3.2 FEM MODELLING

The Finite Element Method (FEM) modelling were done using ANSYS Maxwell simulation during the early stage of the project. ANSYS Maxwell is the premier low frequency electromagnetic field simulation software for engineers tasked with designing and analyzing 2-D and 3-D electromagnetic and electromechanical devices, including motors, actuators, transformers, sensors and coils. Maxwell uses the accurate finite element method to solve static, frequency-domain, and time-varying electromagnetic and electric fields . The modelling were done and the specs of the model was as shown in the Table 2 and the Figure 19 and 20.

Table 2 Modelling Material Specifications

Equipment/Medium	Material	Relative Permittivity	Bulk Conductivity, (Siemens/m)
Crude Oil	Oil	2	0
Water	Sea Water	81	4
Tank	Mu Metal	1	161×10^4
Concentric Tube	copper	1	58×10^6
Probe Insulator	TFE based	2.08	0
Measuring Probe	Copper	1	58×10^6

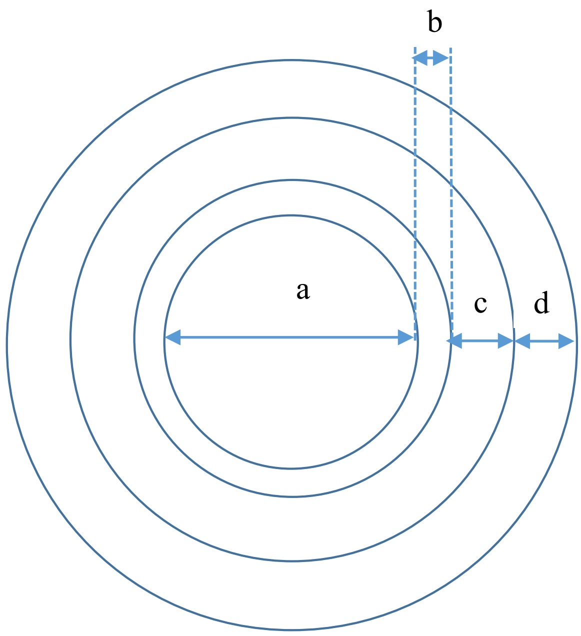


Figure 19 Top view of designed probe

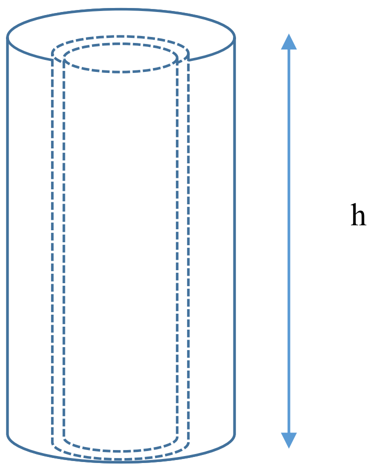


Figure 20 Front View of Designed Probe

The designed probe consist of measuring probe, insulator and outer probe. Based on Figure 19 and Figure 20, the diameter of measuring probe, a is 22 mm. Next, the thickness of the insulator, b is set to 2 mm. Then, the distance between the measuring probe and the outer probe, c is set to 42mm.The thickness of the outer probe, d is set to 20mm.Lastly the probe height, h is set to 3m same as the tank height.

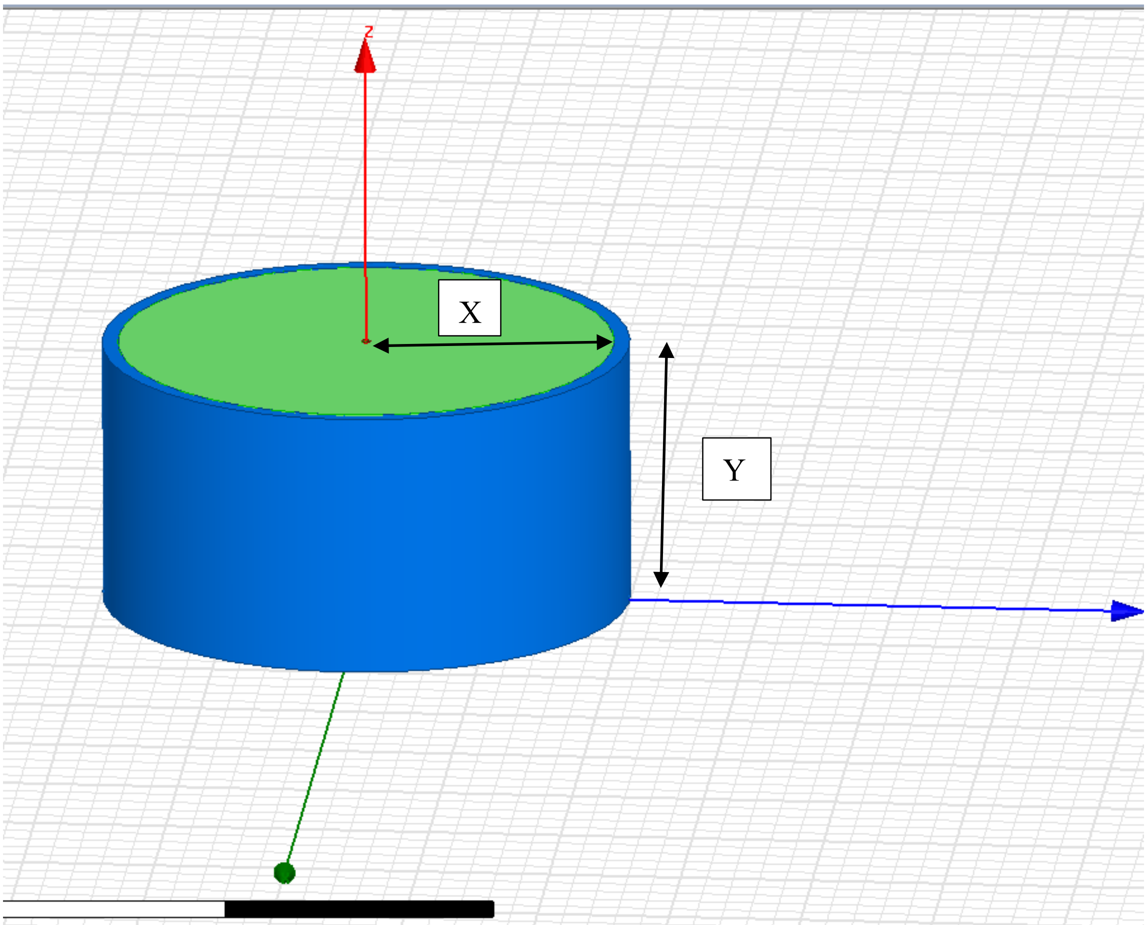


Figure 21 Tank Design

Based on Figure 21, the tank radius, X is set to 5m and the height of the tank, Y is set to 5m.

First the design of the project including the probe and the tank specifications were determined. Two capacitor electrode (one for measurement and one for references) have been carefully designed, one is the measuring probe and one is the concentric probe, simulated with ANSYS Maxwell and developed for this particular design. Each sensor made from copper. The measuring probe is mounted in the center of the tank and concentric tube surrounding it as shown in the Figure. This allow the concentric probe is used to represent a defined geometry and increase the measurement effect by small plate differences. The tank diameter was set to 10m as it is the maximum diameter of the tank which the simulation can run. The purpose of the large 10m tank is to test the effect of large diameter tank towards the reading of capacitance as conventional capacitance level measurement use tank as the reference electrode (second electrode) while the project used concentric tube to reduce the distance between the two electrodes. The height of the tank is 5m.The capacitor probe has initial capacitance of 524.3pF with pure oil as dielectric material.

The electrically conductive concentric tube and the probe inside the tank form a capacitor. The capacity changes which are used to determine the level. In capacitive measurement electrically conductive liquid and non-conductive liquid are differentiated. Measurement in conductive liquid which are normally water based liquids are carried out as follows. The medium form an electric short circuit from the concentric tube to the probe insulation. Therefore, the measurement effect is only form by the probe insulation capacitance gain from the medium. This provide stable measurement which is independent of the tank geometry and the dielectric constant of the medium. If the level rises in the tank, the area of the capacitor increases proportionally. The measured capacitance change is used to determine the level. The capacitance change in non-conductive liquid which in this project case is oil, is caused by higher dielectric constant of the medium in relation to air. The non-conductive medium forms an additional capacitance to the concentric tube connected in series. It determines the total capacitance. If the level rises in the tank, the area of the capacitor increases proportionally. The measured capacitance change is used to determine the level and increases as the level rises due to higher dielectric constant of the medium. Thus, the measurement does depends on the dielectric constant of the medium. In terms of tank geometry, the concentric tube are predominately used which represent a defined geometry and additionally it can increase the measurement affect by small plate distances.

In terms of interface measurement of oil and water, due to the great different dielectric constant of the two media. The measured capacity change of the upper medium(oil),typically the smaller conductive media is considerably smaller than the capacity change of the lower medium(water).Therefore the upper medium participate only to a minor extend of the measured overall capacity which does interpreted as an interface. The capacitance measurement provides the advantage as the measuring signal is not affected by the formation of emulsion. However the capacitance method can only determine the interface. The value for the overall level cannot be derived from a single unit.

The real capacitance equation of capacitance probe, formula 1 is used to determine the capacitance output of the capacitor sensor.

$$\frac{C_{Total}}{L} = C_{water} + C_{Oil} \quad (5)$$

$$\frac{C_{Water}}{L} = \frac{2\pi k_{insulator}\varepsilon_0}{\ln[\frac{b_1}{a_1}]}, in\ respect\ to\ insulator\ capacitance \quad (6)$$

$$\frac{C_{Total}}{L} = \frac{2\pi k_{oil}\varepsilon_0}{\ln[\frac{c_1}{a_1}]} + \frac{2\pi k_{insulator}\varepsilon_0}{\ln[\frac{b_1}{a_1}]} \quad (7)$$

Where

a_1 is the measuring probe outer diameter

b_1 is the insulator outer diameter

c_1 is the concentric tube inner diameter

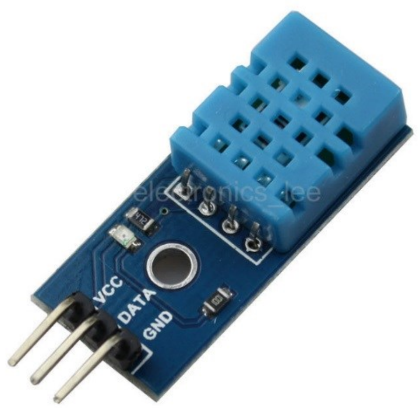
In this case the outer oil and outer water does not affect the measurement. The capacitance of the probe insulator Capacitance is dependent on the dielectric material of the insulator is a constant while the oil capacitance (Co) due to crude oil sample is proportional to the dielectric constant of the crude oil sample filling the tank. The great differences of permittivity value between the oil and water thus causing a great differences in capacitance reading between the two medium. The capacitance reading water level is significant and greatly higher than the capacitance reading of oil level. Therefore the total capacitance (Ct) is approximately equal to the interface layer of the water level as shown in formula 7.

3.3 CAPACITANCE SENSOR EXPERIMENT

As stated in literature review, capacitance level measurement working principle is the measurement of capacitance change produced by. The key to accurate level measurement is knowing the dielectric material of medium and distance between two electrodes.Due to cost and time restriction, the experiment is scaled down to lab size. Below are the table for the parts and materials used for the experiment:

Table 3 Tools and Hardware for Capacitance Sensor Experiment

Parts and Materials
1)LCR Meter 
2) Aluminium Rod and Tube  

3) PTFE Tube 
4) Glass Beaker (As Tank) 
5) DHT11 temperature and humidity sensor 

The experiment was set up in a lab with controlled temperature and humidity. The temperature and humidity of air in the lab were continuously monitored to get a better result. The temperature was kept constant at 22° C. Petrol and salt water was chosen as the measured liquids.

When dealing with capacitance sensor, there are two factors we must consider. First is the design of the capacitance probe. The distance between electrodes must be constant and not too far. Based on the literature review, using a concentric tube as the second electrodes is the best method to gain a constant distant between electrodes and a linear result. First, the measuring probe has a radius of 0.15 cm. Second, thickness of the PTFE insulator is 0.2cm. Third, the concentric tube has the radius of 1cm.

Second factor to be considered is the dielectric constant of measured liquid. The liquid measured is petrol and salt water. Both these liquids have fixed and known dielectric constant. For salt water the dielectric constant is 80 while for petrol the dielectric constant is 2.3.

The maximum height of liquid is set to 12 cm and the minimum height of liquid is 0cm (empty tank). Then, the sensor is calibrated in terms of minimum and maximum liquid level to make sure the sensor measurement always in range and accurate.

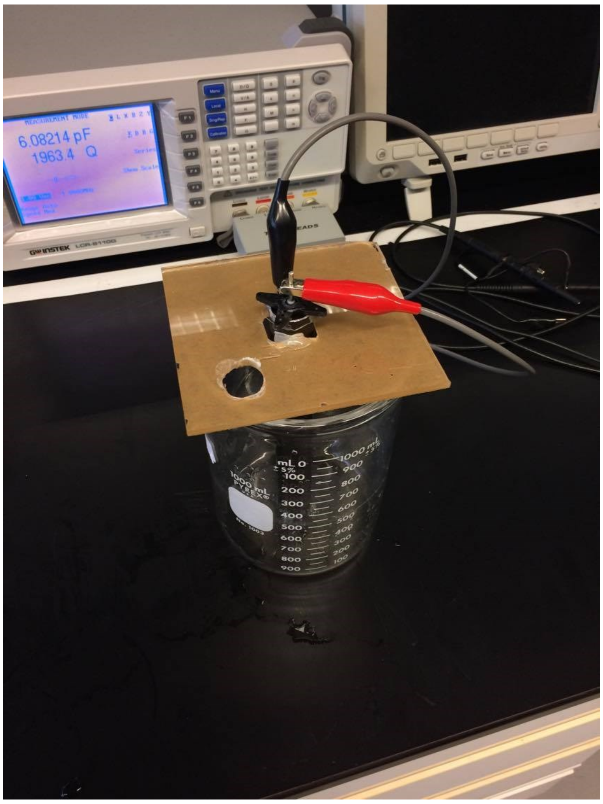


Figure 22 setup for capacitance based liquid sensor experiment

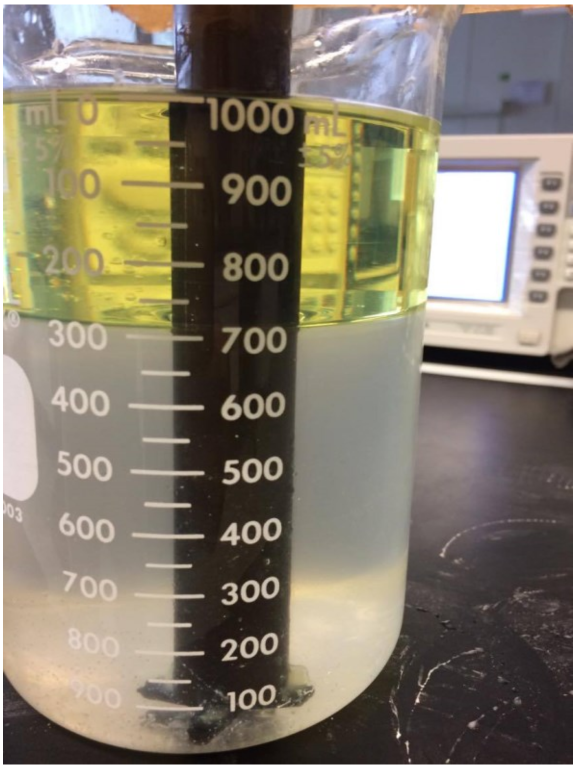


Figure 23 Clear Separation of oil and water

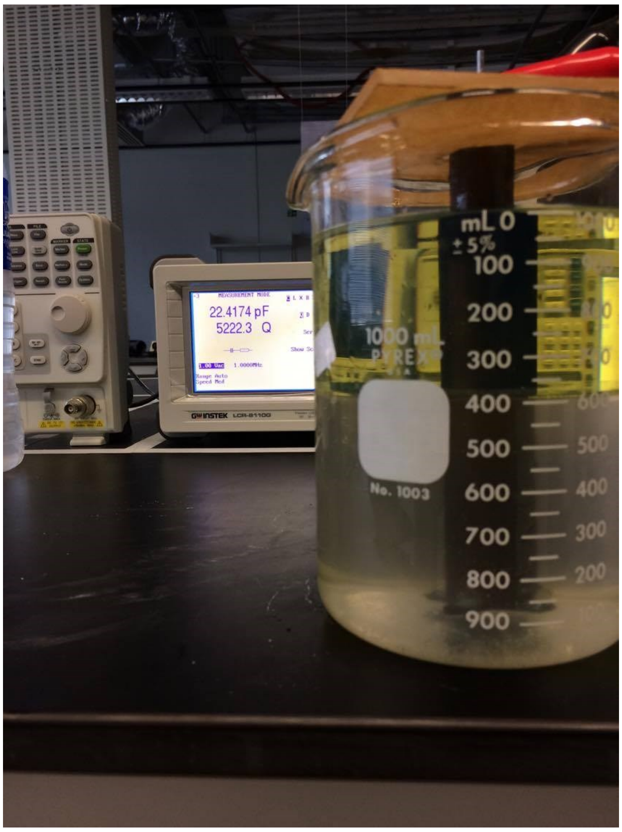


Figure 24 Example of Capacitance Reading from LCR meter

The capacitance reading is recorded and tabulated in Table 4. Formula 5, 6 and 7 is used to verify the reading. Formula 8, 9 and 10 was used to analyse the results in terms of accuracy, percentage error and precision.

$$Percentage\ Error = \left|\frac{Experimental - Theoretical}{Theoretical}\right|\ x\ 100 \quad (8)$$

$$Accuracy, \% = \left|1 - \frac{Experimental - Theoretical}{Theoretical}\right| x\ 100 \quad (9)$$

$$\text{Standard Deviation} = \sqrt{\frac{\sum(\mathrm{X}-\overline{\mathrm{X}})^2}{\mathrm{n}-1}} \quad (10)$$

Where,

X= value trial

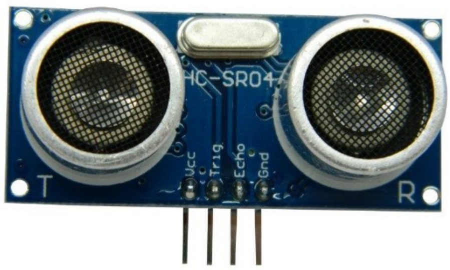
$\overline{X}$=Mean value

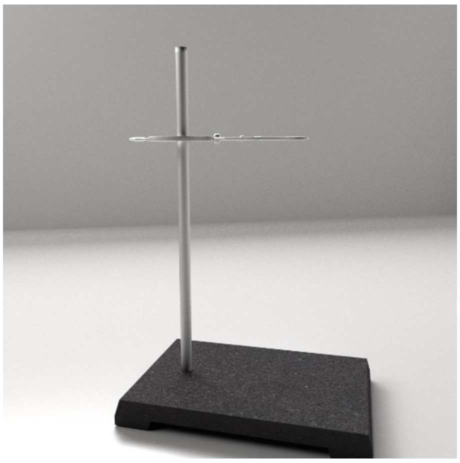
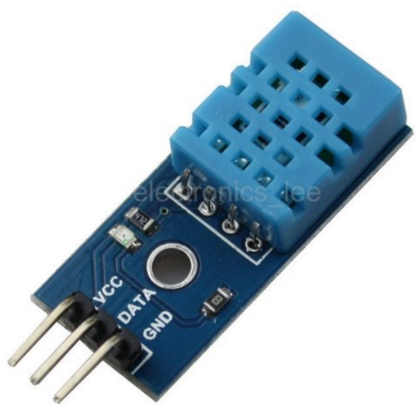
N=number of trials

3.4 ULTRASONIC SENSOR EXPERIMENT

As stated in literature review, ultrasonic level measurement working principle is the measurement of time delay by the sensor to calculate the distance between the sensor and liquid surface. The key to accurate level measurement is knowing the true value of ultrasonic speed which vary with temperature.Due to cost and time restriction, the experiment is scaled down to lab size. Below are the table for the parts and materials used for the experiment:

Table 4 Parts and Material for Ultrasonic Sensor Experiment

Parts and Materials
1)Arduino Uno 
2) Ultrasonic sensor HC SR04 

3) Adjustable Stand Support 
4) Glass Beaker (As Tank) 
5) DHT11 temperature and humidity sensor 

The experiment was set up in a lab with controlled temperature and humidity. The temperature and humidity of air in the lab were continuously monitored to get a better result. The temperature was kept constant at 20° C and the humidity was also kept constant at 63 RH. Plain water was chosen as the measured liquid.

When dealing with ultrasonic sensor, there are two factors we must consider. First is the dead-band area of the sensor. The minimum distance for HC SR04 Ultrasonic Sensor according to the data sheet is 2cm. Thus, the sensor is placed 10cm higher from maximum water level to avoid the dead band area and as a caution distance from liquid splashing to the sensor. This distance is then set as offset distance which was included in the formula 11 to gain accurate height of the liquid.

Second factor to be considered is the beam width of the sensor. According to the datasheet of HC SR04 Ultrasonic Sensor the beam width angle sensor is 15°. A glass beaker was set as tank as it has low acoustic absorption properties same as the metal tank used in real-process industry. Thus the beaker was tested if it causes false reflection due to small diameter. The 10.5cm diameter glass beaker was proved not to be a problem to the beam width of the ultrasonic sensor as the diameter is more than minimum tank diameter required.

The overall distance from ultrasonic sensor to bottom of beaker is set to 22cm.The maximum height of liquid is set to 12cm and the minimum height of liquid is 0cm (empty tank). Figure 25 shows the condition of the experiment according to the minimum while Figure 26 maximum height of the measured liquid. Then, the sensor is calibrated in terms of minimum and maximum liquid level to make sure the sensor measurement always in range and accurate.

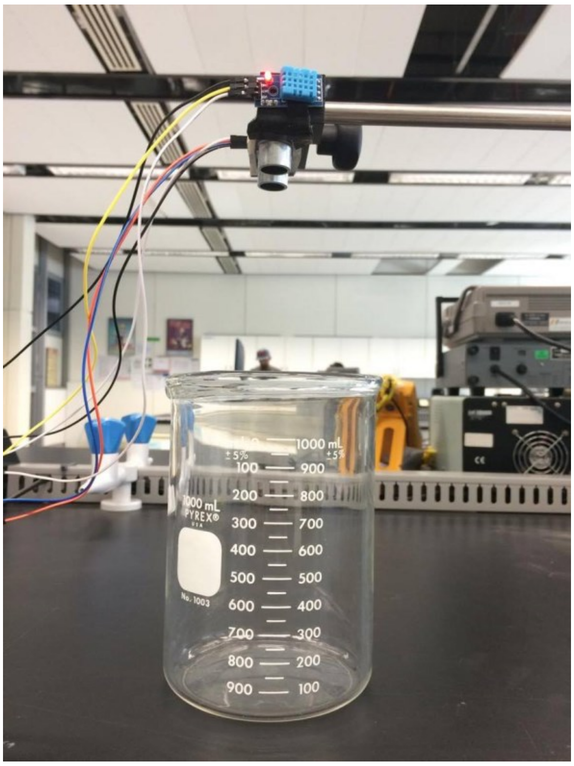


Figure 25 Minimum Level of Measured Liquid

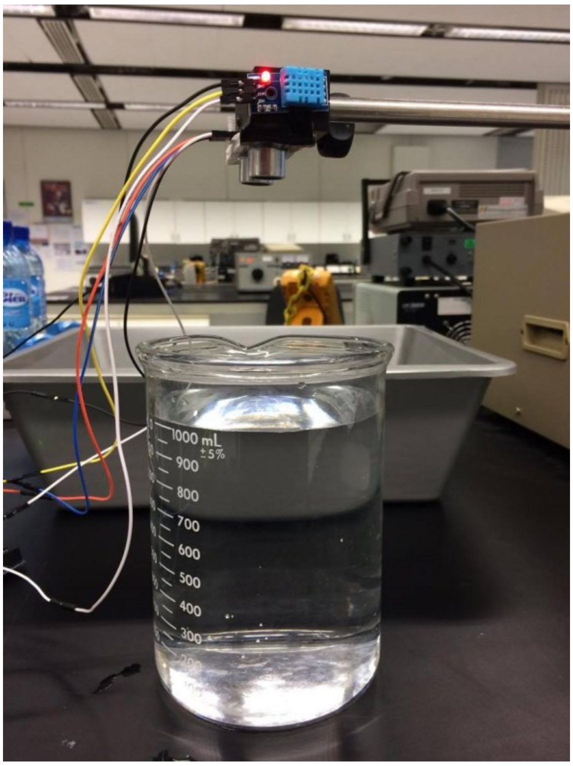


Figure 26 Maximum Level of Measured Liquid

Formula 4 shows the distance can be calculated when the speed and time delay is known using ultrasonic sensor. Then, Formula 11 is used to measure the liquid level.

$$Liquid\ level = Maximum\ level\ of\ liquid - (Distance - 0ffset\ distance) \quad (11)$$

Where,

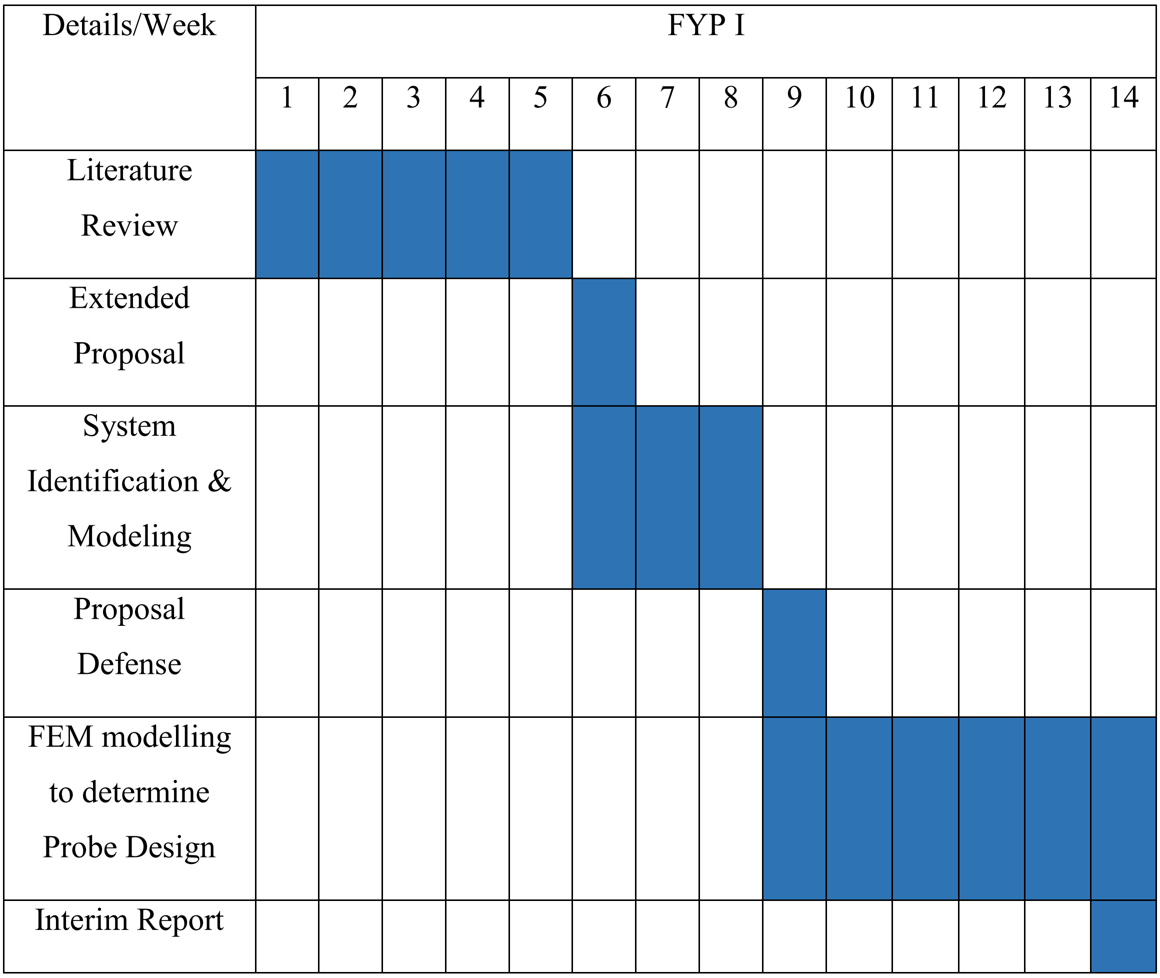
Offset distance = 10cm (sensor is placed 10 cm more than the maximum liquid level)

Maximum level of liquid = 12cm,

Distance = measured distance between ultrasonic sensor and liquid surface

Liquid level = height of liquid measured in glass beaker

3.5 GANTT CHART & KEY MILESTONES



Details/Week	FYP II													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Fabrication of Ultrasonic Liquid Level Sensor and Capacitance Liquid Interface Level Sensor														
Samples gathering, experiments and implementations														
Progress report														
Comparative analysis														
Pre-SEDEX														
Draft final report														
Dissertation														
Technical paper														
Project viva														

3.6 KEY MILESTONES

TASK	WEEKS	COMPLETION
Literature Review On Capacitance and Ultrasonic Level Sensors	4	20%
System Identification & Modeling	8	40%
FEM modelling to Determine Probe Design for Capacitance Sensor	14	60%
Fabrication of Ultrasonic Text Level Sensor and Capacitance Liquid Interface Level Sensor	19	80%
Experiment & Results	22	90%
Progress Report & VIVA	28	100%

3.7 SUMMARY OF CHAPTER 3

In brief, chapter 3 illustrates the flow of the project. First, the flow chart showing general flow of the project itself. Second, capacitance based oil-water level sensor experiment hardware and tools, procedure and factors to be consider when dealing with capacitance based level sensor was briefly explained. Third, ultrasonic based liquid level sensor experiment hardware and tools, procedure and factors to be consider when dealing with ultrasonic based level sensor was briefly explained. Lastly is the Gantt Chart and Key Milestones.

CHAPTER 4 RESULT AND DISCUSSION

4.1 FINITE ELEMENT METHOD (FEM) MODELLING

After the simulation was done. The capacitance reading for the level interface was recorded and tabulated. The tabulated result is presented in table 3 and illustrated in Figure 27.The result achieved is verified by using the known formula of cylindrical capacitance. The capacitance reading obtained has achieved good accuracy when compared to the formula 5, 6, 7.

Table 3 Simulation Result

Water Level Percentage	Capacitance Reading (pF)	Height, H (m)	Calculated Capacitance of Water(pF)	Calculated Capacitance of Oil(pF)	Calculated Effective Capacitance (pF)
0%	521.0	0	0.0	521.0	521.0
10%	1146.8	0.5	664.9	468.9	1133.8
20%	1762.7	1	1329.9	416.8	1746.6
30%	2378.6	1.5	1994.8	364.7	2359.5
40%	2994.3	2	2659.7	312.6	2972.3
50%	3610.1	2.5	3324.7	260.5	3585.1
60%	4225.6	3	3989.6	208.4	4198.0
70%	4841.9	3.5	4654.5	156.3	4810.8
80%	5457.8	4	5319.4	104.2	5423.6
90%	6073.1	4.5	5984.4	52.1	6036.5
100%	6688.1	5	6649.3	0.0	6649.3

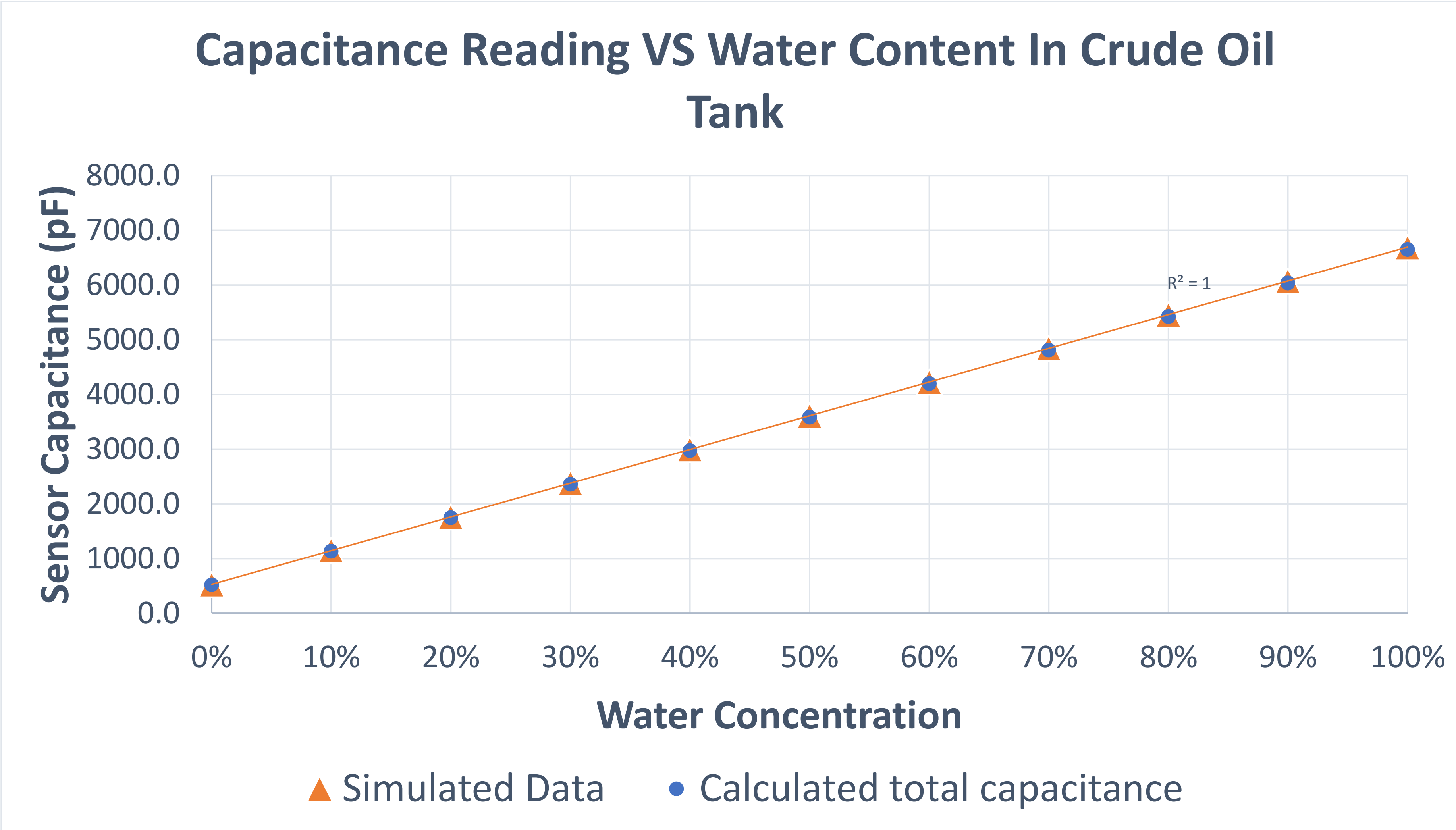


Figure 27 Capacitance Reading VS Water Content in Crude Oil Tank Graph

4.2 CAPACITANCE BASED INTERFACE LEVEL MEASUREMENT

After the experiment was done. The capacitance reading for the level interface was recorded and tabulated. The tabulated result is presented in table 5 and illustrated in Figure 28.The result achieved is verified by using the known formula of cylindrical capacitance, formula 5,6 and 7.The offset capacitance due to the probe being longer than the maximum liquid reading is deducted for calibration. The capacitance reading obtained has achieved accuracy when compared to the formula 5, 6, 7.

Table 5 Capacitance Based Oil-Water Interface Level Sensor Experiment Result (Before Calibrated)

Interface level,%	C_{Total1}	C_{Total2}	C_{Total3}	C_{Total4}	C_{Total5}	C_{Mean}
0	8.964	9.346	9.246	9.544	9.446	9.309
10	10.605	10.987	10.887	10.185	10.087	10.550
20	13.887	13.296	13.169	13.467	13.369	13.438
30	14.751	14.219	14.092	14.390	14.292	14.349
40	18.930	18.783	18.656	18.954	18.856	18.836
50	20.378	20.988	20.861	20.159	20.061	20.489
60	22.417	22.834	22.707	22.005	22.907	22.574
70	23.621	23.021	23.194	23.392	23.594	23.364

Offset capacitance =1.919pF

$$C_{Mean}= C_{Mean}\text{-Offset Capacitance Reading} \qquad (12)$$

Using formula 12, the capacitance reading is calibrated and presented in table 6.

Table 6 Capacitance Based Oil-Water Interface Level Sensor Experiment Result (After Calibrated)

Interface level,%	C_{Total1}	C_{Total2}	C_{Total3}	C_{Total4}	C_{Total5}	C_{Mean}
0	7.045	7.427	7.327	7.625	7.527	7.390
10	8.686	9.068	8.968	8.266	8.168	8.631
20	11.968	11.377	11.250	11.548	11.450	11.519
30	12.832	12.300	12.173	12.471	12.373	12.430
40	17.011	16.864	16.737	17.035	16.937	16.917
50	18.459	19.069	18.942	18.240	18.142	18.570
60	20.498	20.915	20.788	20.086	20.988	20.655
70	21.702	21.102	21.275	21.473	21.675	21.445

The calculated capacitance for the experiment is presented in Table 7 using formula 5, 6 and 7.

Table 7 Calculation of Capacitance Based Oil-Water Interface Level Sensor Experiment (Theoretical)

% of Water Level	C_{Oil}	C_{Water}	$C_{Effective}$
0	7.390	0.000	7.390
10	6.651	2.614	9.264
20	5.912	5.227	11.139
30	5.173	7.841	13.014
40	4.434	10.455	14.889
50	3.695	13.069	16.763
60	2.956	15.682	18.638
70	2.217	18.296	20.513
80	1.478	20.910	22.388
90	0.739	23.523	24.262
100	0.000	26.137	26.137

The percentage error, accuracy and precision is calculated using formula 8, 9 and 10 respectively. Then, the data is tabulated in Table 8.

Table 8 Capacitance Based Oil-Water Interface Level Experiment Analysis

Oil-Water Interface Level,%	$C_{Calculated}$,pF	$C_{Experimental}, pF$	Percentage Error,%	Accuracy,%	Standard Deviation, pF
0	7.390	7.390	0.006	99.994	0.222
10	9.264	8.631	6.835	93.165	0.405
20	11.139	11.519	3.406	96.594	0.274
30	13.014	12.430	4.488	95.512	0.250
40	14.889	16.917	13.622	86.378	0.121
50	16.763	18.570	10.779	89.221	0.416
60	18.638	20.655	10.821	89.179	0.369
70	20.513	21.445	4.546	95.454	0.258

Based on Table 8, the capacitance based oil-water interface sensor has good accuracy when compared to the calculated effective capacitance using formula 5, 6 and 7 with percentage error of ranging from 0.006 to 13.622.In terms of precision, the sensor achieved good precision as the standard deviation ranging from 0.222 to 0.416 pF.

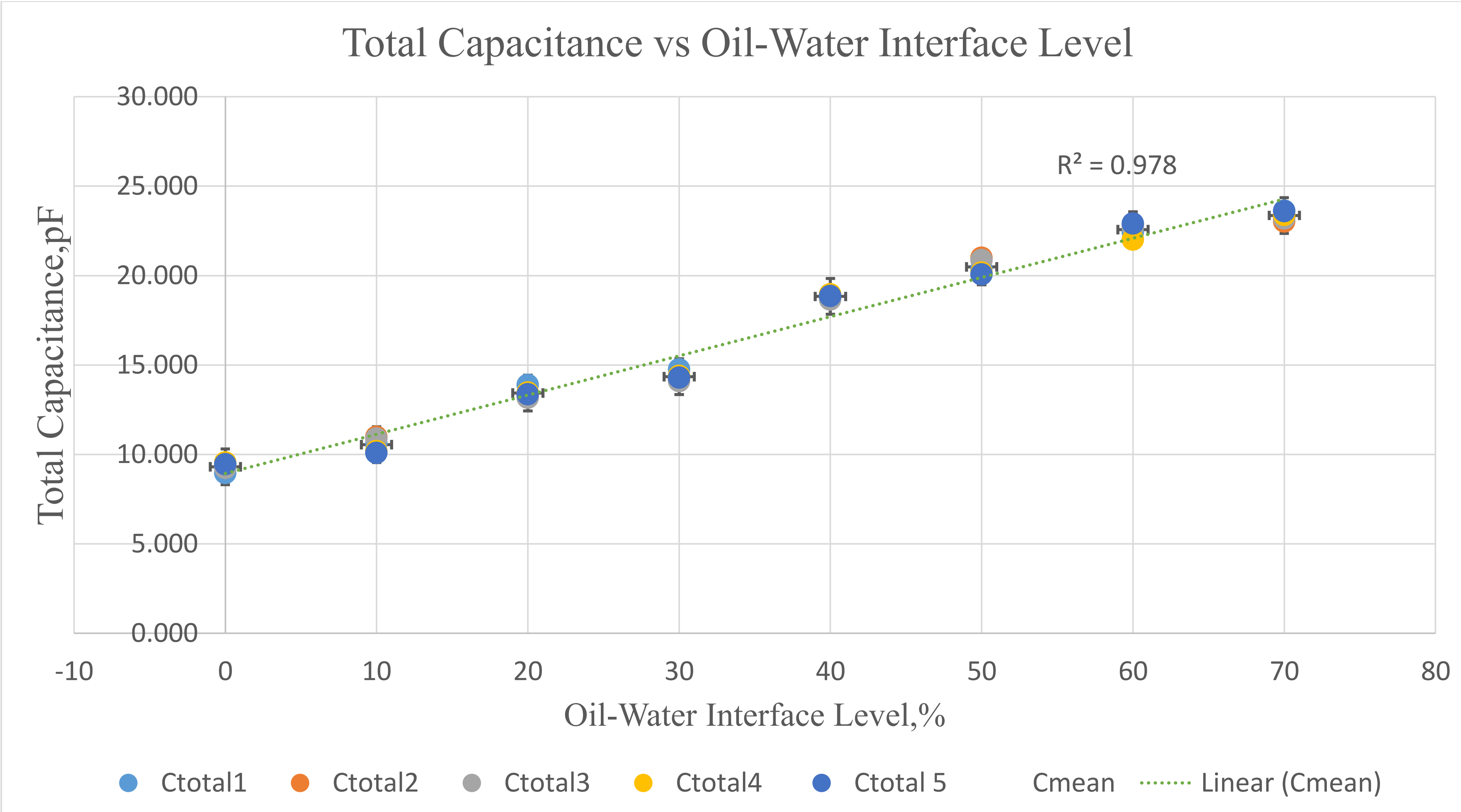


Figure 28 Capacitance Reading VS Water Content In Crude Oil Tank Graph

4.3 ULTRASONIC LEVEL MEASUREMENT

After the experiment was done. The ultrasonic level measurement was recorded and tabulated. The tabulated result is presented in table 9 and illustrated in Figure 29.

Table 9 Ultrasonic Level Measurement Result

Liquid Level Percentage, %	Liquid Level, cm	Ultrasonic Measurement Trial 1,cm	Ultrasonic Measurement Trial 2,cm	Ultrasonic Measurement Trial 3,cm	Ultrasonic Measurement Mean Reading, cm
0	0	0	0	0	0.00
10	1.2	1.42	1.6	1.03	1.34
20	2.4	2.9	2.57	2.16	2.49
30	3.6	3.08	3.78	4.05	3.59
40	4.8	6.03	4.50	5.36	5.27
50	6.0	6.56	5.83	5.52	5.93
60	7.2	6.89	7.56	6.54	6.93
70	8.4	8.81	9.18	8.83	8.63
80	9.6	9.34	9.07	9.95	9.40
90	10.8	10.03	10.63	11.44	10.54
100	12	11.96	11.52	11.81	11.75

Table 10 Ultrasonic Experiment Analysis

Liquid Level Percentage, %	Ultrasonic Measurement Reading, cm	Percentage error, %	Accuracy, %	Standard Deviation
0	0.00	0.000	100.000	0.000
10	1.34	11.667	88.333	0.308
20	2.49	3.750	96.250	0.455
30	3.59	0.185	99.815	0.525
40	5.27	9.722	90.278	0.751
50	5.93	1.111	98.889	0.513
60	6.93	3.704	96.296	0.513
70	8.63	2.778	97.222	0.569
80	9.40	2.083	97.917	0.458
90	10.54	2.377	97.623	0.487
100	11.75	2.056	97.944	0.234

Based on Table 10, the ultrasonic level sensor has a good accuracy when compared to manual measurement with percentage error of ranging from 0.000 to 11667 percent. In terms of precision, the sensor achieved good precision as the standard deviation ranging from 0.000 to 0.751 cm.

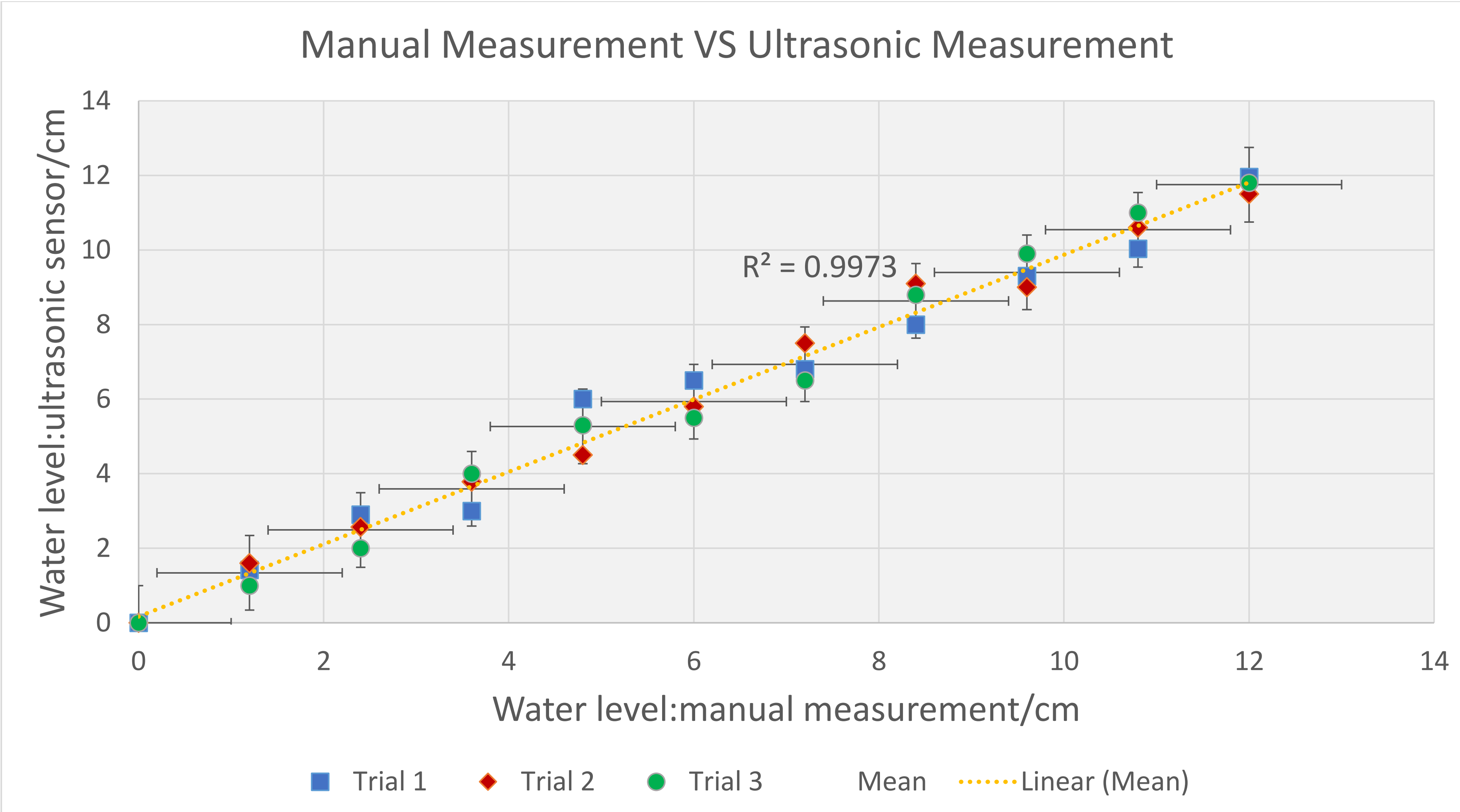


Figure 29 Water Level Measurement Ultrasonic Measurement vs Manual Measurement Graph

4.4 INTEGRATION OF ULTRASONIC-CAPACITANCE LEVEL SENSORS

Both the data from ultrasonic and capacitance liquid level sensors were combined to emulate the capacitance reading when the tank is not full. This will help to pinpoint the oil-water interface level accurately even when the tank is not full. Figure 30 below shows the integration from both of the data.

Table 11 Capacitance Reading when Ultrasonic at Level 1, 30% of Tank

Interface level	C_{Total1}	C_{Total2}	C_{Total3}	C_{Total4}	C_{Total5}	C_{Mean}
0	2.689	2.804	2.774	2.863	2.834	2.793
10	3.182	3.296	3.266	3.056	3.026	3.165
20	4.166	3.989	3.951	4.040	4.011	4.031
30	4.425	4.266	4.228	4.317	4.288	4.305
40	5.679	5.635	5.597	5.686	5.657	5.651
50	6.113	6.296	6.258	6.048	6.018	6.147
60	6.725	6.850	6.812	6.602	6.872	6.772
70	7.086	6.906	6.958	7.018	7.078	7.009

Table 12 Capacitance Reading when Ultrasonic at Level 2, 50% of Tank

Interface level	C_{Total1}	C_{Total2}	C_{Total3}	C_{Total4}	C_{Total5}	C_{Mean}
0	4.482	4.673	4.623	4.772	4.723	4.655
10	5.303	5.494	5.444	5.093	5.044	5.275
20	6.944	6.648	6.585	6.734	6.685	6.719
30	7.376	7.110	7.046	7.195	7.146	7.174
40	9.465	9.392	9.328	9.477	9.428	9.418
50	10.189	10.494	10.431	10.080	10.031	10.245
60	11.209	11.417	11.354	11.003	11.454	11.287
70	11.810	11.511	11.597	11.696	11.797	11.682

Table 13 Capacitance Reading when Ultrasonic at Level 3, 80% of Tank

Interface Level	C_{Total1}	C_{Total2}	C_{Total3}	C_{Total4}	C_{Total5}	C_{Mean}
0	7.172	7.477	7.397	7.635	7.556	7.447
10	8.484	8.790	8.710	8.148	8.070	8.440
20	11.110	10.637	10.535	10.774	10.695	10.750
30	11.801	11.375	11.274	11.512	11.434	11.479
40	15.144	15.026	14.925	15.163	15.085	15.069
50	16.302	16.790	16.689	16.127	16.049	16.392
60	17.934	18.267	18.166	17.604	18.326	18.059
70	18.897	18.417	18.555	18.714	18.875	18.691

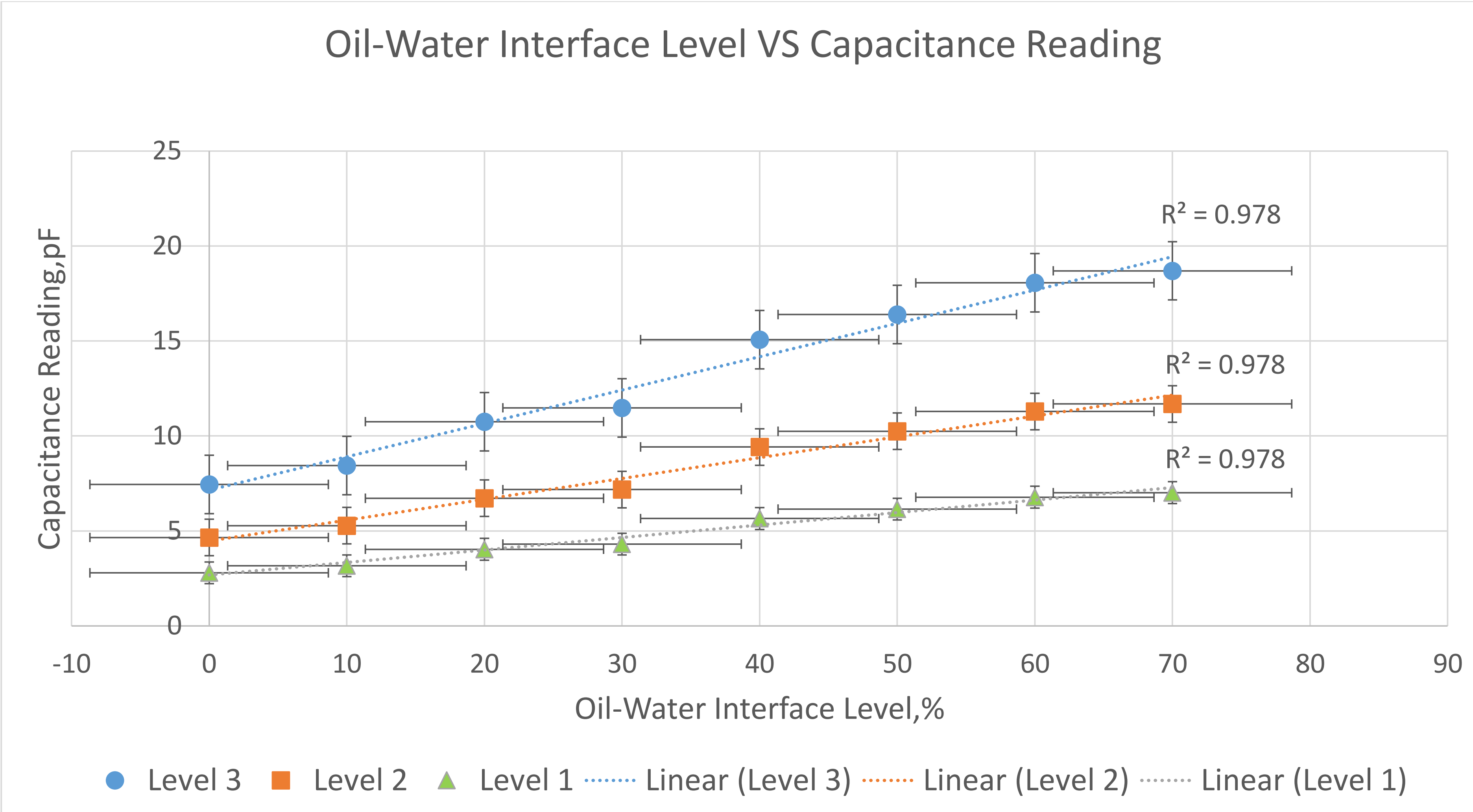


Figure 30 Integrated Ultrasonic-Capacitance Level Measurement Graph

4.5 SUMMARY OF CHAPTER 4

In brief, Chapter 4 discussed about the results of the experiments and simulation. First, the results for the capacitance probe simulation was done to check the effects of the proposed capacitance probe design on capacitance reading. A high accuracy and linearity was obtained from the simulation when compared to cylindrical capacitance formula. Next, for the first experiment, ultrasonic level sensors were tested to detect the total level of water in a beaker. The results were analyzed in terms of accuracy, percentage error and precision. For the second experiment, the design of the capacitance probe was prepared by using a FEM modelling based simulation, ANSYS Maxwell. Then the sensor is developed for oil-water interface level experiment. Then, the results were verified using cylindrical capacitance formula. Moreover, the oil-water interface level experiment results were also analyzed in terms of accuracy, percentage error and precision. Both ultrasonic level measurement and capacitance based oil-water interface level has achieved good accuracy in percentage, low percentage error and good precision when compared to theoretical value. The results were integrated in a single graph and calculated for different total tank level and oil-water interface level.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATION

As a conclusion, this project focused on the improving conventional capacitance based oil-water level measurement method by integrating both ultrasonic and capacitance sensors to measure total liquid level and oil-water interface level. The project provide a complete oil storage level measurement hence bringing better accuracy for conventional capacitance interface level sensor and lower risk of tank overflow. To prove the concept of the integrated sensors, both ultrasonic and capacitance level sensors working principle were studied. Technically, the study was implemented based on two experiments to test the reliability of the sensors. However, due to cost and time constraint the experiments were scaled down to lab size and use a glass beaker instead of a metal tank.

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For future recommendation, the study should be continued by using a real metal tank and real industry condition. This condition will help to verify the theory of the integrated sensors even more. Furthermore, a higher quality of ultrasonic sensors is needed to get better result in terms of its accuracy and precision.

REFERENCES

[1] A. M. C. C. FIChemE, "Over the Top: Process Safety Lessons Related to Liquid Level in Process Vessels and Tanks," 2015.

[2] B. Kumar, G. Rajita, and N. Mandal, "A Review on Capacitive-Type Sensor for Measurement of Height of Liquid Level," *Measurement and Control,* vol. 47, pp. 219-224, 2014.

[3] M. A. H.K.Abdel-Aal, M.A.Fahim, "Petroleum And Gas Field Processing," 2003.

[4] I. A. o. O. G. Producers, "Hydrocarbon process single and multi-layer level measurement –Recommended Practice," 2016.

[5] P. W. Yang, "Sensors and Instrumentation for Monitoring and Control of Multi-Phase Separation," *Measurement and Control,* vol. 39, pp. 178-184, 2006.

[6] A. A. N. a. K. A. B. P. P. V. Mahmoud Meribout, "Interface Layers Detection in Oil Field Tanks: A Critical Review, Expert Systems for Human, Materials and Automation, ," 2011.

[7] A. V. B. U.A.Bakshi, "Electrical Measurements And Instrumentation," 2009.

[8] B. G. Liptak, "Instrument Engineers' Handbook, Fourth Edition, Volume One: Process Measurement and Analysis," pp. 533-537, 2003.

[9] K. K. C. B. C. Nakra, "Electronic instruments," 2003.

[10] D. Gillum, "Level measurement. From tried and true to the newest trends," 2013.

[11] V. Vidyasagar, "Ultrasonic Technology for Level Measurement in Water Processing Applications " 2016.

[12] M. Cartier, ""A Look at Liquid Liquid Level"," 2002.

[13] G. Fowles, "Flow, Level and Pressure Masurement in the Water Industry," 1993.

[14] R. H. a. D. W. G. Perry, "Perry's Chemical Engineers' Handbook. 7th ed. ," pp. 8-49, 1997.

[15] K. Schmidt, " "Level measurement Technologies For the CPI" Chemical Engineering," pp. 34-37, 2008.

[16] Princoinstruments.com. (2016, 12 February 2017). *Theory of RF Level Measurement*. Available: http://www.princoinstruments.com/levmeas.htm

[17] Hyperphysics.phy-astr.gsu.edu. (2016, 12 February 2017). *Cylindrical capacitor*. Available: http://hyperphysics.phy-astr.gsu.edu/hbase/electric/capcyl.html

[18] M. Morrissey, "Thinking caps: understanding capacitance level measurement," 2015.

[19] M. Saeed, "Measurement System to Monitor Interface Level Between Oil and Water in a Rapidly Rotating System," 2013.

[20] C. E. Brennen, "Fundamentals of Multiple Flows," 2005.

[21] H. B. a. R. J., "Process monitoring using ultrasonic sensor systems," vol. 44, pp. 1395-1399, 2006.

[22] I. Ihara, "Ultrasonic Sensing: Fundamentals and Its Applications to Nondestructive Evaluation," 2010.