Waxy Cooled Crude Oil Characterization by Electrical Capacitance Tomography (ECT)

By

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DISSERTATION

Submitted to the Department of Electrical & Electronic Engineering
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CERTIFICATION OF APPROVAL

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Approved:

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December 2012

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.

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Abd Azim B Abd Karim

ABSTRACT

This paper discussed on the project entitled, “Waxy Cooled Crude Oil Characterization by Electrical Capacitance Tomography (ECT)”. Current research towards the characterizing of the crude oil seems to be sprout positively according to different field of studies that try to fulfill demanded from industrial. As parallel towards this growth, in this project the author reported a study regarding the behavior of gelled crude which is a waxy crude oil which undergoes thermal shrinkage or cooling process.

The study is about gathering all possible information about the waxy crude oil for further study which will lead to the result of new correlation for waxy crude oil. The objective of this project to design an Electrical Capacitance Tomography (ECT) sensor for the characterization of cooled waxy crude oil within the pipeline in the static flow condition. Before that, sensor calibration set up must be done for lower and upper range of the material permittivity as the sensor standard detection. For the online measurement, the visualization and other raw measurement in a cross section using multi-electrode capacitance sensor will be observe as the temperature been varied.

The result and discussion contain the fabrication result of the ECT sensor like calibration and online measurement, with some discussion about the result obtained which show the temperature is inversely proportional to the raw capacitance of the crude oil. For future work, the experimental procedure will be developed by further test on dynamic flow measurement in order to get another important variable parameter as to get real characterization of the crude oil as in the real industrial situation.

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LIST OF ABBREVIATION

Electrical Capacitance Tomography	ECT
Electrical Resistance Tomography	ERT
Industrial Tomography System	ITS
Wax Appearance Temperature	WAT
Upper Range Value	URV
Lower Range Value	LRV

CHAPTER 1

INTRODUCTION

1.1 Project Background

The background study of this project covers the research on the characterization of waxy crude oil by using Electrical Capacitance Tomography (ECT). The basic idea of this project is to design a sensor that uses ECT approach to measure raw capacitance value at different surrounding temperature, while at the same time observing the physical phase changes. The data obtained will be used to create some correlation between the dielectric properties of the crude oil as the temperature varies. Besides that, wax fraction also been measured by using the tomograms obtained. Then for the future work, it can be applied towards upstream line industry to prevent from the problem of pipeline blockage as the crude oil become waxy material.

1.2 Problem statement

Normally the temperature at the reservoir will be around 70-150 Celsius and pressures at about 50-100 MPa, where wax molecules are dissolved in the crude oil. However, as the crude oil flows through a subsea pipeline through the ocean floor at a temperature of 4 Celsius, the temperature of oil eventually decreases below its cloud point temperature (or wax appearance temperature, WAT) because of the heat losses to the surroundings. The solubility of wax decreases drastically as the temperature decreases and wax molecules start to precipitate out of the crude oil [26].The issues arise as there are gas void within this wax that could lead difficulties to pump through a pipeline because the tendencies of such crudes to plug and clog the pipe line with wax deposit [4]. In the real world this situation has occurred until for some cases needed for pipeline replacement as the alternative way to overcome stuck waxy crude in pipeline like what happened at the Sepat Field. Before any modeling or design started, there will be some study done in order to understand the characteristic of ECT sensor and waxy crude oil behavior.

1.3 Objective

The main objective of this project is to design and fabricate a sensor for the characterization of waxy crude oil using ECT approach at varies temperature in static flow. Data obtained will be used for further research to resolve the problem of pipeline blockage due to the formation of waxy crude oil. The details of the objectives are as follows:

a) Sensor Design and Fabrication:

Consist of hardware and software. The hardware portion is the ECT sensor fabrication while the software is the application used as the interface for data acquisition. Several considerations have to be made in term of effective electrode size, shielding, and material used to fabricate the sensor.

b) Calibration:

Make up calibration measurement for lower and upper range of the material permittivity for the sensor standard detection.

c) Online Measurement:

Place the crude oil inside the ECT sensor while manipulating the ambient temperature then raw data collected.

d) Phase Behavior Characteristic:

Study the behavior of the crude oil during cooling down period for waxy crude.

1.4 Scope of study

The scope of study will evolve on designing ECT sensor by understanding the concept of ECT. In order to implement the ECT sensor for the measurement of raw capacitance and wax fraction, some basic characteristic of crude oil also must be learned. Besides there will be some theoretical study needed as to create significant correlation between the variable parameter of the experiment that been set up.

1.5 Relevancy of Project

This project is relevant to the study of Instrumentation and Control System background since it focuses on the design capacitance sensor and prototype testing of the ECT system which deals with the application of electronic design in the real world. Although this technology has established, however the characterization for waxy crude by using ECT still at the top surface and can be explored further. If this study manages to provide new information and finding for the characteristic of waxy crude, it can be a new guideline for all the oil and gas operating company in designing the platform that can give more profit with less cost and the most important is to reduce energy usage. Since cost and profit are of the utmost importance in every industry especially in the Oil and Gas industry, the outcome from this study will give a lot of benefits to the industry in terms of profit and cost benefit.

1.6 Feasibility of Project within the Scope and Time Frame

This project is about the experimental of raw capacitance measurement besides wax fraction measurement within crude oil by using Electrical Capacitance Tomography (ECT) which will simulate the condition of the waxy crude oil in the pipeline. The project scope and time frame is referred to the project key milestone and Gantt chart. The project begins with the review on related material in order to have strong understanding regarding to this project especially on ECT application and the behavior of waxy crude oil. In doing this project, the tool needed is a fabricated ECT sensor, data acquisition system, and PC as the data monitoring device. The crude oil will be placed inside the cylindrical ECT sensor body during the experiment thus simulating a pipeline which is cylinder in shape. For the sensor fabrication, the cable, SMB plug connector, copper tape and other tools like crimping device been provided and the other main machine need to be used is electric motor pump for the dynamic measurement purpose. For the time constraint, the experimental setup must complies with the allocated time as in Gantt chart while for the cost demand does not required such expensive tools.

CHAPTER 2

LITERATURE REVIEW

2.1. Wax Fraction Measurement

Lot of technologies nowadays was invented in order to improve the monitoring based control of enclosed chamber like vessel, pipeline transportation and other applications. Wax fraction measurement also impacted by this technologies development until there are lots of methods can be used like tomography system, advanced radiation technique, and differential pressure approach. All the stated above method will be discuss as per below explanation.

2.1.1 Tomography System

Tomography is the process of exploring the internal characteristics of a particular area throughout integral measurements related to the internal characteristics of the specified domain. The approach behind tomography technique firstly is Non-invasive (no direct contact between the sensor and the object or domain of interest) and secondly is Non-intrusive (the object being explored does not disturbed) [2]. Besides, Tomography also capable to measure multi-phase flow component directly in single pipeline without need separation like conventional single flow measurement by Differential Pressure approaches [6].There are many types of sensor for tomography system like X-ray, γ-ray, nuclear magnetic resonant (NMR), optical, electrical and ultrasonic. By looking at several engineering aspects the electrical tomography has many advantages over the other tomography modes, such as low-cost, no radiation, rapid response and robust [5]. However there are many types of electrical tomography established nowadays and the most suited approach with this project most likely either the electrical capacitance tomography (ECT) or electrical resistance tomography (ERT) due to the effectiveness and low cost to fabricate the design. While between this approaches there are advantages and disadvantages that can be illustrated as below.

Table 1: Comparison between ECT and ERT

	Advantages	Disadvantages
ECT	• No radiation, rapid response, low cost, non-intrusive and non-invasive and the ability to withstand high temperature and pressure [6].	• The electrode need to be put inside if the tube wall is conductor [1].
ERT	• The phase distribution of two phase flow in the pipe can be reconstructed at various times as the way to compensate the error [7].	• Low measurement precision[7]

2.1.2 Advance Radiation Techniques

This type of technique usually will be using ionizing radiation approach to obtain single phase fraction measurement in two phase flow. This techniques also been considered as one of the best option since the data of single phase fraction can be obtained non-intrusively like Real Time Neutron Radiography (RTNR) and a high speed X- ray Computed Tomography system (X-CT). The concept used basically as liquid in test section will attenuates radiation without the radiation depositing significant amounts of energy. The void fraction will be the percentage of the flow channel volume not occupied by liquid phase. Therefore the attenuation of radiation beam can detect the void fraction in the flow channel [8]. However this advance radiation techniques still has disadvantage compare to tomography since it involve with hazard of radiation ray besides the high cost as to purchase and also for maintenance issues.

a) RTNR

Approached applied behind this method is by using the generated radiographic images by the real-time neutron radiography system (RTNR) that will be analyzed for the determination of instantaneous void fraction distribution. The cross-sectional averaged axial void fraction profiles and the two-dimensional void fraction profiles are determined simultaneously for each image. Various flow regimes are generated to determine if the RTNR system can accurately predict the void distribution in the radial, axial, and temporal coordinates. However, accuracy decreases with decreasing void fraction. For example net water thicknesses >1.0 cm, the accuracy decreases with increasing water thickness due to the extreme sensitivity of thermal neutron interactions with light water (liquid) [9]. Based on this information the efficiency of this method due to imprecise of accuracy measurement is being doubt for the project applied since this project will involve in dynamic online situation that can vary in term of product thickness.

b) X-CT

X-ray computed tomography (X-CT) is one of the techniques that enable non-destructive visualization of the internal structure of objects. However there are several disadvantages relates with this techniques like the small size of the detector. According to the imaging principle of X-CT, the imaging region of the scanned object must fit within the X-ray beam formed by the X-ray generator and the detector. Usually it is difficult to image the object beyond the scan field of view. Besides that, the merging method is too time consuming [10]. Since this method involve in many issues in order to capture data, it still need time as the way of improvement and not suitable to be execute in experimental project.

2.1.3 Differential Pressure (DP) Approach

a) Conventional Dp Flow Measurement

Most of the conventional flow measurement are being set as the single phase flow measurement and one of the most popular method been used would be differential pressure (DP). Differential pressure transmitters measure the difference between two pressures, a high pressure and a lower pressure, in a pipe or tank. At the inlet of pipe, the pressure drop is created by constricting the flow stream. The constricting device is called a primary element while the secondary element is the pressure transmitter that measures the differential pressure. The flow rate is proportional to the square root of the differential pressure and relies on Bernoulli's equation [11].

There are several type of primary element like Orifice plates, Venturi tubes, averaging Pitot tubes, and flow nozzles which normally will intrusively disturb inlet flow since its will constrict flow stream in order to create differential pressure. However this kind of approach normally well suited with the single phase flow measurement which is not really suitable for this project applied since it will involve in multi-phase flow measurement.

b) Multi-Phase Flow Measurement By Dp

As the initiatives way to improvise the limitation of conventional DP measurement there are some invention been done to measure multiphase flow by using DP approached. Two pairs of pressure measuring point will be used where both pairs will be not the same. The first pair will be measuring differential pressure of primary upstream and downstream measuring point separated by a primary pipe distance, ‘a’ as in Figure 1. Then for the second pair will measure differential pressure of secondary upstream and downstream point separated by a secondary pipe distance, ‘b’ as in Figure 1. The time delay between this two pair of pressure measurement point will correspond towards multiphase flow analysis [12]. This method has extended the capability of differential pressure measurement in multi-phase flow monitoring. However it is still has disadvantage compared to tomography approach because it is impractical to be execute since the restriction applied to create differential pressure will just fastened the blockage formation in the pipeline. Besides, the high viscosity of the crude oil also make this type of measurement are not really suit to be applied.

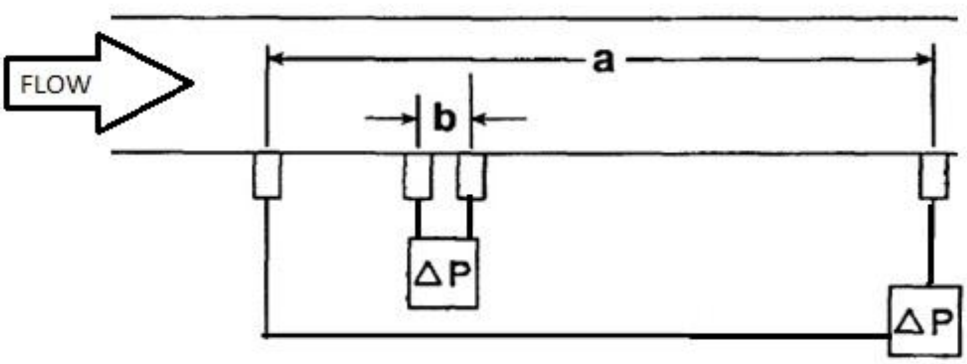


Figure 1: Two pairs pressure measuring point

2.2 Electrical Capacitance Tomography (ECT)

Electrical capacitance tomography (ECT) approached choose due to the flexibility offered for determination of the dielectric permittivity distribution of a mixture of 2 dielectric materials inside a closed vessel which in parallel with objective of this project to measure wax fraction distribution within waxy crude oil [1]. The principle is based on capacitance measurements which are done by placing electrodes around the known dielectric medium like PVC and the unknown dielectric specimen is put inside the cylinder as implicit capacitor and capacitance value is measured. The capacitance will vary based on the area of the plates, distance between plates and dielectric material which will vary according to the object and other factors remain constant. Since the capacitance depends on the permittivity value of the material located between the electrodes, substances of differing dielectric properties can be distinguished by means of this method. The measured capacitance values are converted into voltage and it is fed into the computer where reconstruction is done by using Linear Back Projection Algorithm [2].

2.2.1 ECT Design

Electrical Capacitance Tomography has mainly 3 major units. Sensing unit, functions to capture capacitance values from the specimen under electrodes. Then the Industrial Tomography System (ITS) M3000 Multi Modal Tomography System as the interface module for data acquisition hardware. Image reconstruction and displaying unit will reconstruct image from the digitized readings using appropriate algorithm to displays the result. A basic module of ECT is shown in Figure 2.

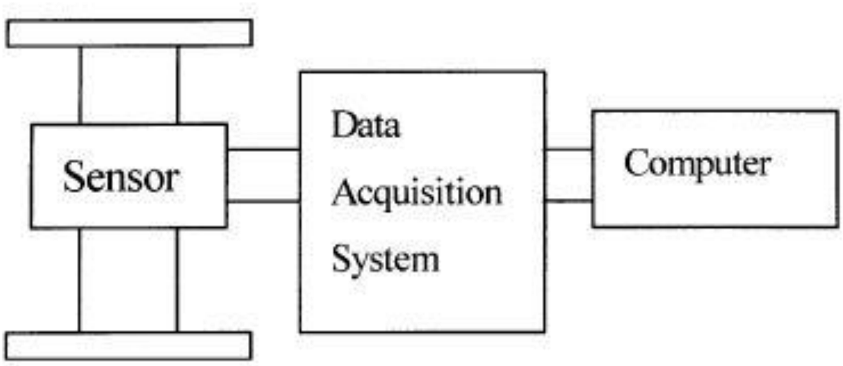


Figure 2: Basic Module of ECT System

2.2.2 ECT Sensor Design

Part of consideration that need to be understudy in order to design ECT sensor which are capacitance measurement principle, capacitance electrode location, number of electrodes, earthed screen.

a) Capacitance Measurement Principle

The basic capacitance measurement principle used in ECT is shown in figure 3. An alternating voltage (Vi) is applied between one electrode (the source electrode) towards ground and the resulting currents which flow between the source electrode and the remaining (detector) electrodes to ground are measured. These currents are directly proportional to the capacitances between the source and detector electrodes. The set of capacitance measurements, made when one electrode is excited as a source which known as a "projection"[1]. As in figure 3, by 12-electrode sensor, there will be 12 x 11 = 132 possible capacitance measurements, or Cx. Cmos switches will play the rule as the switching element either at the voltage source or ground side in order to obtain 132 possible capacitance measurements [27]. However, as half of these will be mutual measurements (the same capacitance should be measured by exciting electrode 1 as a source and measuring the current into electrode 2 as is obtained by exciting electrode 2 as a source and measuring the current into electrode 1 etc.), there will only be 66 unique capacitance measurements for a complete set of projections. In general for a sensor with E (number of electrode), there will be E.(E-1)/2 unique capacitance measurements, which make up one frame of capacitance measurement [1].

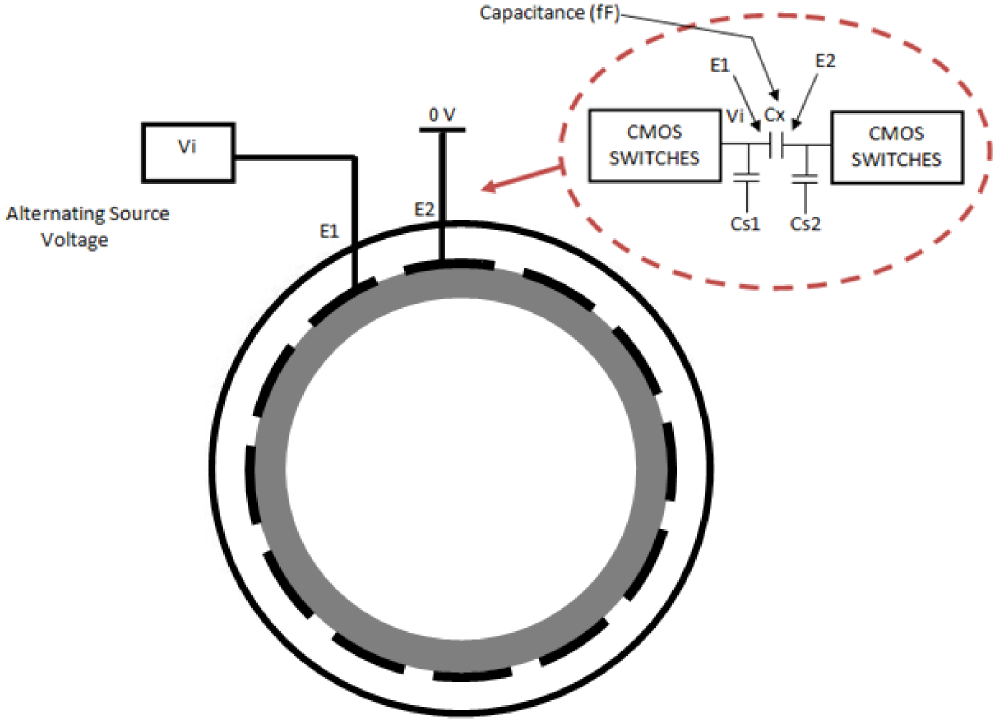


Figure 3: Capacitance Measurement Principle

b) Capacitance Electrode Location

If the vessel wall is non-conducting, capacitance electrodes can be located inside, within or outside the wall as shown in figure 4. However, if the tube wall is a conductor, internal electrodes must be used. The numbering of electrodes is synchronized at anticlockwise directional, starting at the electrode at or just before 3 o'clock [1].

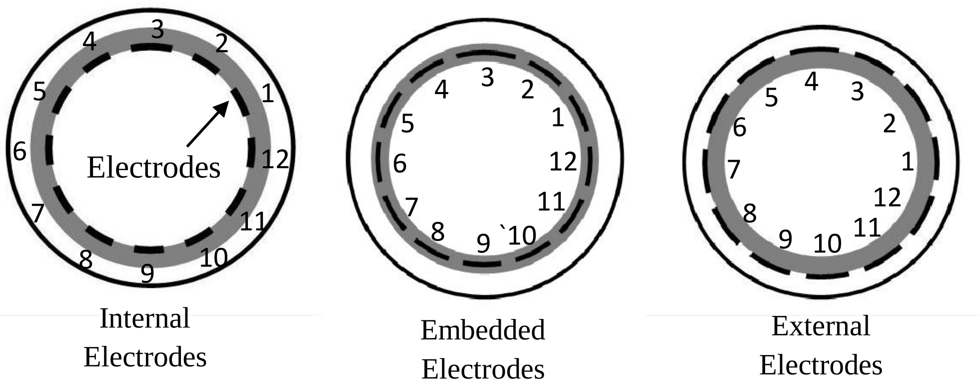


Figure 4: Circular Sensor Electrode Configuration

c) Earthed Screen

Earthed screening tracks between the sets of electrodes (to reduce the adjacent electrode capacitances) together with earthed areas at the ends of the sensor (to allow the cable screens to be terminated). Coaxial leads are connected to the electrodes and an earthed screen is located around the sensor to exclude any external signals. Discharge resistors (typically 1 MOhm) must be connected between each electrode and the cable screen to ensure that no static charge can build up on the electrodes and connecting leads, otherwise damage may occur when the sensor is connected to the capacitance measurement circuit [1]. It is common to use earthed axial end screen at both ends of measurement electrode which can reduce external noise to some extent [5]. The standing capacitance between adjacent electrode pairs can be reduced by using earthed radial screen.

d) Number of Electrode

The number of sensor electrodes that can be used depends on the range of values of inter- electrode capacitances and the upper and lower measurement limits of the capacitance measurement circuit. The capacitance values when the sensor contains air are referred to as "standing capacitances" and their relative values are shown in figure 5 for a 12-electrode circular sensor with internal electrodes.

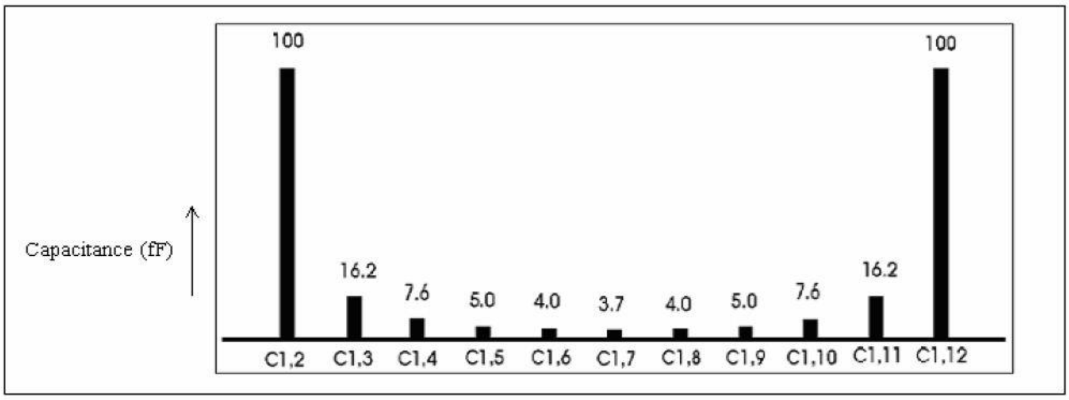


Figure 5: Inter Electrode Capacitance

Sequential electrode-pairs are referred to as adjacent electrodes, and have the largest standing capacitances, while diagonally-opposing electrode-pairs (opposite electrodes) have the smallest capacitances. As the number of electrodes increases, the electrode surface area per unit axial length decreases and the inter-electrode capacitances also decrease. When the smallest of these capacitances (for opposite electrodes), reaches the lowest value that can be measured reliably by the capacitance circuitry, the number of electrodes, and hence the image resolution, can only be increased further by increasing the axial lengths of the electrodes. However, these lengths cannot be increased indefinitely because the standing capacitances between pairs of adjacent electrodes will also increase and the measurement circuitry will saturate or overload once the highest capacitance measurement threshold is exceeded [1]. However there are some result shows that a sensor with up to 12 electrodes to be used in a multi-phase flow measurement system with a maximum imaging rate of 100 frames per second, and thus provides an improved image resolution compare to 8 electrodes sensor [22].

2.2.3 Image Reconstruction

Image reconstruction algorithms for ECT can be categorized into two groups, non-iterative algorithms, and iterative algorithms. Amongst the non-iterative algorithms, the (Linear Back-Projection (LBP)) algorithm is the simplest and fastest. Although it has some limitations in terms of accuracy and spatial resolution, it is well suited for fast dynamic processes like multiphase flow, and widely used for on-line image reconstruction [3].

a) Procedures of Image Reconstruction:

The basic steps involved in image reconstruction and displaying operation are as follows:

1) The properties of the sensor are measured or calculated to produce a sensitivity matrix, S of the sensor. This is a set of sub-matrices whose elements correspond to the individual pixels in a rectangular grid which is used to define the sensor cross-section. The sub-matrices are known as sensitivity maps and database is prepared [2].

2) The sensor is usually calibrated at lower range value (LRV) and upper range value (URV) of permittivity to be measured. Filling the sensor with the lower permittivity material (gas) initially and the measured capacitance become as C_L. This operation is then repeated using the higher permittivity material

(distilled water) and the measured capacitance become as C_H. While online measurement gives measured capacitance value as C_M . All subsequent measured capacitance values C_M are then normalized to become as C_N between “0” (LRV) and “1” (URV) according to the equation (1), [2][24]:

$$C_N = \frac{C_M - C_L}{C_H - C_L} \qquad \text{Eq(1)}$$

3) With the 66 number of independent capacitance which makes up one frame of capacitance measurement for a 12-electrode ECT system [1], need to be projected onto a (32 X 32) square pixel grid to generate the current permittivity distribution image. For this situation on a (32 X 32) square pixel grid containing 1024 pixels, only 812 pixels are needed to construct the cross-sectional image of the vessel and the remaining are neglected [15].Where each value of independent capacitance will be expressed based on equation (2),[24]:

$$C_i = \iint_D \varepsilon(x,y) Si(x,y)\, dxdy \quad i = 1,2, \dots 66 \qquad \text{Eq(2)}$$

Where:

- $\varepsilon(x,y)$is the dielectric (permittivity) distribution,
- $Si(x,y)$ is the sensitivity distribution function of C_i,
- D is the cross-section of pipe (image area).

4) An image reconstruction algorithm is used to compute the cross sectional distribution of the permittivity of the material inside the pipe. Images can be constructed from the capacitance measurements at the time of measurement (on-line). Linear Back-Projection (LBP) algorithm been used because it is fast but approximate algorithm which uses the capacitance measurements, together with the sensitivity map to produce the image [2].

b) Linear Back-Projection (LBP) algorithm

Usually the sensing electronics provides excitation signals and convert the capacitances into voltage signal, which are conditioned and then digitized for data acquisition. The computer controls the system hardware and implements the image reconstruction algorithm to show the permittivity distribution. The LBP has been implemented to reconstruct images for ECT using 12-electrode sensor and a transputer-based multiprocessor system. The relationship between capacitance and permittivity distribution can be approximated and written in a linear normalized form as:

$$C_N = SK \qquad \text{Eq(3)}$$

Where C_N is the normalized capacitance matrix, S is the transducer sensitivity matrix (normalized capacitance with respect to normalized permittivity), and K is the normalized permittivity distribution [3].In this algorithm, the transpose of the sensitivity matrix, S^T is used and the permittivity distribution can be obtained as follows [2].

$$K = S^T C_N \qquad \text{Eq(4)}$$

2.2.4 Void Fraction Calculation

After image reconstruction, the concentration of two-phase flow could be calculated by

$$c = \sum_{j=1}^{M} \mathrm{I} \qquad \text{Eq(5)}$$

Where M is the total number of pixel (812), I is the level of intensity for each pixel, and C is total concentration of intensity. Thus, the void fraction of two-phase flow is [24],

$$v = \left(1 - \frac{C}{255 \times 812}\right) \times 100\% \qquad \text{Eq(6)}$$

2.2. Waxy Crude Oil Features

2.2.1. Physical Formation of Waxy Crude Oil

Thermal reduction occur to the crude oil in the pipeline naturally as the temperature of the seabed is low and become worst during the plant shutdown period since the crude oil remains in the pipeline for a certain period of time. Based on the study, the petroleum crude contains paraffin (CnH2n+2) and if the carbon atoms contained are more than eighteen the petroleum crude is then known as waxy crude oil [17]. During the thermal shrinkage or cooling process of this crude oil, wax or gelled crude will start to form at the Wax Appearance Temperature (WAT) and the wax starts to form at the pipeline forming a solid layer that decrease the available flow area [20] As well as the same period of wax formation, there were gas voids produced by cooling process of the crude oil in the flow line [18]. The gas voids appearance may affect the compressibility of the gelled crude since there are spaces for the gelled crude to move after some amount of pressure applied.

2.2.2. Issues of Waxy Crude Oil

The waxy crude oil that formed in the pipeline will need high pressure enforcement in order to move since the waxy crude oil will behaves as an incompressible high viscous fluid [19]. Since high pressure is needed to move the waxy crude, a huge amount of money needs to be invested for the high horse power pump at the platform. However for the worst case new pipeline need to be constructing in order to overcome this problem like what happen at SEPAT field.

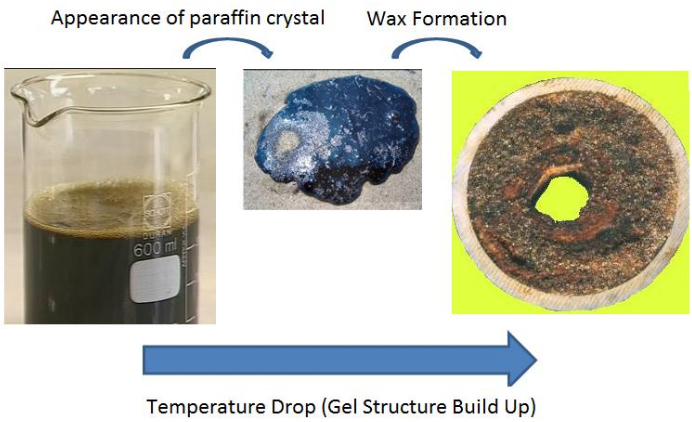


Figure 6: Wax Formation

2.2.3. Yield Stress Analysis for Waxy Crude

The analysis to verify waxy crude oil behavior normally will be based on a three characteristic of yield stress model which are elastic limit, a static and a dynamic yield stress [16].Both the elastic-limit and static yield stresses are dependent on the strength of the interlocking network of wax crystals in the oils before the structure is disturbed, while the dynamic yield stress is related to the concentration and size of the wax particles in the oils after the structure is completely destroyed. The results showed that yielding of waxy crude oil occurs by an initial elastic response, followed by viscoelastic creep and a final fracture [13].

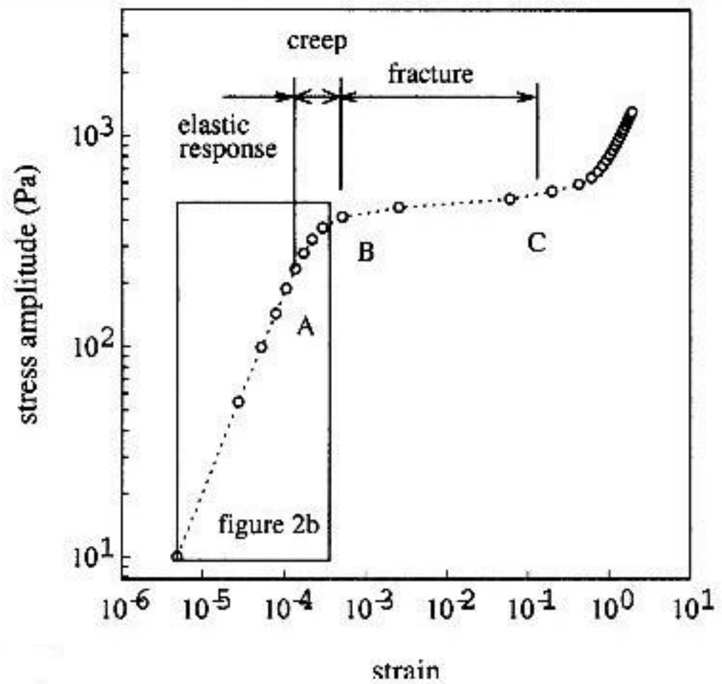


Figure 7: Yielding Process of Waxy Crude Oil:

The complete yielding process gained by performing an oscillatory test with a gradually increasing controlled stress. Figure 7 shown typical curves recorded for a waxy crude oil where shear strain was measured rather than shear rate. Before approaching point A, elastic behavior shown where the strain increases linearly with shear stress. After point A, creep occurs that caused the linearity of stress-strain was deviated. Fracture starts at point B Where there is a significant increase of the strain which indicate the breakdown of the structure[21].The stress value when the fracture occurs is the most interested part as this stress value effectively determines the pump capacity required to initiate flow after being block by the wax formation and ensure pipeline restart [13].

2.2.4. Flow Regime in Multiphase Flow

Multiphase flow describes two or more types of liquid components flowing in the gas stream at the same time. Typical liquids include oil, condensate and water, sometimes solids may be entrained which can make the mixture harder to measure [14].The distribution of the fluid phases in space and time differs for the various flow regimes, and are usually not under control situation. Flow regimes vary depending on operating conditions, fluid properties, flow rates and the orientation and geometry of the pipe through which the fluids flow. The major factor that caused different type of flow regimes are transient effects, geometry/terrain effects, hydrodynamic effects and combinations of these effects. Transients occur as a result of changes in system boundary conditions like opening and closing of valve. Geometry and terrain effects occur as a result of changes in pipe-line geometry or inclination. In the absence of transient and geometry/terrain effects, the steady state flow regime is entirely determined by flow rates, fluid properties, pipe diameter and inclination. Such flow regimes are seen in purely straight pipes and are referred to as “hydrodynamic” flow regimes. The entire flow regimes however, can be grouped into dispersed flow, separated flow, intermittent flow or a combination of these. Dispersed flow is a uniform phase distribution in both the radial and axial directions [16].

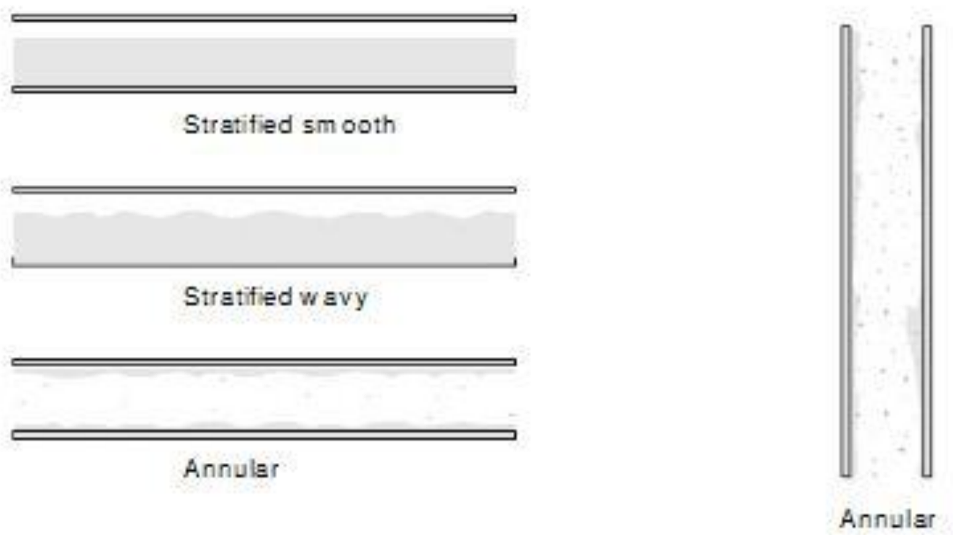


Figure 8: Separated Flow

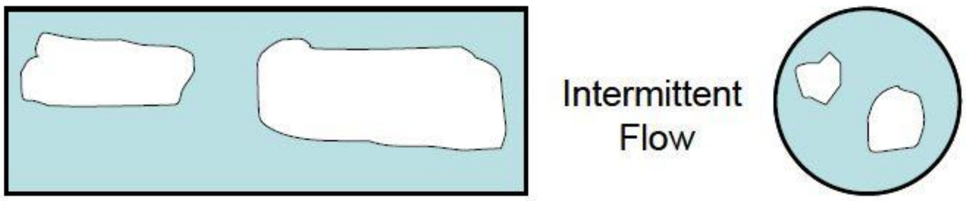


Figure 9: Intermittent Flow

a) Effect of Flow Regime on Wax Deposition

The behavior of the multiphase fluid in a flowing pipe will exhibit various characteristics of flow depending on the pressure of the gas, velocity of the gas, and liquid content, as well as the piping orientation, (horizontal, vertical or sloping) [14].There are some result established has demonstrate the effect of flow regime on wax deposition by the tests at different flow rates with the same difference between the oil and glycol inlet temperatures. The deposit thickness was found to decrease rapidly with increasing flow rate in laminar flow and after the flow became turbulent, the thickness was much less sensitive to an increase of flow rate [23]. Although the situation of this experiment no really similar with this project based, however this statement has correlate the effect of flow regime on wax deposition.

2.2.5. Phase Diagram for Waxy Crude

Phase diagram of a crude oil prone to both asphaltene and wax precipitation as shown in Figure 10. During an isothermal de-pressurization, depending on the temperature, only the precipitation of asphaltenes (Point A) may be encountered or the precipitation of wax (Point B) followed by the precipitation of asphaltenes (Point C) may be encountered. Precipitation of asphaltenes followed by wax is also possible. A co-precipitation may also occur at the same pressure (Point D) [25].

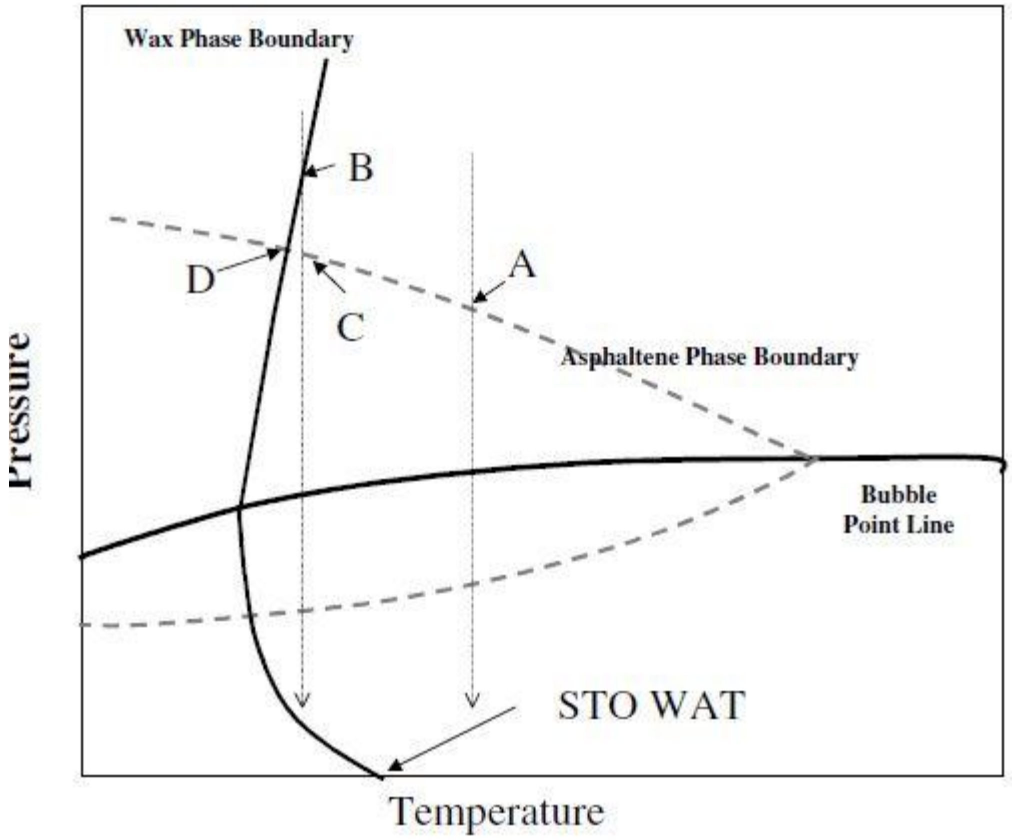


Figure 10: Conceptual P-T Phase Diagram of a Crude Oil

CHAPTER 3

METHODOLOGY

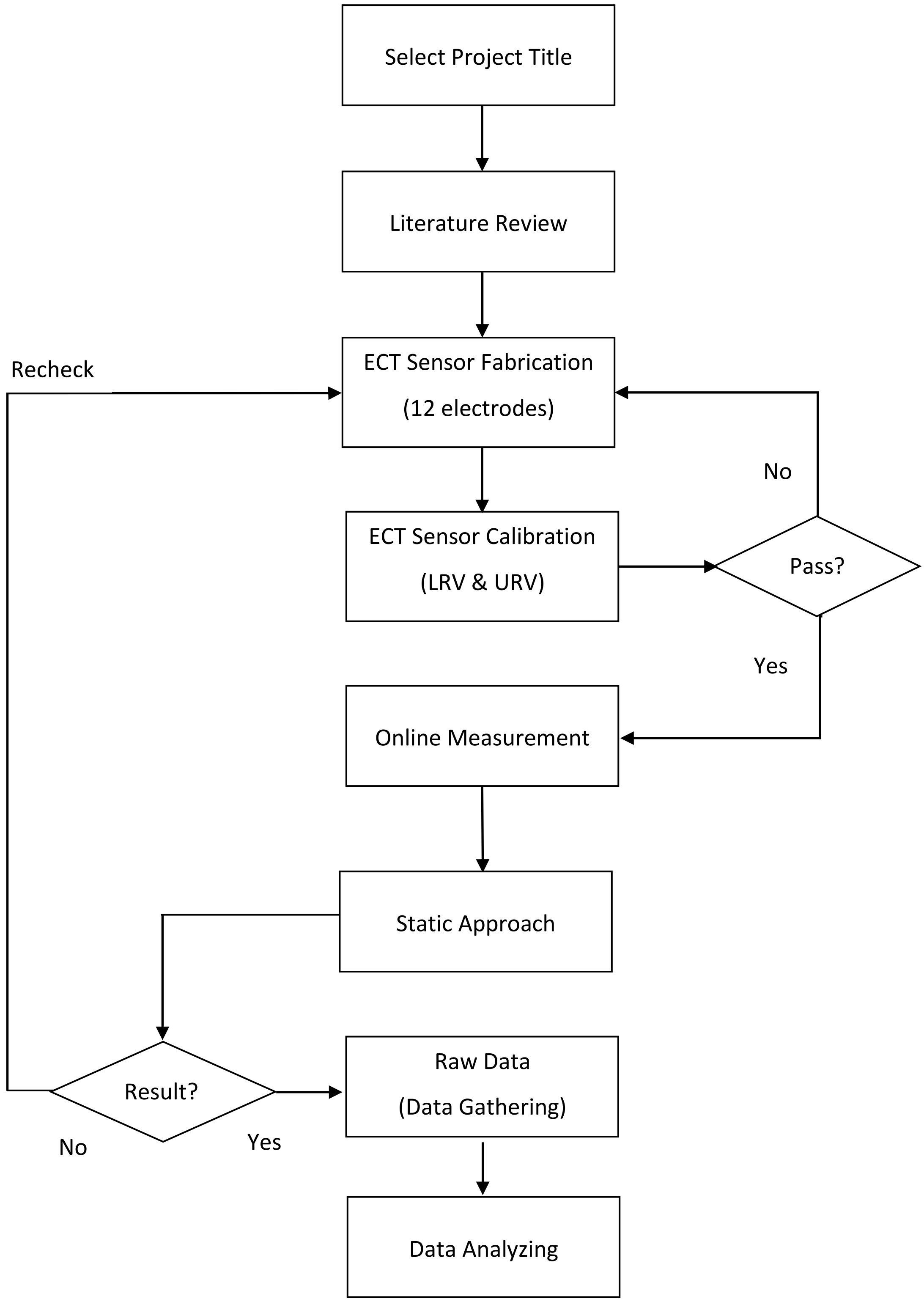
3.1. Project Planning

First step taken for this project begin with the topic selection which based on background understudy in Electrical and Electronic Engineering course as the way of implementation towards knowledge learned. There are several references like journals and research paper being study in order to get the right understanding either for sensor design, waxy crude behavior and also data acquisition approach where these concepts will be applied in this project later on. Based on literature review taken, twelve electrodes is the most suited number of electrode to measure multi-phase flow as in this project. By this decision the sensor can be fabricate which will involve some hardware material.

The interface module of Industrial Tomography System (ITS) M3000 Multi Modal Tomography System is used as an interface between sensor and computer for either sensor calibration, online measurement and also for data acquisition that will be tabulates by computer. For the calibration purpose the sensor will be set at lower range value (LRV) and upper range value (URV) based on dielectric constant value. For the LRV is done by measuring fully gas phase in the pipeline and for the URV is done by measuring pure distilled water. After pass the calibration procedure, then the online measurement is conducted as the value of raw capacitance and wax fraction will be measured in percentage between LRV and URV.

For the online measurement, the procedure will be mainly varying the temperature where the crude oil will be static inside the body of ECT sensor. Then data been gathered and computer are used to record data which then will be used for analyze purposes.

3.2. Flow Chart of Project



3.3. Tools and Equipment

No	Software/ Hardware	Description
1	Industrial Tomography System (ITS)	As the interface module to conduct calibration, data acquisition, data processing, and data analyzing
2	Data Cable And SMB plug	Interconnection between each electrodes of sensor to ITS electrode plane (one SMB Cable for each electrode)
3	Copper Tape	Used for electrode fabrication which arrange around outer side of PVC
4	Aluminum Plate	Earthed radial screen (shielding)
4	Cylindrical Acrylic Tube	As body material and holder of sensor
5	Soldering Iron and lead	Interconnection of data cable terminal to copper tape.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Sensor Fabrication

Procedure in order to fabricate ECT sensor will be as listed in the Table 2.

Table 2: ECT sensor components fabrication steps

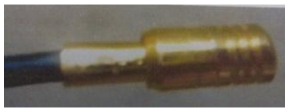
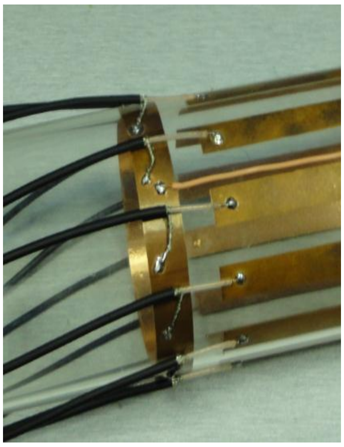
Steps	Procedures	Images
1	Prepare data cable with the SMB plug, as below : a) Gather the SMB plug portion b) Solder the SMB plug needle with the gold multi core wire in the data cable c) Assemble the SMB plug with the data cable	a)  b)  c) 
2	Measure the sensor body diameter and decide the length and the width of the electrodes included the ground electrode. Detail dimension refer to Table 3.	
3	Mount the earth screen cable to the ground while the center core at the electrodes portion.	

Table 3: ECT sensor shielding fabrication

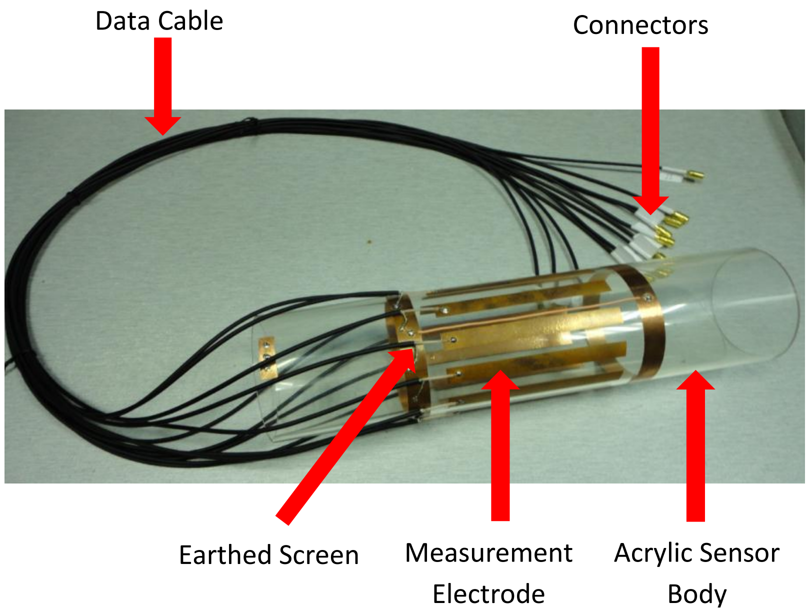
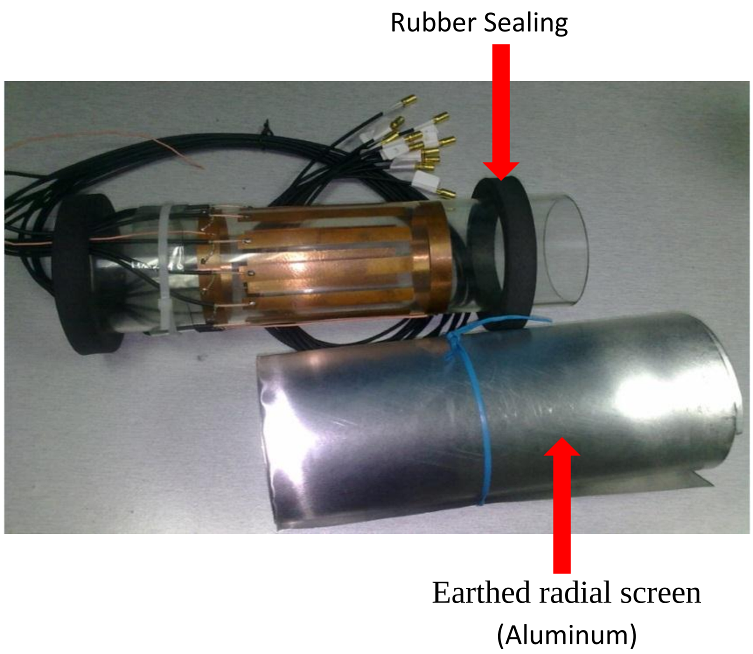
ECT Sensor	**Description**
	ECT sensor with measurement electrodes and earth screen at both ends of the measurement electrodes
	ECT sensor with outer earthed shield that will be connected with earthed screen that attached to body of the sensor. Rubber sealing will protect the measurement electrode from water ingress.

Figure 11: Assembled ECT Sensor

Table 4: ECT sensor specification

No	ECT sensor components	Specification
1	Number of electrodes	12
2	Measurement electrodes length	10.00 cm
3	Measurement electrodes width	1.00 cm
4	Distance between electrodes	0.20 cm
5	Ground electrode width	1.00 cm
6	Inner body diameter	7.80 cm
7	Outer body diameter	8.00 cm

4.2 Sensor Validation Test

After completing the fabrication of sensor, there will be some inspection need to be done in order to ensure it is capable to perform measurement correctly. Among test that been executed is as below:

4.2.1 Cable Connectivity Test

The purpose of this test to make sure all the cable from the end center pin connector is in contact with each electrode. Method used to perform this test is by checking the resistance between these two points, and supposedly there will be some reading in ohm Ω if there are contacts. Detail result can be referring to Table 4.

Table 5: Connectivity Test

No of Electrodes	Measurement (Ω)
1	0.34
2	0.33
3	0.33
4	0.35
5	0.34
6	0.34
7	0.33
8	0.33
9	0.35
10	0.34
11	0.33
12	0.34

4.2.2 Sensor Calibration Test.

Calibration test been done purposely to set the lower range value (0) and upper range value (1) within span measurement. The sensor is first filled with the lower permittivity material in this case air as to set lower range value. It is next filled with the higher permittivity material that is distilled water for the upper range value which must has higher dielectric property than the crude oil. This is important in order to maintain the span of measurement is within the range. The calibration range from the tomograms data differs from blue to red that is indicating ‘0’ for low (blue) and ‘1’ for high (red) as per result below:

a) Lower Range Calibration:

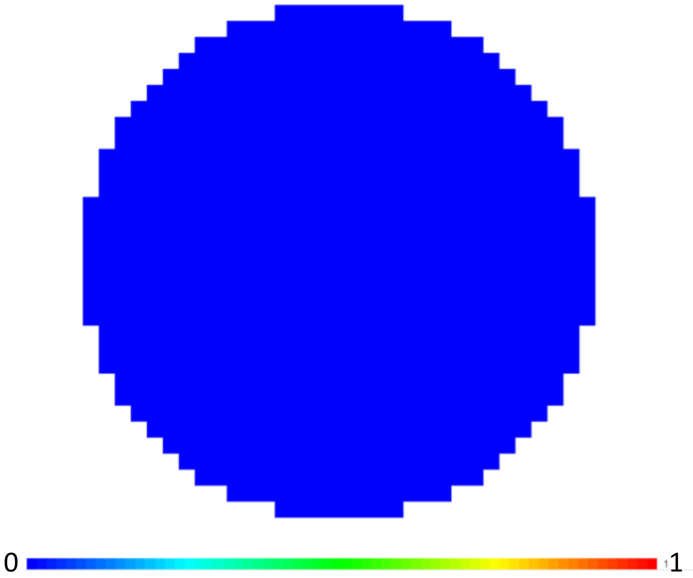


Figure 12: Lower Range Tomograms

b) Upper Range Calibration:

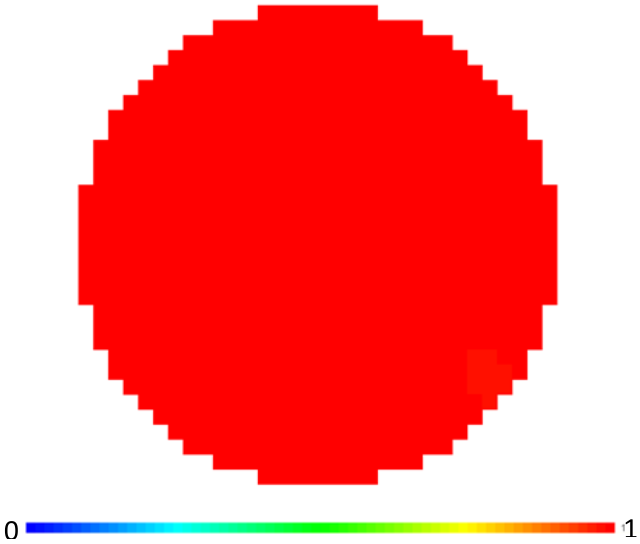


Figure 13: Upper Range Tomograms

Besides the tomograms image obtained there will be also data measured for each independent capacitance value that consist of 66 different measurements either for low and high calibration. The result gained will indicate span of capacitance measurement as below:

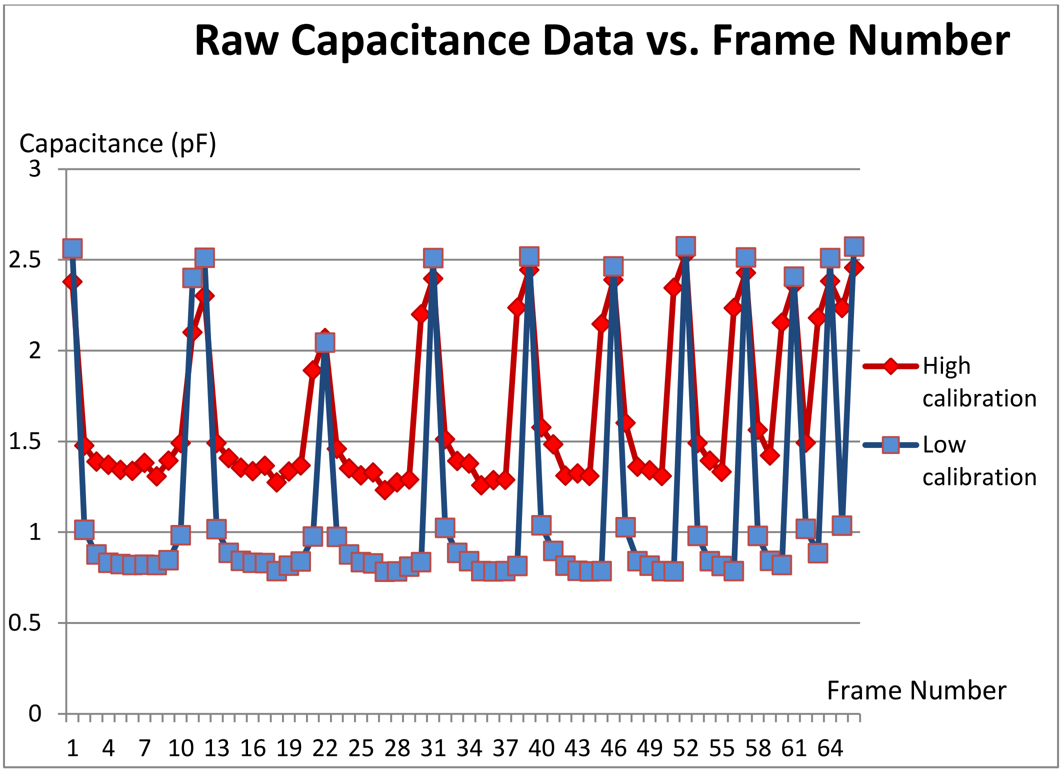


Figure 14: Calibration Span Measurement

4.3 Crude Oil Preparation

The sample of crude oil from the Sepat field firstly needed to be heat up in order to change back towards liquid phase since at the room temperature it is still below the WAT (wax appearance temperature) which at 35° Celsius. After the changes into liquid phase, the crude oil needs to be stirred as to maintain fine homogeneity characteristic. At this moment the crude oil can be transfer from the barrel as in Figure 15 towards small container for further experimental procedures.

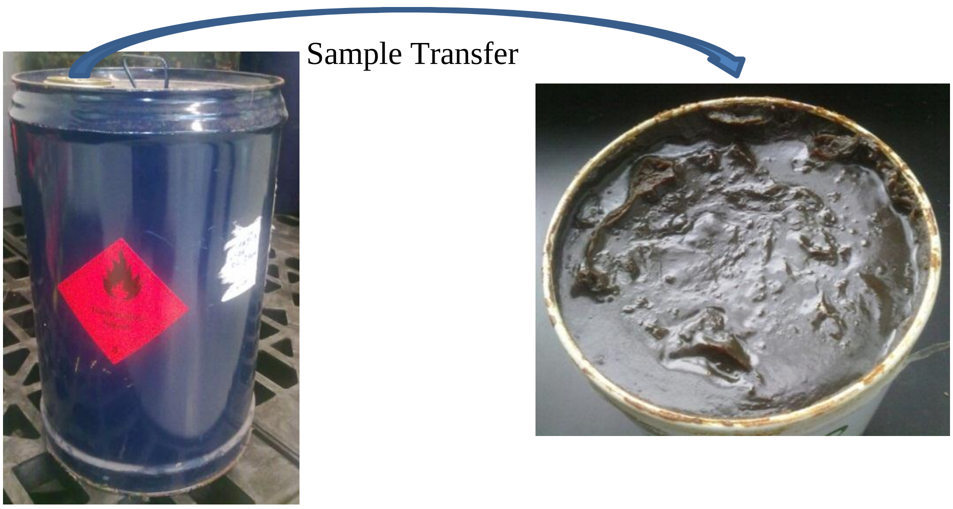


Figure 15: Crude Oil Sample

4.4 Online Sensor Measurement

For the online measurement, the surrounding temperature of the sensor will be varies while maintaining the crude oil under same pressure which at fixed position inside the sensor. One of the characterization that been measured from this experiment will be the independent raw capacitance value that can be verified in the Figure 16. Based on the raw capacitance value obtained, the measurement shows that as the surrounding temperature varies there will be some significant correlation towards the sensitivity of the electrodes in ECT sensor. As the temperature decreases from 50° Celsius to 20° Celsius, the capacitance measurement seem to keep very close value to each other however there are constant trending showed. This behavioral showed that as the crude oil cooled down the raw capacitance slightly increases.

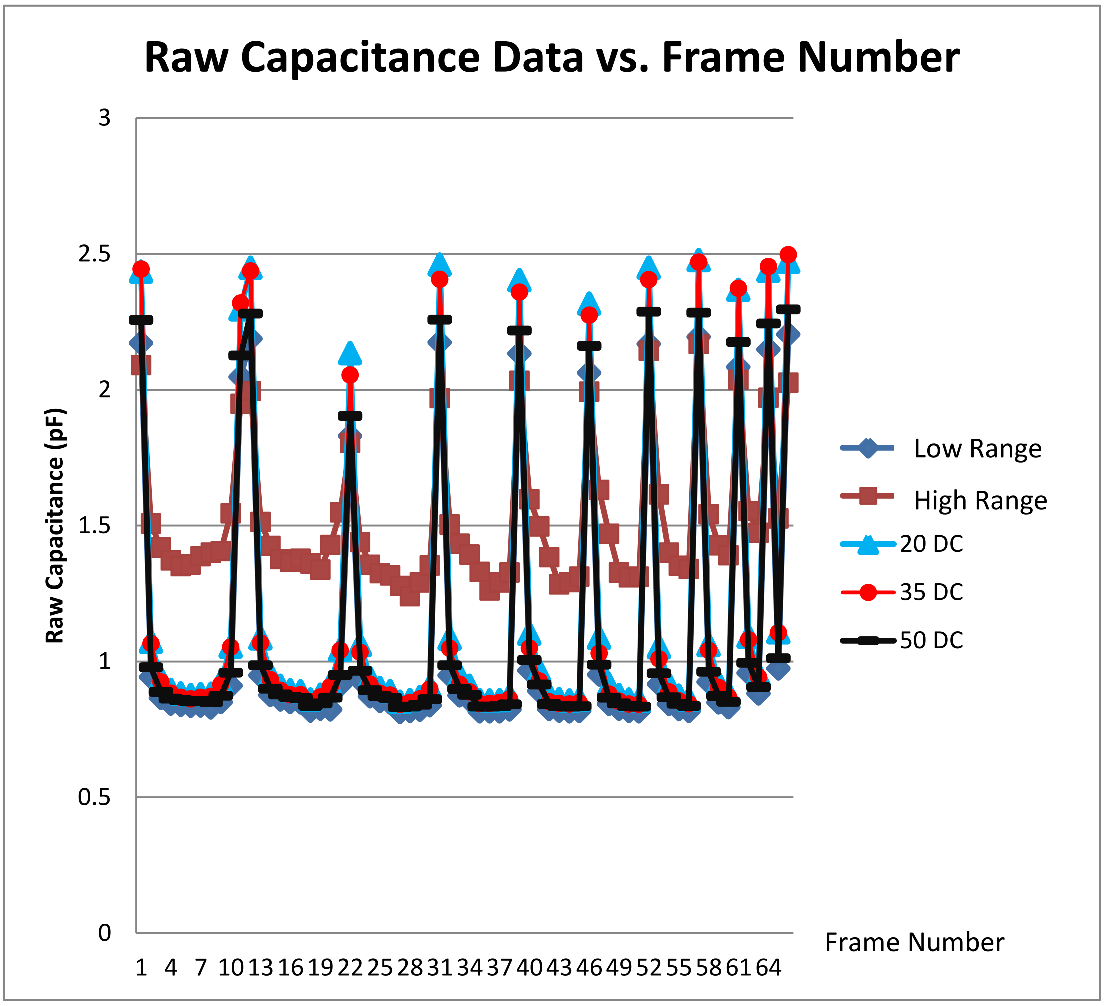


Figure 16: Temperature Effect on Crude Oil

4.5 Measurement Result

Raw capacitance value for 12 electrodes sensor supposing will consist 132 number of raw capacitance measurement but there will be just 66 number of independent capacitance measurement which recorded by ITS data acquisition system. Based on the Figure 16, there are some data obtained cannot be used further due to some technical error and the classification been done in order to get an appropriate result. Figure 17 will be the result by taking the best three set iteration of raw capacitance result that can be used as data information.

Based on Figure 17, as the temperature keep increasing, the raw capacitance value showing some trending that quiet similar from all the series in the Figure 17. After passing over 30˚C, the raw capacitances start to going down until 50˚C whereby before 30˚C the raw capacitance slightly at the constant value. Whereas for the observation done at the physical phase showed that, 35˚C will become as the turning point for the crude oil either for the wax formation (decreasing temperature) or deformation (increasing temperature).

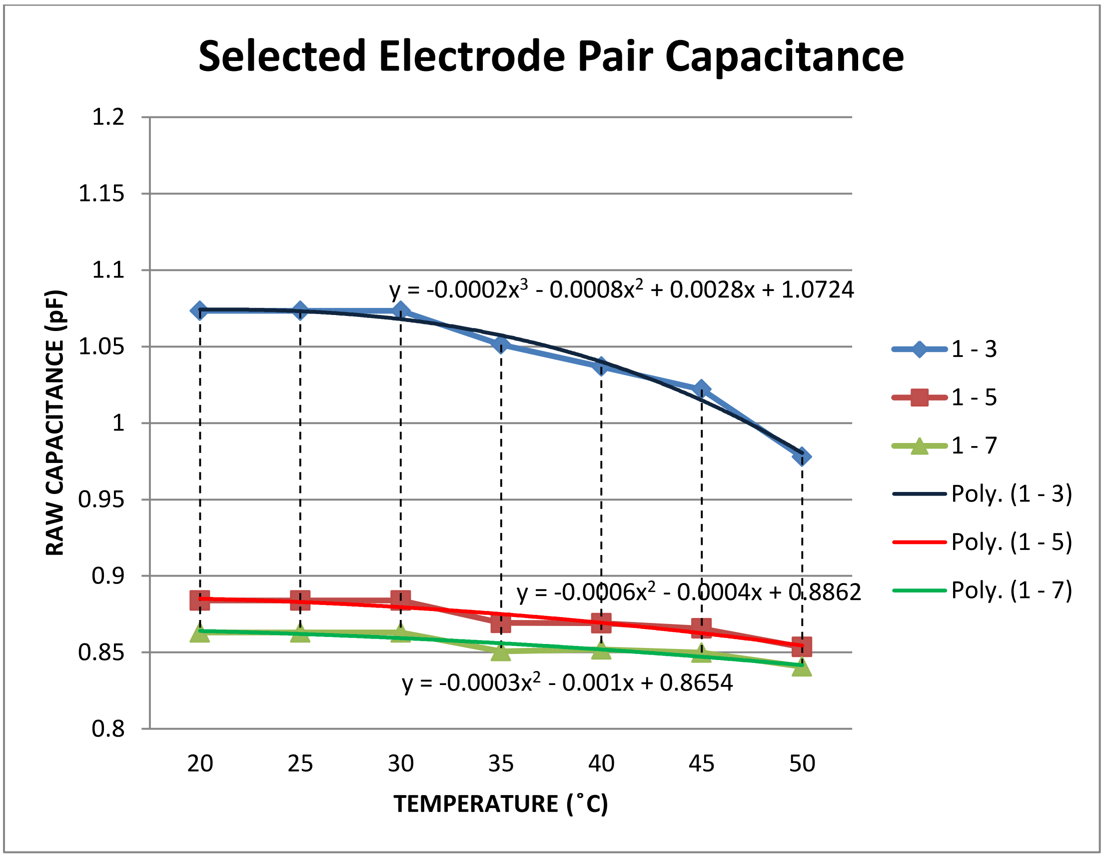


Figure 17: Raw Capacitance versus Temperature (℃)

4.6 Discussion

Based on the information gained, by using polynomial line graph estimation there will be a relation that can be created for this type of crude oil where the temperature is inversely proportional to the capacitance of the crude oil.

$$Temparature \propto \frac{1}{Capacitance(Crude\ Oil)} \qquad \text{Eq(7)}$$

This finding also can be support by another established correlation as showed in the equation 8 and equation 9.

$$Temparature \propto \frac{1}{Dielectric\ Constant} \qquad \text{Eq(8)}$$

For the equation 8, as the temperature increase, molecules will has more thermal energy that lead to greater amplitude of random thermal motion. This cause greater range of deviation with field and less aligned to each other which reducing the orientation polarization that will root to decreasing the value of dielectric constant. In another word dielectric constant value is inversely proportional with temperature [28].

$$Capacitance\ (Crude\ Oil)\ \propto Dielecctric\ Constant \qquad \text{Eq(9)}$$

This relation been engaged from one of the capacitance fundamental explanation where as the positive charge from the capacitance electrode will attract negative charge in the dielectric. While for the negative capacitance electrodes will attracts positive charge in the dielectric. This cause electric field inside the dielectric will be in the opposite direction to the capacitance electrodes electric field. The capacitance electrodes electric field will reduce due to some cancellation that occurs. As the capacitance electrodes is already charged up and disconnected, the charge Q is constant. The potential different, V must be smaller since the electric field of the capacitance electrodes that reduced. With the same charge, Q but smaller potential difference, V this will lead for higher value of capacitance. [29]

As the equation 8 and equation 9 been merged by replacing dielectric constant, equation 7 comes out and this showed that the experimental result obtained follows the established theoretical equation.

Whereas for the online tomograms image obtained, the measurement procedure has been focusing on the WAT (wax appearance temperature) of this type of crude oil which at 35℃. The image of the tomograms will be as in Figure 18.

(a) Picture of waxy crude (b) Image from ECT

Figure 18: Online Tomograms (at 35℃)

Tomograms image will be analyzed further by using image processing method in order to obtained wax fraction percentage within the crude oil which gives 15.28%. This data gives some information that as the temperature achieved at the wax appearances temperature there will be a formation of wax within crude oil. Although the data obtained for the tomograms image quiet limited but this initial founding can lead towards another hypothesis for further research.

Based on the connectivity test, result showed the connection for each electrodes can be consider in the good condition since all the resistance measurement are precise and accurate which are around 0.33Ω to 0.35Ω. While for the calibration test, the sensor seems to be operate with the whole system at satisfied level although the ITS data acquisition system that did not give consistent measurement but the data gained still can be used for further study. As the sensor been calibrated, either for the lower or the upper range of calibration, the result gained show that the measurement data nearly follow standard calibration output. During the calibration, the sensor was held vertically and was occupied by air for the low calibration while distilled water for the high calibration. The raw capacitance data is higher for the high calibration than lower calibration because the distilled water medium that has higher dielectric constant value. Where dielectric constant value for distilled water is 80 compare to the value for air which at 1.

During the online measurement, crude oil been placed in the section of sensor that will surrounded by water as the temperature control media. Although the fabricated sensor is already equipped with the ground shielding with rubber as seal, but as the precaution way some temporary plastic shielding was attached to the sensor as to protect the electrode from short circuit due to water contaminated. As per figure 17, the temperature founded to be inversely proportional to the raw capacitance of the crude oil as for all three pair set of capacitance. This correlation founded also can be related with the dielectric constant of the crude oil since dielectric constant is also affected by the temperature. As the temperature increase, this will root to decreasing the value of dielectric constant. In another word dielectric constant value is inversely proportional with temperature [28].

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In the conclusion, the ECT sensor is fabricated successfully as to achieve the first objective of this project which consists of measurement electrodes, earth screen at both ends of measurement electrodes, outer earth shield, and mounted data cables that crimped with connector at single ends. The measurement electrodes are located outside the sensor body to prevent from direct contact with the waxy crude oil, (non-invasive and non-intrusive). While the earth screen used to reduce interference between the sensors applied signal and any devices present near the sensor. 12 measurement electrodes are chosen in order to obtain 66 independent capacitance measurements.

As been planned, the sensor need to be calibrate before proceed with the online measurement procedures. The calibration procedures will includes low and high calibration that using lower permittivity material (low dielectric constant) that is air and high permittivity material (high dielectric constant) which is distilled water respectively. The air is chosen as the lower range calibration because it has lower dielectric property compare to crude oil which lead to lower capacitance value as well. While distilled water was chose as high calibration range due to its higher dielectric property compare to the crude oil value which will proportionally give higher capacitance value. This arrangement is important to ensure the online raw capacitance measurements of the crude oil are within the calibration range. Since this procedure has successfully been done, the second objective of this project seems to be under the satisfaction.

In online measurement, the surrounded temperature has been varies as started from 0° Celsius up until 30° Celsius for the time being result. Further temperature increment will be run up to 50° Celsius. The data obtained for the online measurement showed a significant correlation between the surrounded sensor temperatures with the raw capacitance measurement as in Figure 16. Based on the selected electrode pair as in Figure 17, as the temperature increased especially near the WAT (35° C) the raw capacitance measurement indicated a drastic decrement compare to the lower temperature increment before that. This state occurs might be due to the physical phase changes from the liquid to solid phase which effected the raw capacitance measurement. As the result obtained from the online measurement has established some significant correlation, the third objectives of this project that rely on online measurement also seem to be reached. However in order to get concrete statement regarding this situation other further research need to be explore as to get better proving which rely based on the experimental result.

As the conclusion, crude oil characterization is very important for the industry since this will be the initial point before all the other industry especially oil and gas going to operate. This project has done on the crude oil characterization on phase behavior during cooling down period through the experimental work that creates some relation of the crude oil sample towards the thermal effect. The capacitance (crude oil) is inversely proportional to the temperature and directly proportional to the dielectric constant value. This correlation has establishing the phase behavior characteristic during cooling down period for waxy crude which in line with the last point of objectives that been issued. The differing data obtained can be improved by identifying accurate data and good measurement procedure. This paper is part of ongoing research. The correlation obtained from this project still at general phase and advance research can be proceed in order to get further detail characterization of the crude oil.

5.2 Recommendation

The recommendation during the project is that the procedure of the experiment can be improved so that accurate and precise data can be measured during the experiment either for calibration or online measurement. For the online measurement of this project, method used to control the ambient temperature as well as the crude oil temperature inside the sensor is by adding hot water to the surrounded of the sensor as temperature controlling strategy. Although the demanded temperature can be achieved, but there will be inconsistent in measurement since the temperature cannot be control at consistent value while measuring the data. So for more accurate temperature controlling procedure, the crude oil can be immersed within water bath since it can provide stable temperature control.

5.3 Future Works

The experiment will be continued by further research on the characterization of the crude oil by varying another parameter in order to observe the behavior as in real industry situation. The parameter that can be considered mostly by varying pressure applied towards the crude oil while measuring the capacitance and tomograms image. This experimental could lead to another spectrum of finding which might reveal something that can help to resolve the problem that faced at SEPAT field. This is because pressure and temperature are the two main parameter that give big impact towards the problem of pipeline blockage as to transfer the crude oil from the underneath earth toward the oil rig at the surface of the sea.

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APPENDICES

APPENDIX A

1.1 GANTT CHART

	week 1	week 2	week 3	week 4	week 5	week 6	week 7	week 8	week 9	week 10	week 11	week 12	week 13	week 14
Title selection / proposal	■	■												
Literature Review		■	■	■	■	■								
Conceptual Study			■	■	■	■	■	■	■					
Extended proposal			■	■	■	■ ▲								
Proposal defense							■	■	■ ▲					
Hardware Design & Fabrication							■	■	■	■	■	■	■	■
Submission Interim Draft Report													■ ▲	
Submission Interim Report														■ ▲

Suggested Milestone	▲

Figure 10: Gantt Chart Final Year Project 1

1.2 GANTT CHART

	week 1	week 2	week 3	week 4	week 5	week 6	week 7	week 8	week 9	week 10	week 11	week 12	week 13	week 14	week 15
Sensor Calibation	■	■													
Online Sensor Measurement		■	■	■	■	■									
Preparation of Progress Report						■	■	■ ▲							
Analysis and Conclusion							■	■	■	■	■				
Preparation for Pre-EDX										■	■ ▲				
Preparation of Report (Draft)										■	■	■ ▲			
Submission of Dissertation (soft bound) & Technical Paper													■ ▲		
Slide Preparation and Oral Presentation													■	■ ▲	
Submission of Project Dissertation (Hard bound)															■ ▲

Suggested Milestone	▲

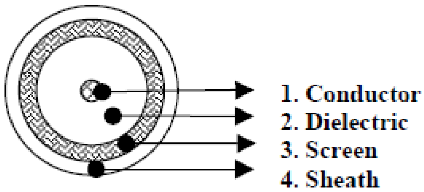
Figure 21: Gantt Chart Final Year Project 2

APPENDIX B

	TECHNICAL DATA SHEET	code	**MRG1740**
		version	**2**
		date	**2005-11-09**
	R.F. CABLE 50 OHM RG 174 U CCS	page	**1/2**

APPLICATION
Coaxial cable used for Radio-frequency, designed according MIL-C-17F/119F

CONSTRUCTION



1) Conductor	7x0.16 mm copper clad steel wire
Diameter	0.5 mm
2) Dielectric	Solid PE
Diameter	1.50 mm ± 0.10 mm
3) Screen	braid
Material	0.1 mm tinned copper wire
Diameter	1.97 mm ± 0.11 mm
4) Sheath	PVC
Diameter	2.80 mm ± 0.10 mm
Color	black

REQUIREMENTS AND TEST METHODS
Test methods generally in accordance with MIL-C-17F/119F

1) Conductor	
Elongation at break	$\geq$ 1%
3) Screen	
Coverage	86 %

Electrical characteristics

Mean characteristic impedance	50 ± 2 Ohm	
DC resistance inner conductor	$\leq$ 317 Ohm/km	
Capacitance at 1 kHz	100 ± 3 pF/m	
Velocity ratio	0.66 ± 0.02	
Insulation resistance	> 10^4 MOhm.km	
Voltage test of dielectric	3 kV dc	
Corona	$\geq$ 1.5 kV ac	
Return loss at..	100 – 400 MHz	$\geq$ 22.5 dB
	400 – 900 MHz	$\geq$ 19.2 dB

APPENDIX C
Partial List of PETRONAS Carigali Fields with WAT, Pour Point, and Wax Content

Field	Fluid	Location	WAT/Cloud Pt (°C)	Pour Point (°C)	Wax Content (wt%)
Angsi	Oil	Malaysia	39	26	12
Anding Utara –1	Oil	Malaysia	61	30	11
J4	Oil	Malaysia	32	27	26
D21	Oil	Malaysia	41	32	22
Penara	Oil	Malaysia	68	51	24
Sepat	Oil	Malaysia	35	35	18
Malikai	Oil	Malaysia	22 (CWDT)	18	5
Diyaberkir	Oil	Turkmenistan	36	17	17
Thang Long	Oil	Vietnam	60	36	19
Topaz	Oil	Vietnam	49	30	12
Chinguetti	Oil	Mauritania	39	15	5
Adar	Oil	Sudan	66	42	27
Owez	Condensate	Turkmenistan	17	-3	4
Rehmat	Condensate	Pakistan	22	19	15
Mehar	Condensate	Pakistan	41	-12	3
Mashrykov	Condensate	Turkmenistan	20	-3	1