STUDY ON DRILLING FLUID USING ELECTRICAL CAPACITANCE TOMOGRAPHY (ECT)

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MECHANICAL ENGINEERING

UNIVERSITI TEKNOLOGI PETRONAS

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Study on Drilling Fluid Using Electrical Capacitance Tomography (ECT)

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Dissertation submitted in partial fulfillment of
the requirement for the
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CERTIFICATION OF APPROVAL

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Approved by,

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MECHANICAL ENGINEERING
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SEPTEMBER 2011

CERTIFICATION OF ORIGINALITY

This is 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 the original work contained herein have not been undertaken or done by unspecified sources or person.

MOHD ATIQULLAH CHE GHAZALI

ABSTRACT

This paper discusses on the applications of Electrical Capacitance Tomography (ECT) system in order to develop a new technique for assessing the drilling fluid. It is widely popular and non-intrusive technique for sensing and measuring the spatial distribution, voidage, and velocities of flow in vessel or pipe. Hence, it helps the mud engineer to access the drilling mud circulation with real time monitoring inside the borehole because traditionally, data collection was acquired at the surface in the mud pit. As kick start of exploration ECT's technique into drilling operation, this project is mainly focusing on the evaluation of drilling fluid using the ECT. The drilling fluid will be placed inside the vessel container with sensor to monitor the projected images at round pixel map based on a set condition in static condition. The findings will give better prediction of data patterns for dynamic condition of the drilling fluid.

ACKNOWLEDGEMENT

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND STUDY

1.1.1 Overview

Drilling fluid (or mud shall carry the same meaning) is a fluid used to aid during the drilling operation. The main functions of drilling fluid are to clean the drill cuttings from beneath the bit and carry them to the surface, exert sufficient hydrostatic pressure against subsurface formations to prevent formation fluids from flowing into the well, keep the newly drilled borehole open until steel casing can be cemented in the hole and moreover to cool and lubricate the rotating drill string and bit. Generally, drilling fluid circulation is start by pumping drilling fluid from the mud pit down through the drill pipe, before come out from the drill bit and going back to the mud pit via annulus.

1.1.2 Types of Drilling Fluid

The drilling fluids can be classified under three major categories which are:

1) Liquids:
    - Water –Base Muds
    - Oil – Base Muds
2) Gases:
    - Foam (Mostly Gas)
    - Aerated Water (Mostly Water)
3) Gas-Liquid Mixtures:
    - Air
    - Natural Gas

So, during the drilling operation, knowing the drilling fluid properties is crucial because this mud needs to perform all those functions as stated earlier, otherwise the borehole will collapse or drill cutting will accumulates at the drill bit.

1.1.3 Composition of Drilling Fluid

Typical type of drilling fluid used during the drilling operational is liquid base which are water based mud or oil based mud. This liquid base is a mix up of liquid phase (water or oil), solids particle and additives. As it name, water and oil are the main component with containing almost 80% of overall composition. While solids particle is means to give desired mud properties. Then, the additive is to control viscosity, yield point, strength, fluid loss, pH value, and filtration behavior.

The following is the composition of the water based mud and oil based mud:

I. Water based mud

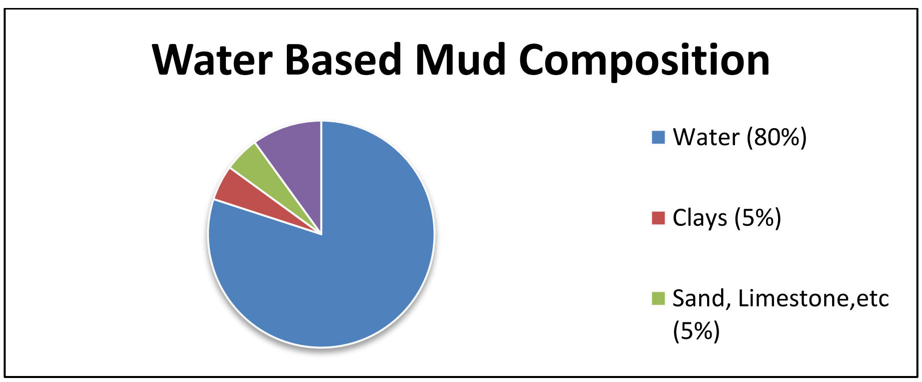


Figure 1.1: Water Based Mud Composition

II. Oil based mud

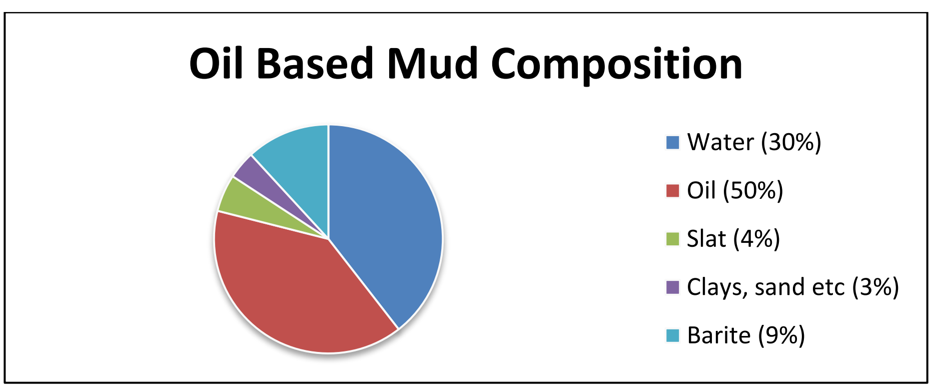


Figure 1.2: Oil Based Mud Composition

The water-base mud are commonly used due to less strictly pollution control and much cheaper compared to oil-based mud. Others are rarely used and only if there is certain condition that required more attention on the formation problems.

1.2 PROBLEM STATEMENT

1.2.1 Problem Identification

Each and every well has a unique formation and characteristic; hence to encounter this problem, the drilling fluid must constantly undergo the diagnostic testing to ensure it meets and fulfill the design functions. In compliance to do this performance testing, there are five factors needed to be considered which are accuracy requirement, personnel availability, time constraint, operating environment and investment and operating cost. Generally, the drilling fluid tests are run in a field support laboratory, in R&D laboratory, or at the well site. For example, usually the field support laboratory is a trailer house equipped with drilling fluid testing equipment at the well site to supplement routine field testing (Zamora et al. 1990).

Therefore, there are needs to develop a new method to evaluate the drilling fluid performance. This method should be efficient in terms of outcome, easy handling and space requirements. With all these criteria, the new method could improve the delivery of information about drilling fluid and further this could help the mud engineer to minimize the drilling operation cost due to high performance of drilling fluid.

1.2.2 Significant of the Project

Based on the problem identification, the method that will be developed is to make image reconstruction of drilling fluid using electrical capacitance tomography (ECT). ECT is widely used in the Oil & Gas and industrial applications such as to monitor the flow inside the pipelines and to obtain information about the contents of process vessels. Other advantage of ECT is it can provide real time monitoring of multicomponent flows within the pipelines. By referring to this advantage, it can be used to monitor drill fluids properties simultaneously while drilling. So, this project will be conducted in series of experiment to explore and examine the drilling fluids properties using ECT.

1.3 OBJECTIVE

- To explore the effectiveness of evaluating the drilling fluids using ECT.

1.4 THE SCOPE OF STUDY

The scope of study is mainly focusing on the precipitation of drilling fluid under static condition. Through this project, different drilling fluid formulation will be used and effects of precipitation drilling fluid from its original condition which is homogeneous state to heterogeneous state as the solids inside the drilling fluid settling down at the bottom over time. Hence, the laboratory work will be done by observing closely on the voltages difference measured and projected images produced by ECT.

1.5 THE RELEVANCY OF THE PROJECT

By executing this project, there will be various options to the mud engineer to evaluate the drilling fluid performance. Hence, this method provides understanding on the precipitation of drilling fluid under static condition which could be evaluated inside the borehole with real time monitoring system.

1.6 TIME FRAME

With proper planning and efficient work load distribution, this project shall meet the time frame which is 6 months to accomplish including all the experimental and documentation process.

CHAPTER 2

LITERATURE REVIEW

2.1 ELECTRICAL CAPACITANCE TOMOGRAPHY (ECT)

2.1.1 Overview of Electrical Capacitance Tomography (ECT)

ECT is a measurement technique to obtain information about dielectric materials inside the vessel by using two set of electrodes placed around its inside or outside of the vessel to measure the electrical capacitance and convert it into an image of the distribution of permittivity. The image projected is using the format of a square grid of 32 X 32 pixels to display the distribution of permittivity.

2.1.2 Capacitance

Capacitance is a measure of the amount of electric potential energy stored for a given electric potential. For a capacitance common device like parallel-plate capacitor, capacitance is directly proportional to the surface area of the conductor plates and inversely proportional to the separation distance between the plates which means the charges (Q) on the plates are proportional with capacitance while the voltage (V) between the plates are vice versa:

$$\boldsymbol{C = \frac{Q}{V}} \qquad (1)$$

Where:

C = capacitance in farads (F)

Q = charge in coulombs (C)

V = voltage in volts (V)

Capacitance also can be measured if the geometry of the conductor plates and the dielectric properties of the insulator between the conductor plates. The equation as following:

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

Where:

C = capacitance

$\mathcal{E}_r$ = relative static permittivity ($\mathcal{E}_r$ = 1), known as dielectric constant, k

$\mathcal{E}_0$= electric constant ($\mathcal{E}_0 \approx 8.854 \times 10^{-12}$ F m^{-1})

d = separation between the plates

2.1.3 Dielectric Material

Dielectric material is a material that has poor electric conductivity. Instead of letting the electric charge flows through the material as in a conductor, this dielectric material may drift the electrons as they pass through it and causing a so called electric polarization. The figure below is showing the orientation of charges before and after applied electric field is introduced.

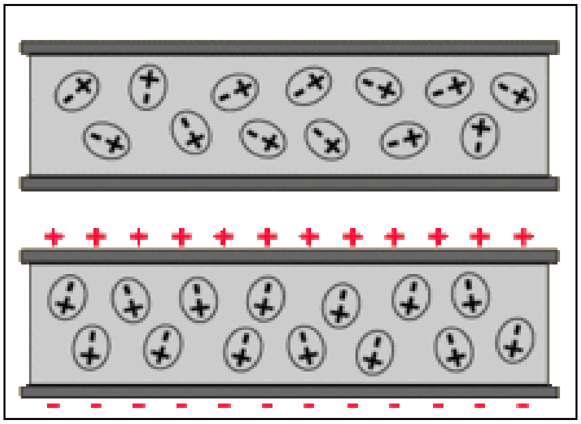


Figure 2.1: Electric Polarization
Above: Random orientations without applied electric field
Below: When applied electric field is introduced, positive charges are displaced towards the field.

2.1.4 Permittivity

By definition, permittivity is the measurement of the resistance that is encountered when forming an electric field in a medium. It is determined by the ability of a material to polarize in response towards the electric field. Below is the permittivity value (dielectric constant, k) for typical materials:

Material	k
Air	1.005
Bakelite	4.8
Cotton	1.3
Glass	4-7
Oil (Petroleum)	2
Paper	3.3
Polyvinyl chloride (PVC)	4.5
Salt	5.9
Silicon	11.8
Vacuum	1
Water, liquid, 20 ℃	80.2
Wax, Paraffin	2.1 -2.5

Table 2.1: Dielectric constant, k, for different materials

2.1.5 Permittivity Model

The capacitance measured depends on the relative permittivity of the materials between the electrodes. There are two relations that can be neither linear nor nonlinear and it depends on the permittivity characteristic on contents of the material inside the vessel. Hence, the permittivity models used to present both relations are the series model, parallel model and Maxwell’s model (Sharath, 2004).

I. Series Permittivity Model

This model can be identified when the two components in the vessel occur as discrete bands and it lies on top of another vertically (refer to Figure 2.2). With that, the effective capacitance could be considered as two capacitances connected in series. In this case, the capacitance and permittivity are related in a nonlinear state. The respective relation of effective permittivity and overall capacitance are shown below:

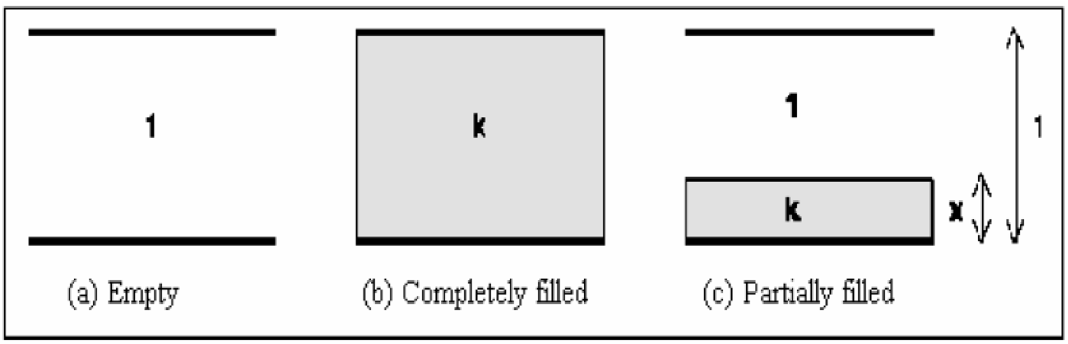


Figure 2.2: The series permittivity model

$$\boldsymbol{\varepsilon_s = \frac{\varepsilon_0 \varepsilon_r x(1-x)}{1-x(\varepsilon_r-1)}} \qquad (3)$$

$$\boldsymbol{C_s = \frac{A\varepsilon_s}{d}} \qquad (4)$$

Where:

Ɛs = relative permittivity for series model

x = height of k level

Cs = capacitance for series model

II. Parallel Permittivity Model

This model can be identified when the two components in the vessel occur as discrete bands and appear horizontally (refer to Figure 2.3). With that, the effective capacitance could be considered as two capacitances connected in parallel. In this case, the capacitance and permittivity are related in a linear state. The respective relation of effective permittivity and overall capacitance are shown below:

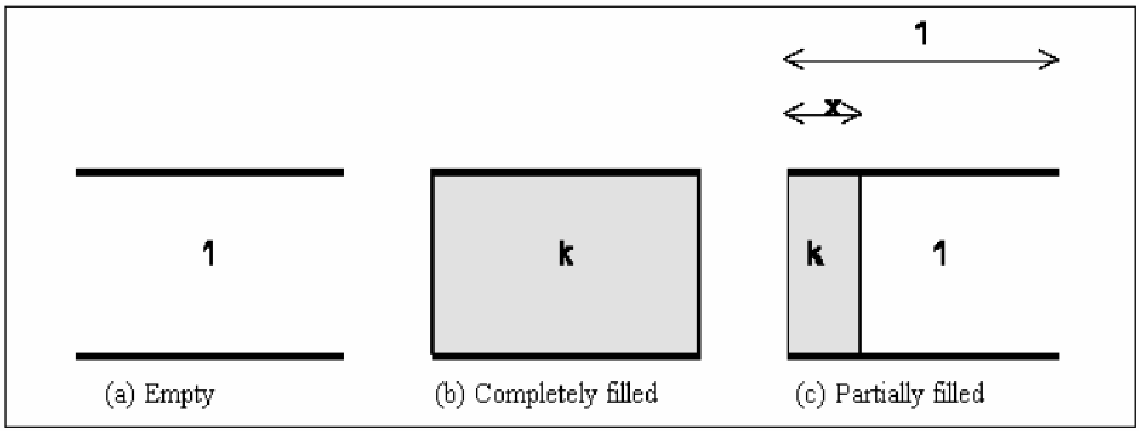


Figure 2.3: The parallel permittivity model

$$\boldsymbol{\varepsilon_p = \varepsilon_0[1 + x(\varepsilon_r - 1)]} \qquad (5)$$

$$\boldsymbol{C_p = \frac{A\varepsilon_p}{d}} \qquad (6)$$

Where:

$\mathcal{E}_p$ = relative permittivity for parallel model

x = length of k level

C_p = capacitance for parallel model

III. Maxwell's Permittivity Model

This model represents the condition when distribution of the materials in the vessel is random. The components of the relative permittivity which are ε_1 and ε_2 mixed, and then the effective permittivity and overall capacitance of the combination is per below:

$$\boldsymbol{\varepsilon_m = \frac{\varepsilon_1[2\varepsilon_1+\varepsilon_2 - 2x(\varepsilon_1-\varepsilon_2)}{2\varepsilon_1+\varepsilon_2+x(\varepsilon_1-\varepsilon_2)}} \qquad (7)$$

Since air is one of the components, ε_1=1. Hence, simplified the equation to

$$\boldsymbol{\varepsilon_m = \frac{[2+\varepsilon_2 - 2x(1-\varepsilon_2)}{2+\varepsilon_2+x(1-\varepsilon_2)}} \qquad (8)$$

$$\boldsymbol{C_r = \frac{A\varepsilon_m}{d}} \qquad (9)$$

2.1.6 Normalization of Measured Capacitance and Permittivity

Prior to the constructing of permittivity distribution images, all values measured from capacitance and subsequently obtained the permittivities required to be normalize. The absolute value of inter-electrode capacitances C_{MA}, is normalized to C_N as per below:

$$\boldsymbol{C_N = \frac{C_{MA} - C_{LA}}{C_{HA} - C_{LA}}} \qquad (10)$$

Where:

C_{HA} = the absolute value of the capacitance measured during the calibration, when the sensor is completely filled with higher permittivity material.

C_{LA} = the absolute value of the capacitance measured during the calibration, when the sensor is completely filled with lower permittivity material.

Similarly with the permittivities value KMA which obtained from (4), (6), and (9) by measuring the inter-electrode capacitances are normalized to KN as per below:

$$\boldsymbol{K_N = \frac{K_{MA} - K_{LA}}{K_{HA} - K_{LA}}} \qquad (11)$$

Where:

K_{HA} = the absolute value of the capacitance measured during the calibration, when the sensor is completely filled with higher permittivity material.

K_{LA} = the absolute value of the capacitance measured during the calibration, when the sensor is completely filled with lower permittivity material.

This normalized value of capacitances and permittivities is ranging between 0 and 1. The value 0 will indicates the sensor is completely filled with the lower permittivity material and the value 1 will indicates the sensor is completely filled with the higher permittivity material.

Same goes to the pixel values in the permittivity image which also should be normalized and the value 0 and 1 indicates the same meaning respectively.

While measuring the capacitance between a pair of electrodes, the first measurement is taken by connecting one electrode to excitation and the other one to measuring circuit (refer to 2.2.2). This capacitance is denoted with C_M. A second measurement is taken between the same pair, but this time the excitation settling is to be zero. In principle, the measured capacitance under these conditions should be zero. In practice, however, a finite capacitance is measured with the excitation voltage set to zero. Eventually, this is caused by spurious capacitive coupling of the CMOS switch gate control waveforms into the capacitance measurement circuit and also known as the charge injection capacitance C_0.

So, the actual measured capacitance is:

$$C_{MA} = C_M - C_0 \qquad (12)$$

And also C_{HA} and C_{LA} can be calculated from the measured values of C_H and C_L:

$$C_{HA} = C_H - C_0 \qquad (13)$$

$$C_{LA} = C_L - C_0 \qquad (14)$$

All the values of absolute capacitances obtained from (12), (13) and (14) are substituted back into (10) in order to calculate normalized capacitances during measurement.

The figure 2.4(a) and 2.4(b) are showing the normalized capacitance and permittivity respectively.

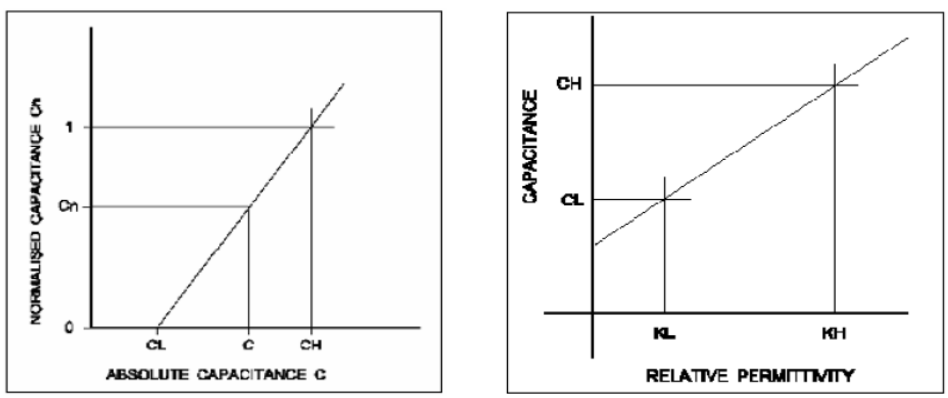


Figure 2.4: (a) Normalized capacitance graph b) Normalized permittivity graph

Next, the normalized permittivity values are mapped onto a square grid of 32 X 32 where the pixel values are presenting same value as normalized permittivity and ranging between 0 and 1. The value of 0 is indicated in blue while the value of 1 is indicated in red on the grid. Subsequently, the intermediate values are represented by the colours between blue and red as it varying gradually during the process.

2.2 ECT SYSTEM COMPONENTS

There are three major components in ECT which are namely capacitance sensor, Capacitance Measurement Unit (CMU) and a control computer.

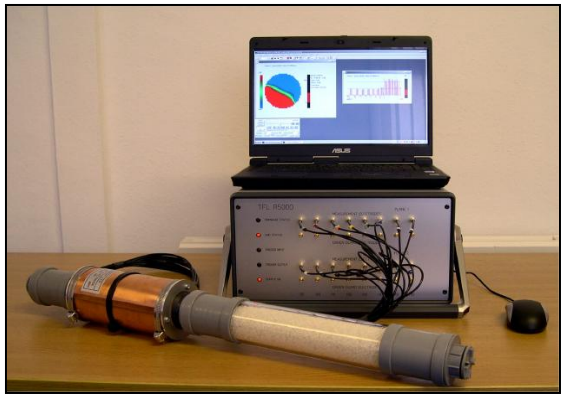


Figure 2.5: ECT major components

2.2.1 Capacitance Sensor

A capacitance sensor is made of a ring of adjacent rectangular electrodes placed around a non-conducting vessel and it's separated by small gaps between them. Both end of the vessel was covered by two cylindrical end guards and the whole assembly grounded by covering with metallic screen in order to avoid external interference.

Basically, number of sensors use is ranging between 8 -12 electrodes sensor per plane. More data can be collected if more sensors are used in single plane. This is because the number of data, M, in one plane can be calculated depending on number of sensors. The formula is per below:

$$\boldsymbol{M} = \frac{\boldsymbol{N}(\boldsymbol{N}-\mathbf{1})}{\mathbf{2}} \qquad (15)$$

Where:

M = Number of data

N = Number of sensors

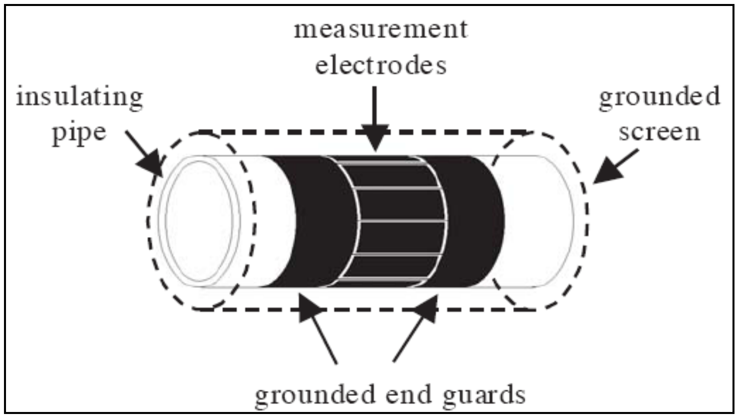


Figure 2.6: The whole assemble of capacitance sensor

2.2.2 Capacitance Measurement Principle

An alternating voltage (Vs) is applied between one electrode (the source electrode) and ground and the resulting currents which flow between the source electrode and the remaining (detector) electrodes to ground are measured (refer to Figure 2.7). These currents are directly proportional to the capacitances between the source and detector electrodes.

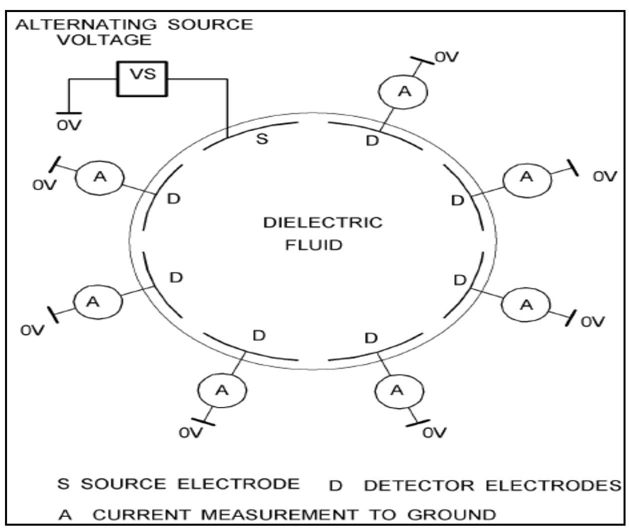


Figure 2.7: Capacitance Measurement Principle

2.3 ECT ADVANTAGES

Gamio et al. (2004) had listed the advantages of ECT compared with other tomography modalities such as:

1) No radiation
2) Rapid response
3) Low-cost
4) Non-invasive
5) Able to withstand high temperature and high pressure.

2.4 DRILLING FLUID PROPERTIES

It is essentially important to regularly measure the drilling fluid during the operational environment since the quality of the drilling could be deteriorated over time. If there are any, immediate action is required to treat the drilling fluid to ensure it performs based on their design function. Basically, the main drilling fluid properties namely are mud density, viscosity, gel strength, filtration and pH. All these parameters are constantly measured using the standard testing methods that have been endorsed by American Petroleum Institution (API).

2.4.1 Testing Methods

Hence, API has provided a guideline for recommended practice in testing the drilling fluid properties. The followings are the testing methods for drilling fluid properties:

1) Mud Balance
    - Determining drilling fluid density/weight
2) Marsh Funnel
    - Checking drilling fluid consistency
3) Rotational viscometer
    - Determining gel strength and apparent viscosity at various shear rates

4) Filter Press
    - Determining mud filtration rate and mud characteristics
5) High Pressure, High Temperature Filter Press
    - Determining mud filtration rate and mud characteristics at elevated temperature and pressure.
6) pH meter
    - Determining H+ concentration
7) Sand Screen
    - Determining sand content
8) Mud Still
    - Determining solids, oil and water contents
9) Titration Apparatus
    - Chemical analysis

CHAPTER 3

METHODOLOGY

3.1 RESEARCH METHODOLOGY

3.1.1 Flow Chart

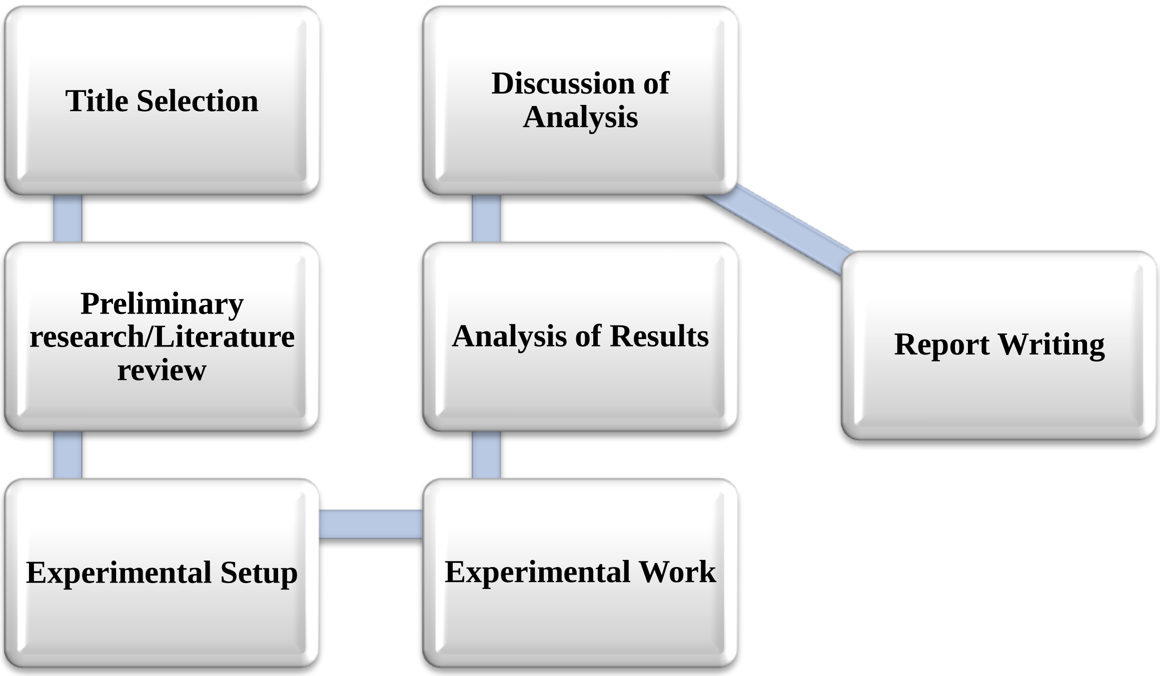


Figure 3.1: Flow chart of Research Methodology

Title Selection: After few discussions with Supervisor, it has been decided to do a research on precipitation of drilling using ECT under static condition.

Preliminary research/Literature review: Study has been made about basic understanding on the drilling fluid properties, ECT system functions and others related to the project.

Experimental Setup: The experiment will be carried out using standard laboratories setup for drilling fluid before proceed to ECT for tomography process.

Experimental Work: In this experiment, different types of drilling fluid formulations (which are the base sample and two formulations with different types of Loss Circulation Material such as nut plug and pineapple) will be used to study the effectiveness of using ECT to evaluate the drilling fluid. Prior to the actual experiment, a testing experiment will be conducted in order to understand the outcome produces by the ECT.

Procedures:

1) Prepare the samples or material
2) Switch 'On' the equipments
3) Set the low and high value for calibration.
4) Do the testing with set of three different conditions
   - Full
   - Half Full
   - Empty
5) Analyze the data using offline tool suite software.
6) Record all the findings.

3.2 Gantt Chart and Key Milestones

Activity	FYP 1			FYP 2		
	June	July	Aug	Oct	Nov	Dec
Title Awarded						
Research on Drilling Fluid Properties and ECT system						
Design and Fabricate the ECT			7th Oct			
Calibration of the equipment				14th Oct		
Conduct the experiment				18th Nov		
Data analysis					2nd Dec	
Draft of Report						16th Dec
Report Completion						23rd Dec

Table 3.1: Gantt chart

3.3 ECT OPERATION SYSTEM

3.3.1 Data Acquisition Unit

For this project, ITS M3000 Multi-Modal instrument is used to conduct the experiments for drilling fluids tomography. The instrument supports both Electrical Capacitance Tomography (ECT) and Electrical Resistance Tomography (ERT) modules. Each module has separate sub-system which supply timed-stamped data and operate concurrently between modules, facilitating multi-modal process tomographic sensing, for example, synchronized data streams.

The Capacitance Measurement Unit (CMU) or Data Acquisition Unit is illustrated below in Figure 3.2.

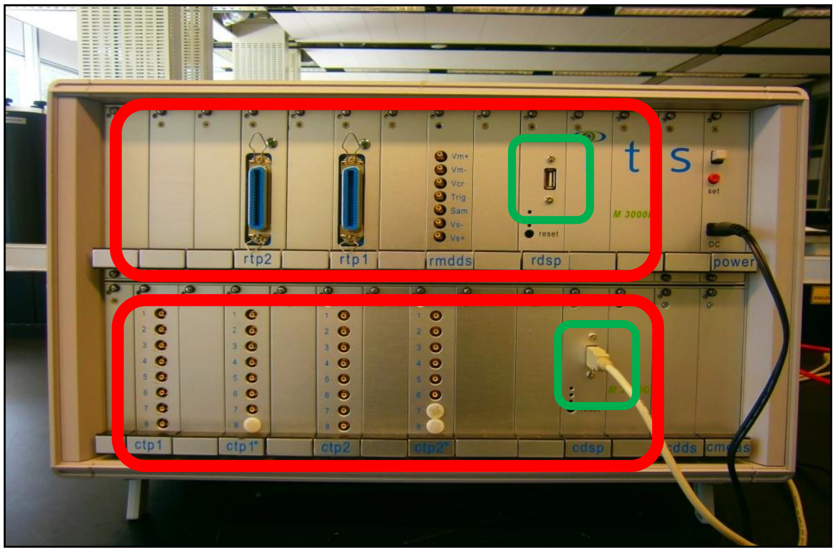


Figure 3.2: M3000 Multi-Modal Data Acquisition Unit

There are two sections at Data Acquisition unit which are upper and lower section. The upper section shown is the ERT sub-system and the lower section is the ECT sub-system.

Data Acquisition unit is link to the PC using USB link cable for each of the ERT and ECT sub-systems.

3.3.2 Sensor

The container used is equipped with 12 electrodes sensor. Hence, based on (15), the number of data will be collected during the experiment is 66

Figure 3.3: The Container with the electrodes sensor

3.3.3 PC System

The ITS M3000 Multi-Modal Tomography system also come with software system known as MMTC for online (during experiment) while ITS tool suite programme for offline (after experiment) and usually used for further analysis of the result.

One of the benefits using the ITS M3000 system is there it has pre-set application used for different set of sensor and plane configuration. Below is the ECT operation function for pre-set application:

File name	Number of		Function
	Planes	**Electrodes per plane**	
Ect-onep-1	1	12	Online Measure, Display, Save
Ect-onep-2	1	12	Offline Display saved data
Ect-onep-ref-3	1	12	Online Measure, Display, Save but using pre-saved reference
Ect-dualp-1	2	12	Online Measure, Display, Save
Ect-dualp-2	2	12	Offline Display saved data
Ect-dualp-ref-3	2	12	Online Measure, Display, Save but using pre-saved reference
Ect-onep8e-1	1	8	Online Measure, Display, Save
Ect-dualp8e-1	2	8	Online Measure, Display, Save

Table 3.2: The ECT operation function for pre-set application.

(For ERT or Both modules Operations, refer to ITS M3000 manual)

3.4 ECT Equipment Testing

In order to comprehend the data obtains from ECT, the calibration test was conducted using plastic PVC pallets and water before proceeding to actual material which is drilling fluid. Thus, it is vital to understand the data obtains since the data pattern almost similar between the experiments.

Figure 3.4: PVC Pallets

Procedures:

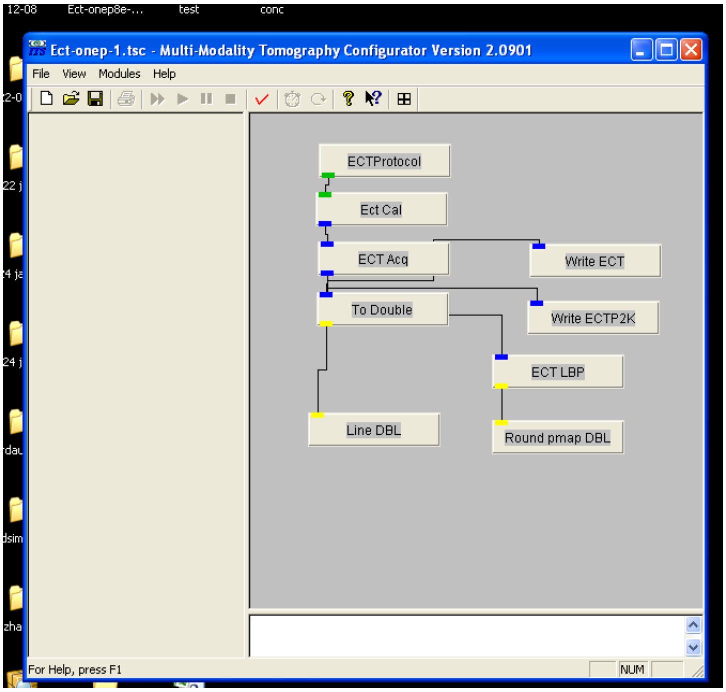
1) The permittivity of the materials is needed to be identified.

2) Before testing can be conducted, ECT must be calibrated first with low and high value. Hence, knowing the permittivity value for material is essential because it used to set the low and high value calibration.

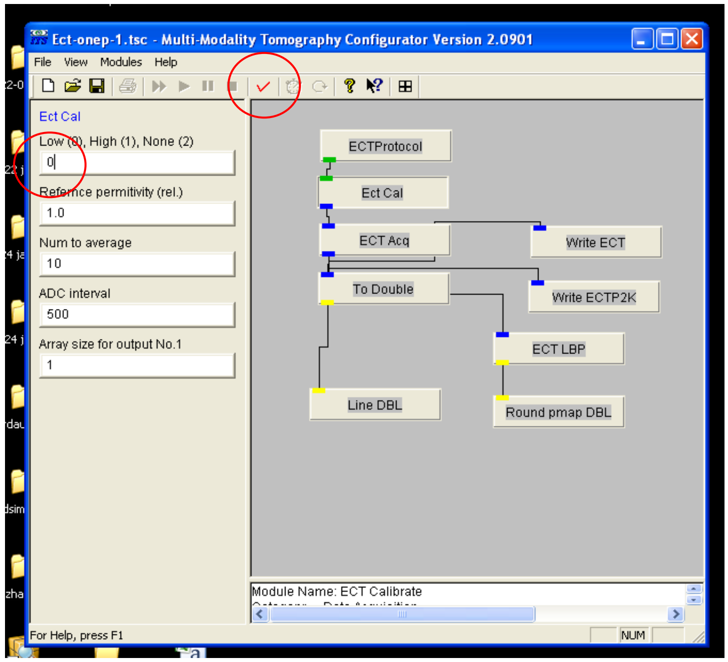
3) Switch On the Data Acquisition Unit and advisedly to provide at least 30 minutes dwell time in order to stabilize the unit prior to conduct the testing.

4) Click the mmtc.exe icon and the mmtc configuration window will appear on the screen

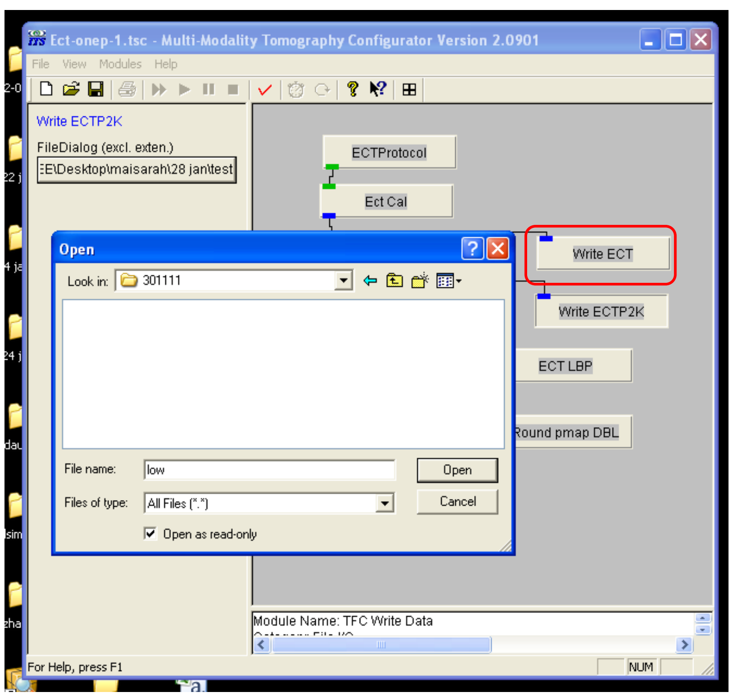
5) Press file management "open" and the pre-application files can be loaded from directory 'c:\Program Files\its\Mmts\Examples' and choose file name 'Ect-onep-1' because the container has 12 electrodes sensor with single plane.



6) Click ‘EctCal’ and set to 0 for the lower case calibration reference. Then, click button ‘right’ for confirmation.

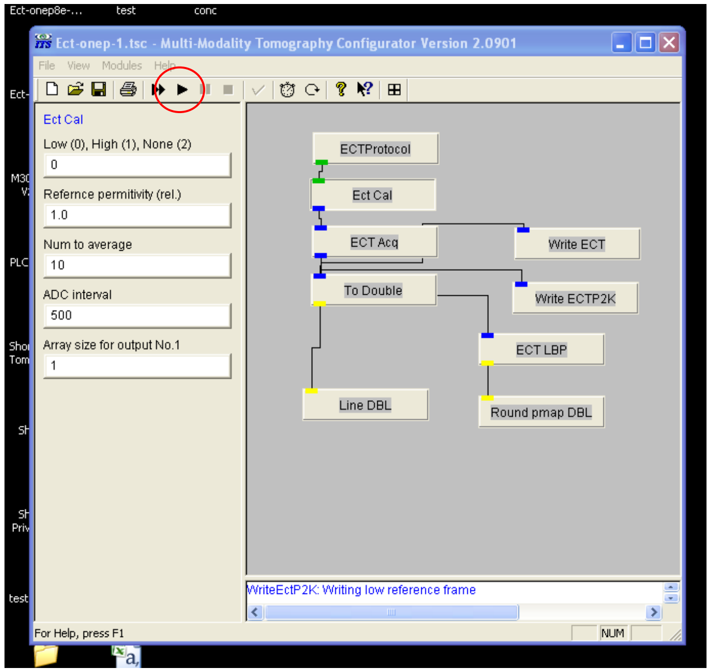


7) In order to use ITS tomography toolsuite software for offline assessment, the data needed to be saved in ‘.p2k’ format form. So, click on ‘Write ECTP2K’ to save instead of ‘Write ECT’.

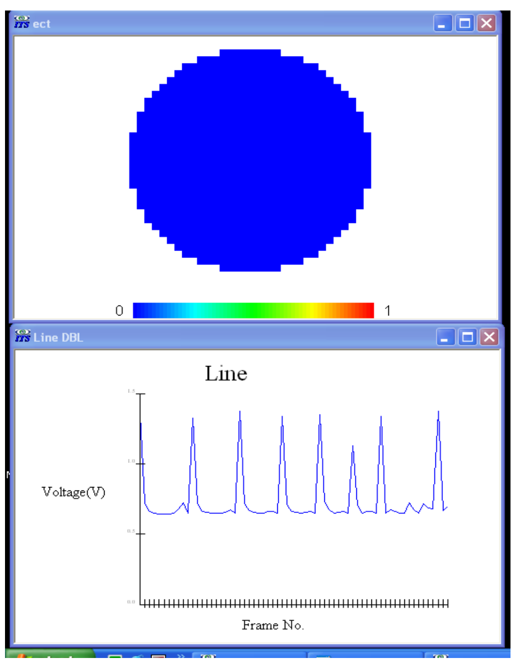


8) Then, click on FileDialog to save the file at your desired folder and name it as 'Low' for low case calibration.

9) Find k value, in this case for air is 1.005 while PVC is 4.5 (refer to Table 2.1). Thus, air is used for low case calibration. Let the container empty and consider it filled with air. Then, click button 'run' to start the calibration.

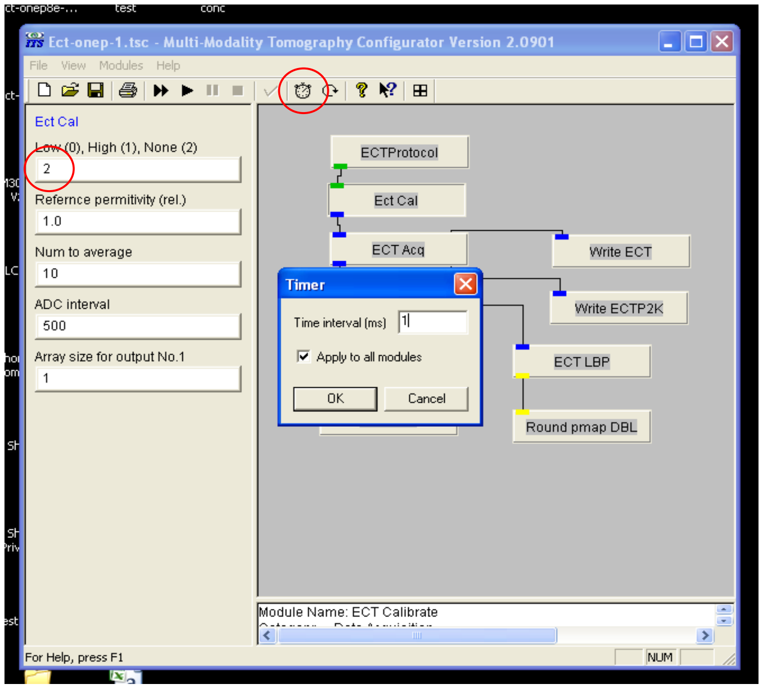


10) Then, wait for a while until these two windows which showing the round pixelmap and voltage reading are pop up to the screen.

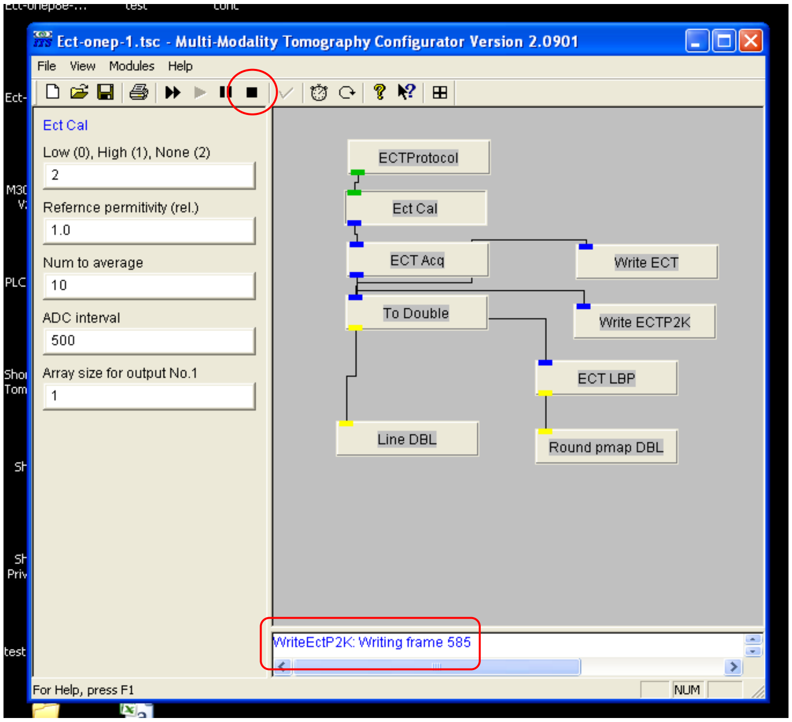


11) Please do not close these two windows otherwise it will reset again, now proceed to the high case calibration using PVC. Click ‘EctCal’ and change to 1 for high case. Similarly to step 6 until 10, however, the file name should be save as ‘High’.

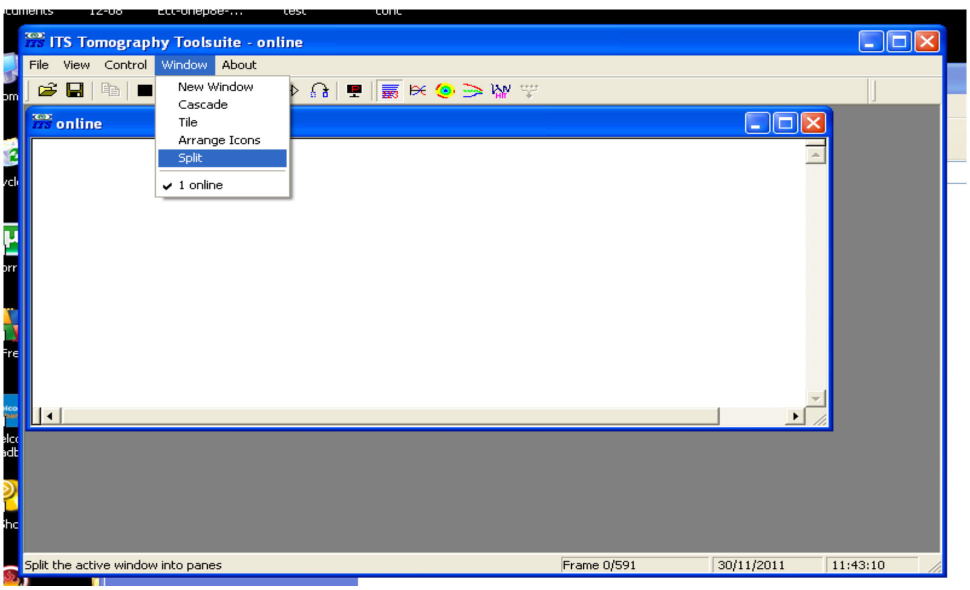
12) Next, to pursue the experiment, click ‘EctCal’ and change to 2 for none before saving at ‘WriteECTP2K’ as online test. Then, set the clock as any time (e.g. 1 ms) and click ‘run’ to start the experiment.

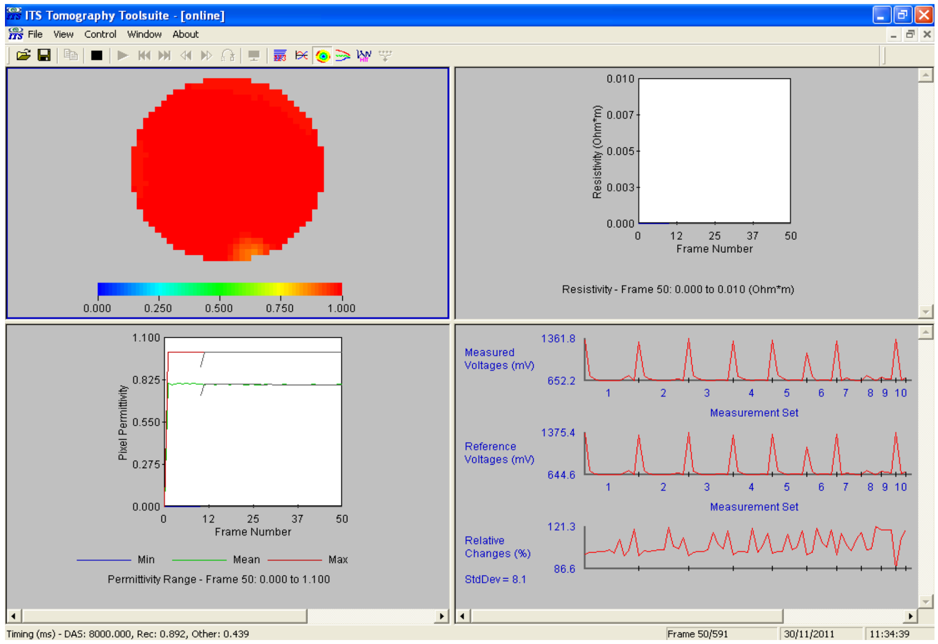


13) The system will do the continuous measurement frame by frame until you press stop button.

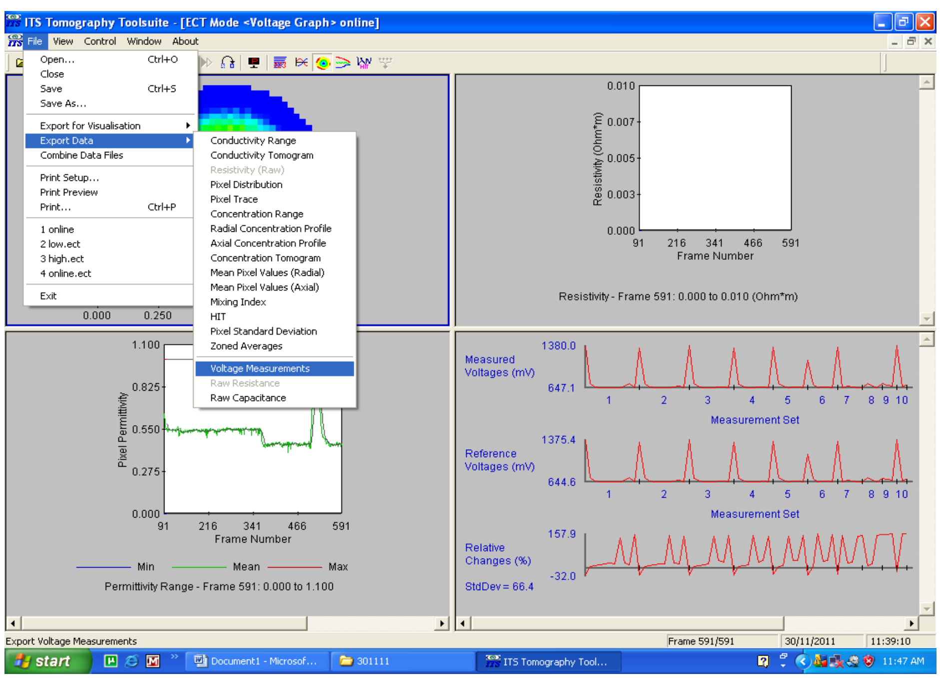


14) After finishing the experiment, close all the windows related to the mmtc.exe **without saving**. Then, find your file and open it up at ITS tomography toolsuite software. Click 'Window' and then 'Split' to obtain 4 different graphic displays.

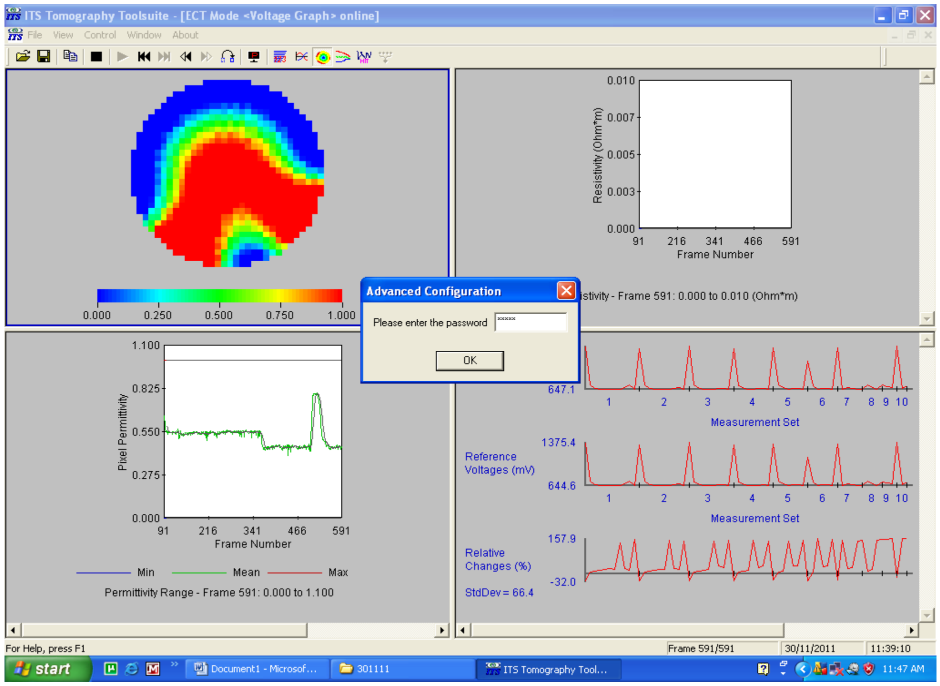




15) From ITS toolsuite, further analysis can be done based on the round pixelmap and pixel permittivity. If additional information is required, the data also can be exported into excel form. Click ‘File’ then ‘Export Data’ and select the data required, for example ‘Voltage Measurements’.



16) Please request the password from the technician. After that, the system will allow you to save the excel file. Repeat the same procedure if you want to export for ‘Raw Capacitance’ value.



CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 PVC TESTING RESULT

4.1.1 Round Pixel Map

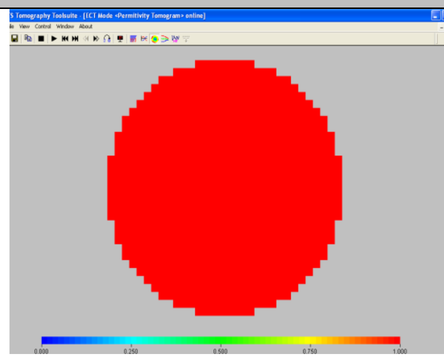
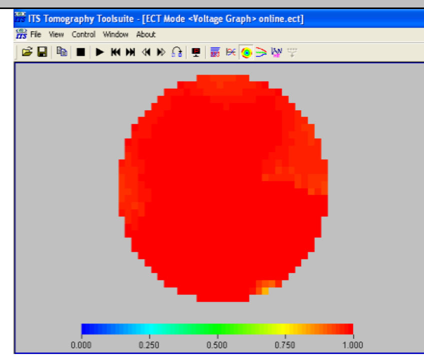
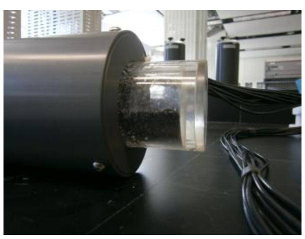
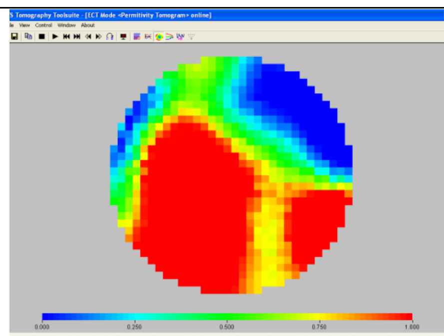
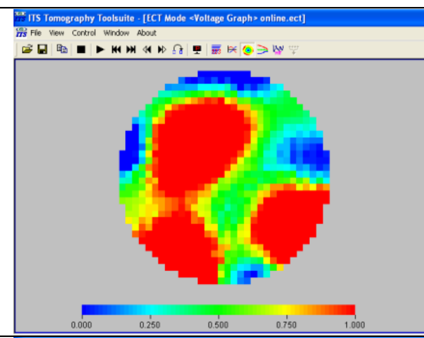
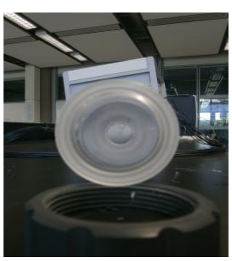
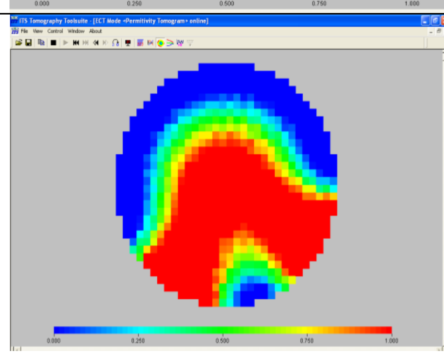
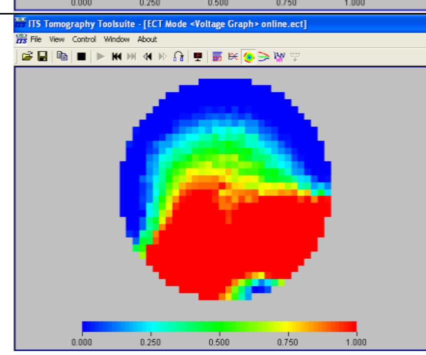
Condition	Run 1	Run 2
Full 		
Half Full 		
Empty 		

Figure 4.1: Round Pixel Map for PVC Pallets

4.1.2 Capacitance Measurements

- **Run 1**

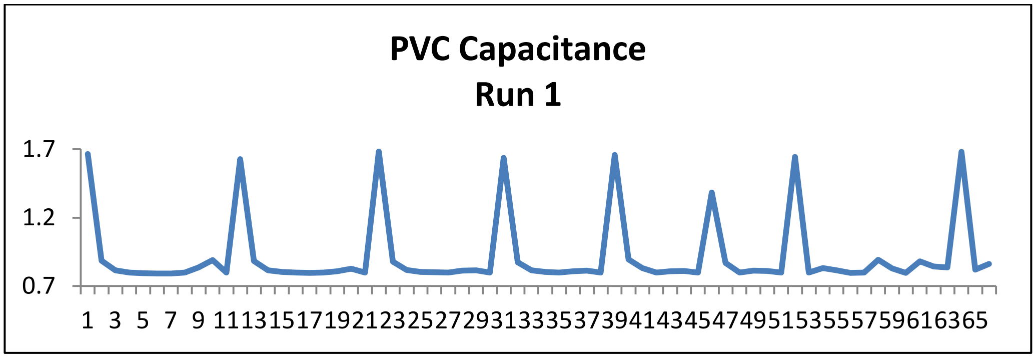


Figure 4.2: PVC Pallets capacitance measurement for Run 1

- **Run 2**

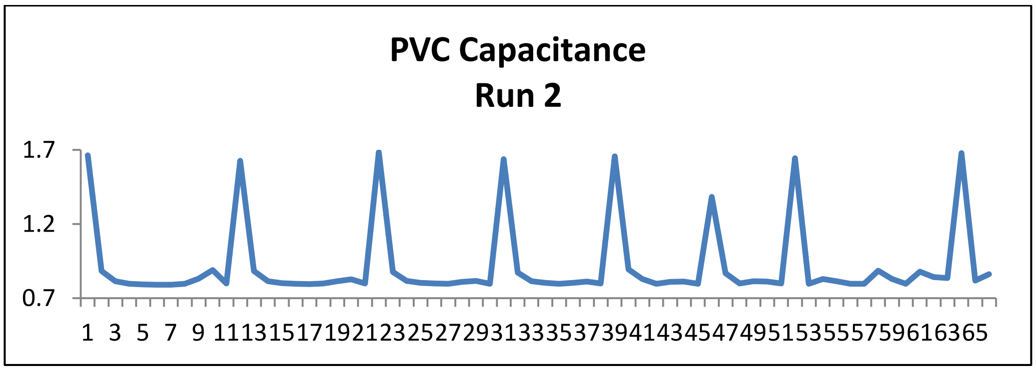


Figure 4.3: PVC Pallets capacitance measurement for Run 2

4.1.3 Voltage Measurements

- **Run 1**

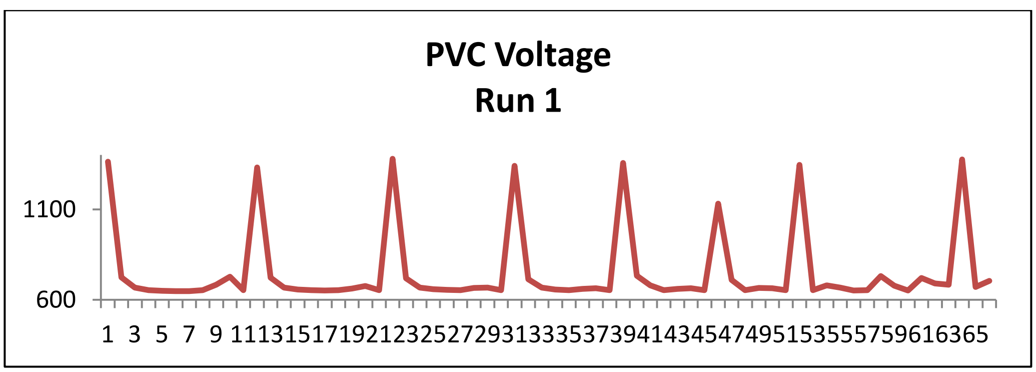


Figure 4.4: PVC Pallets voltage measurement for Run 1

- **Run 2**

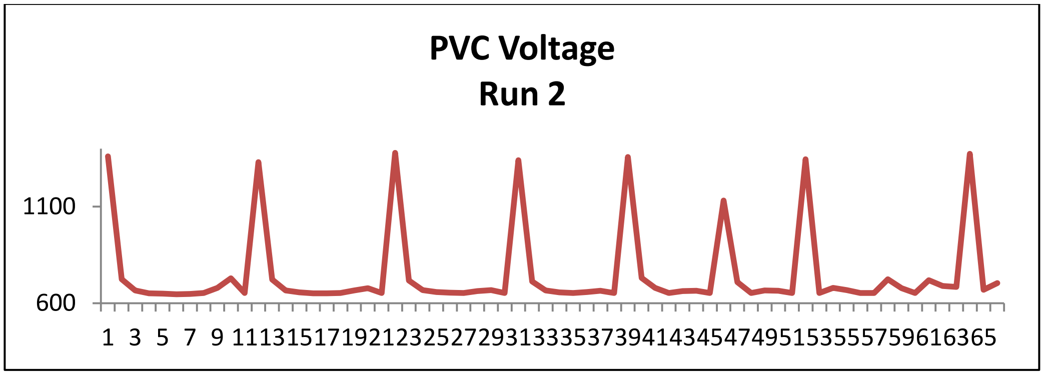


Figure 4.5: PVC Pallets voltage measurement for Run 2

4.1.4 Pixel Permittivity

- **Run 1**

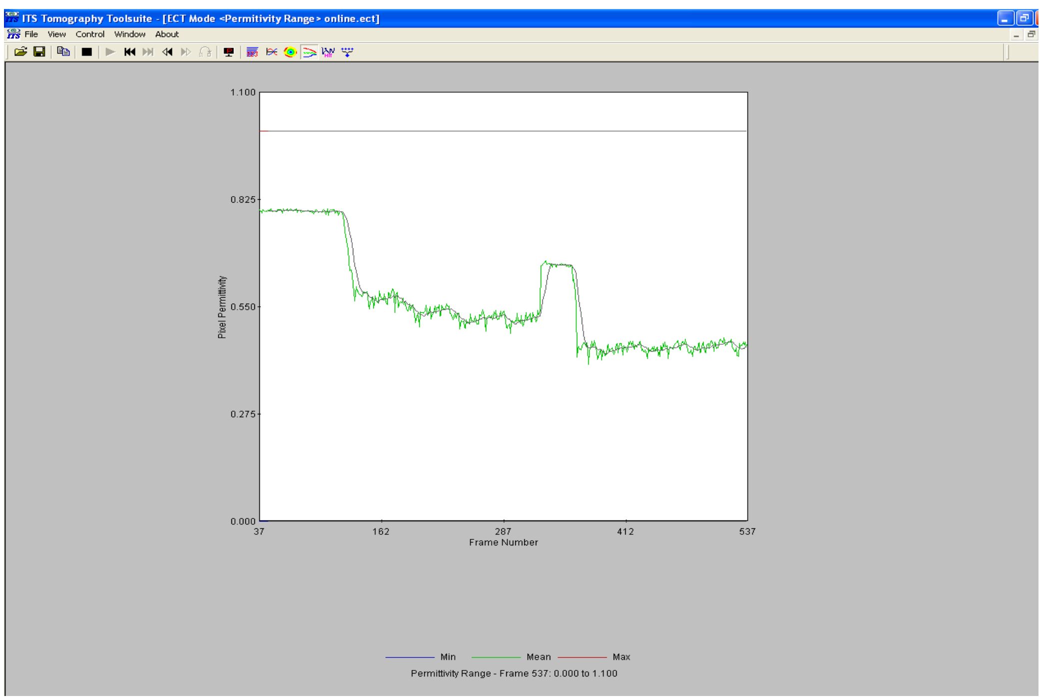


Figure 4.6: PVC Pallets pixel permittivity for Run 1

- **Run 2**

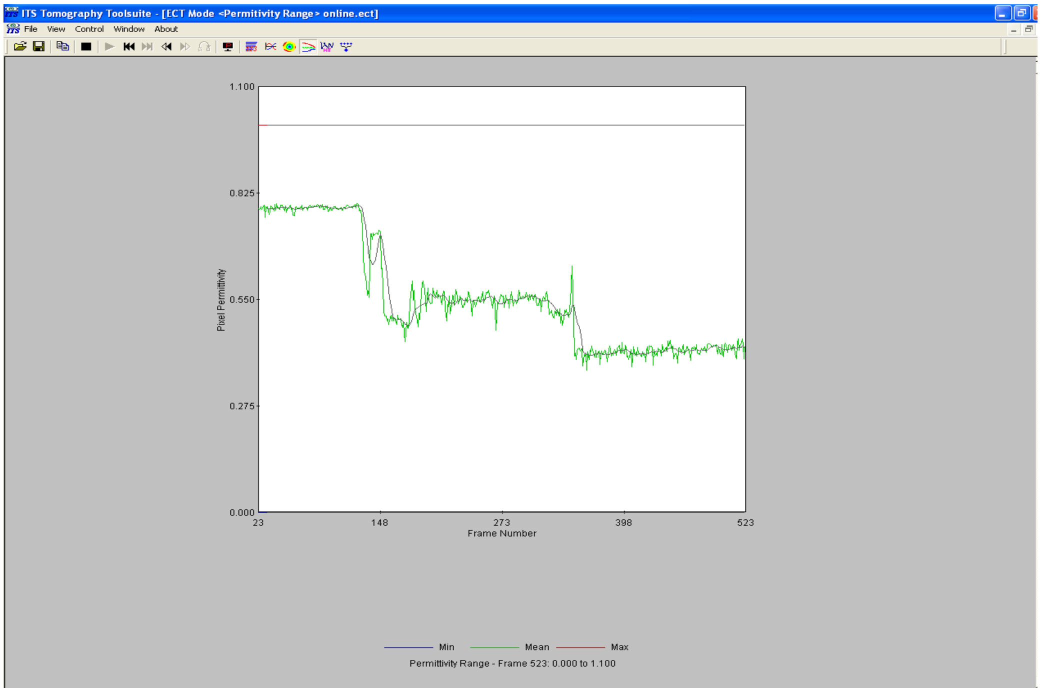


Figure 4.7: PVC Pallets pixel permittivity for Run 2

4.2 WATER TESTING RESULT

4.2.1 Round Pixel Map

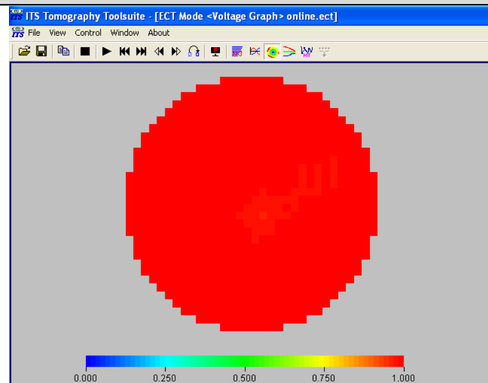
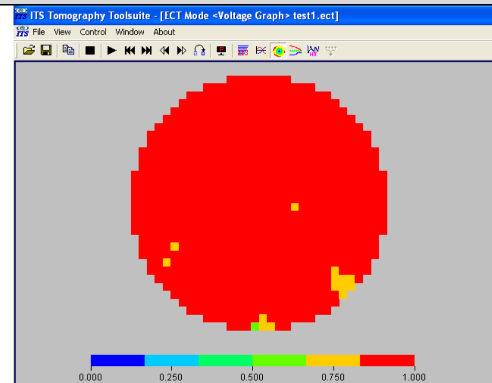
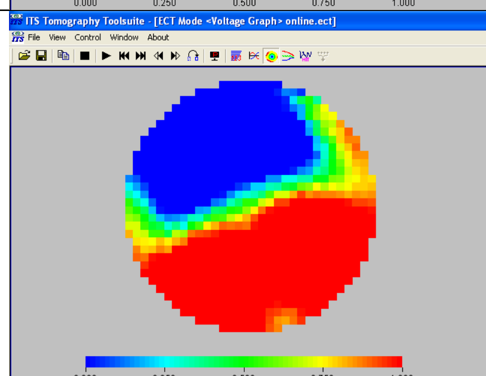
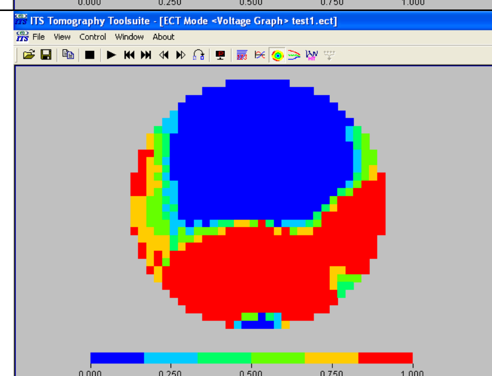
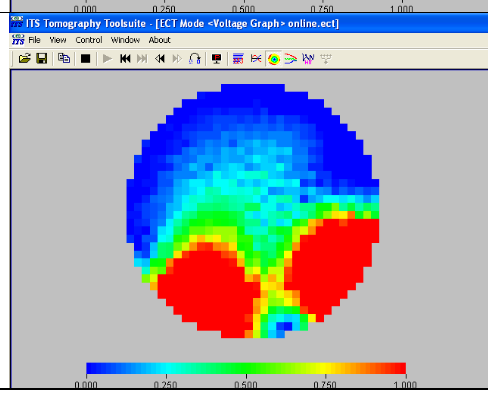
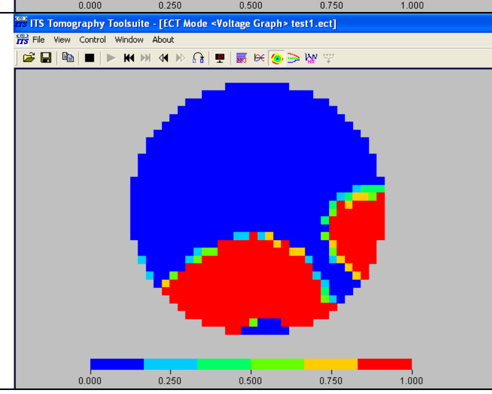
Condition	Run 1	Run 2
Full		
Half Full		
Empty		

Figure 4.8: Round Pixel Map for Water

4.2.2 Capacitance Measurements

- **Run 1**

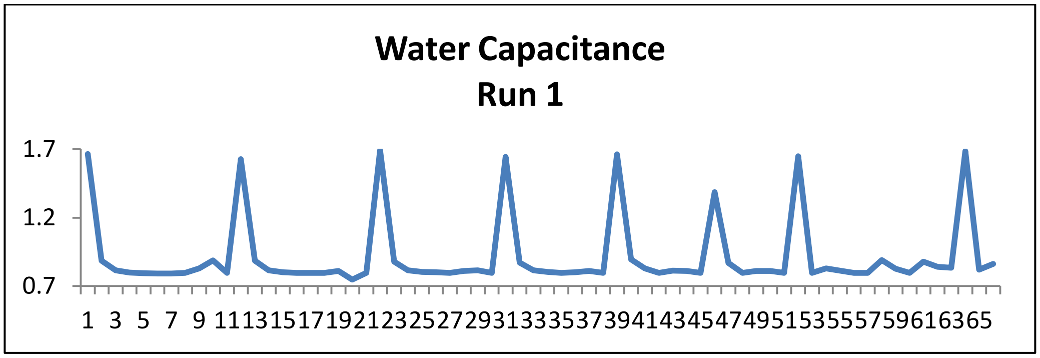


Figure 4.9: Water capacitance measurement for Run 1

- **Run 2**

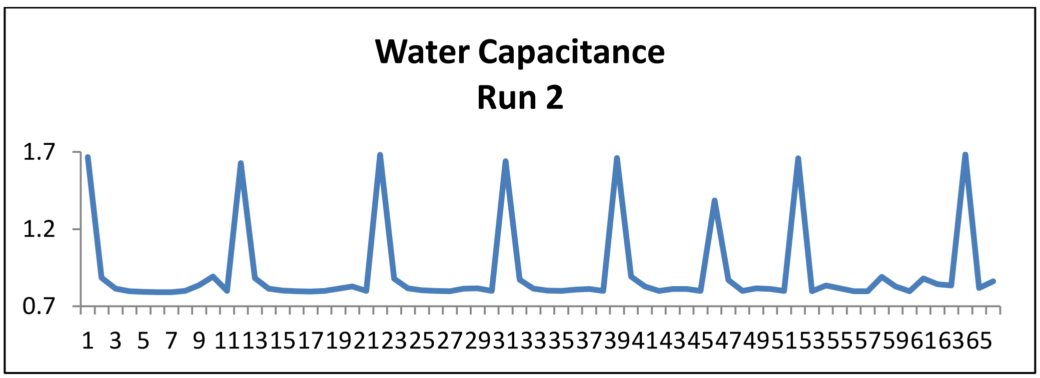


Figure 4.10: Water capacitance measurement for Run 2

4.2.3 Voltage Measurements

- **Run 1**

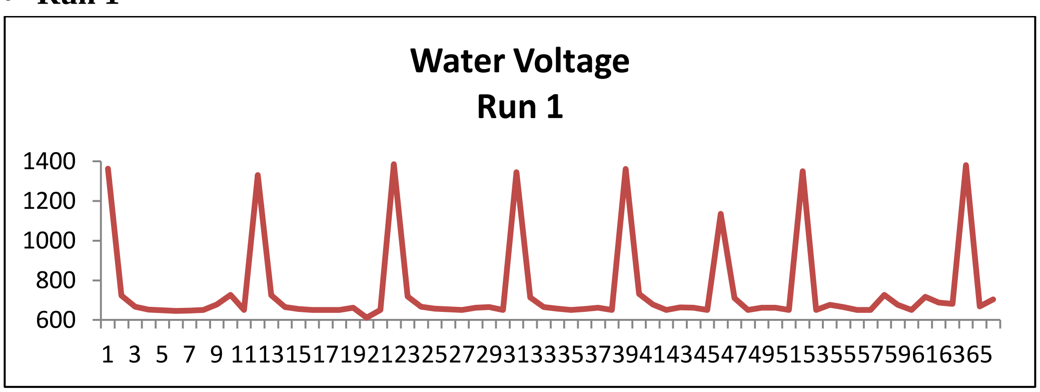


Figure 4.11: Water voltage measurement for Run 1

- **Run 2**

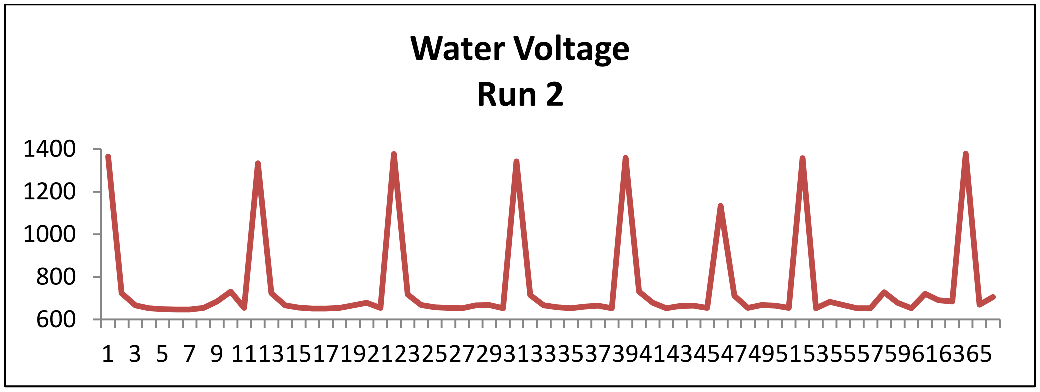


Figure 4.12: Water voltage measurement for Run 2

4.2.4 Pixel Permittivity

- **Run 1**

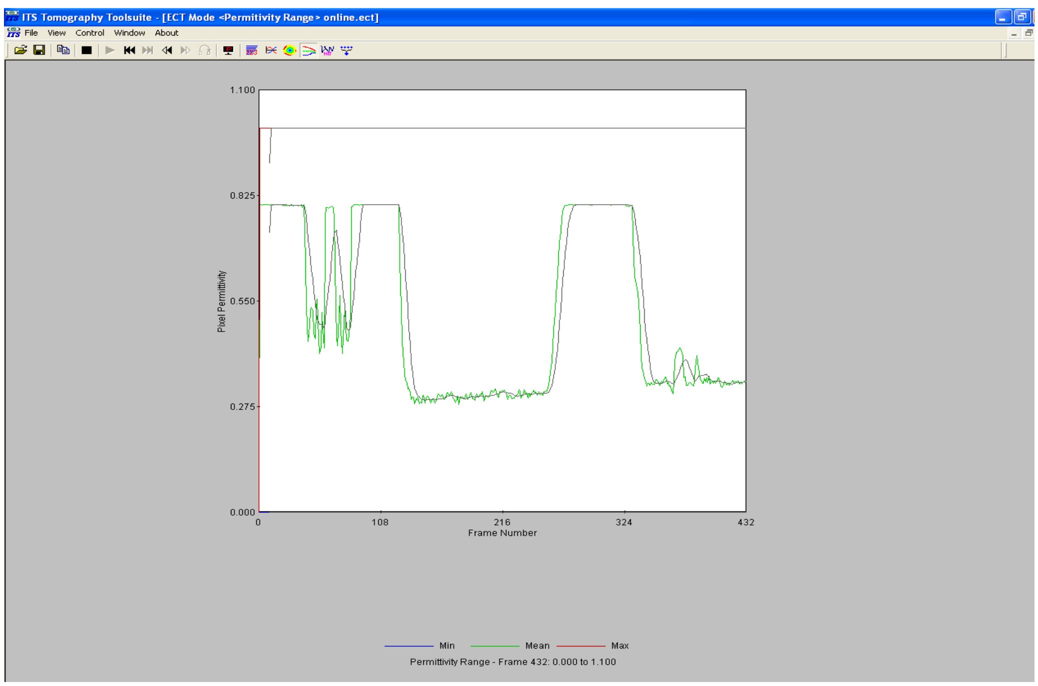


Figure 4.13: Water pixel permittivity for Run 1

- **Run 2**

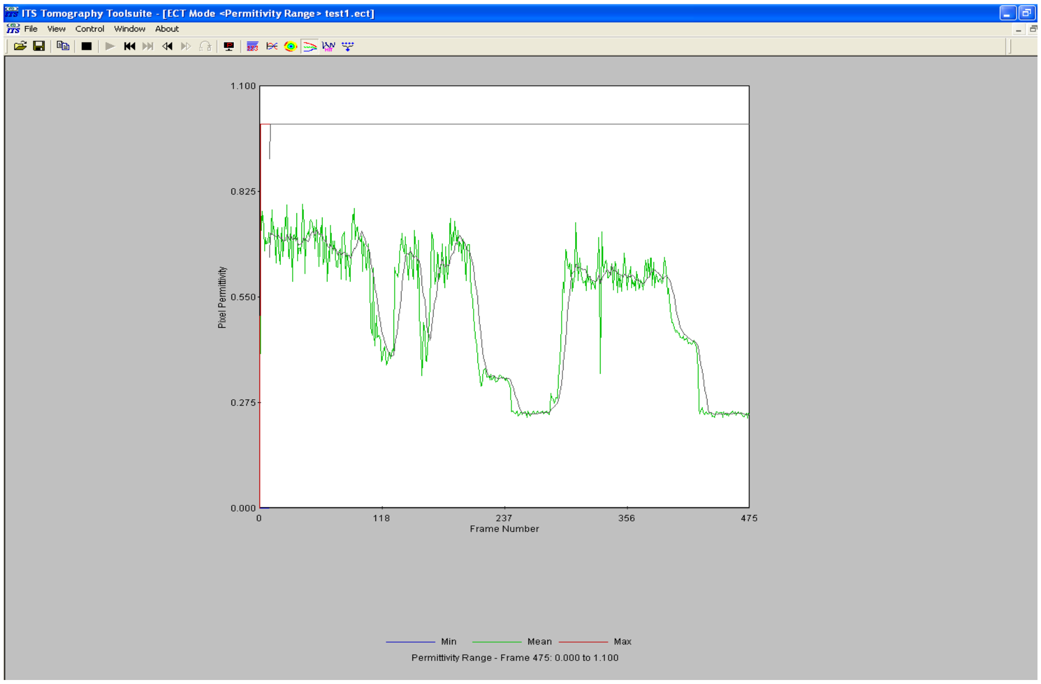


Figure 4.14: Water pixel permittivity for Run 2

4.3 DRILLING FLUID TESTING RESULT

4.3.1 Round Pixel Map

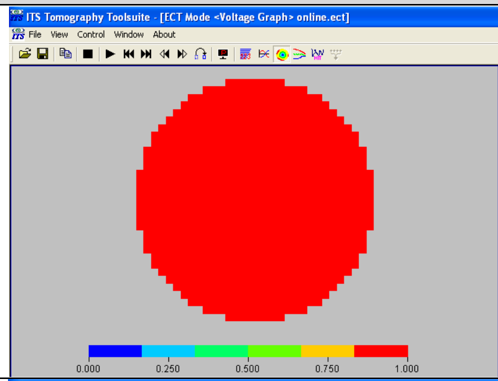
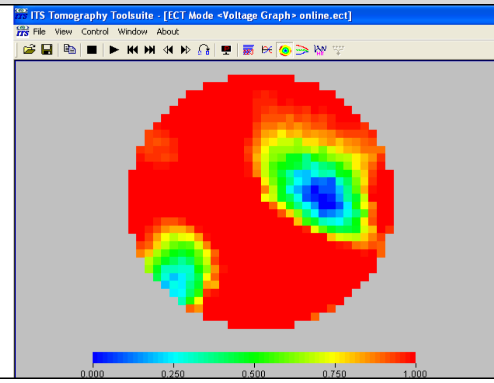
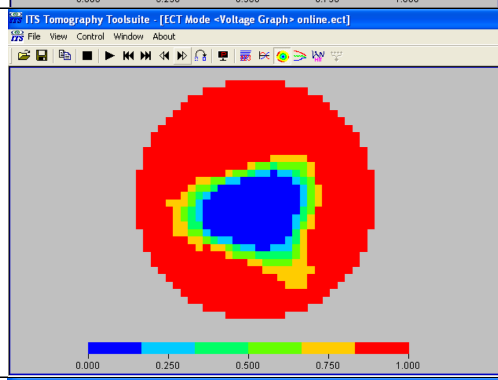
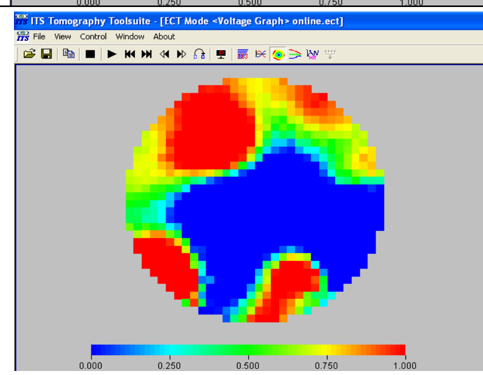
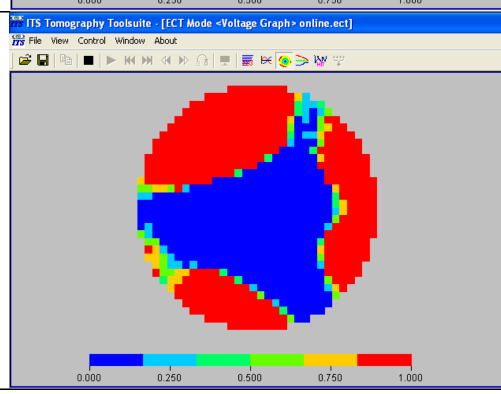
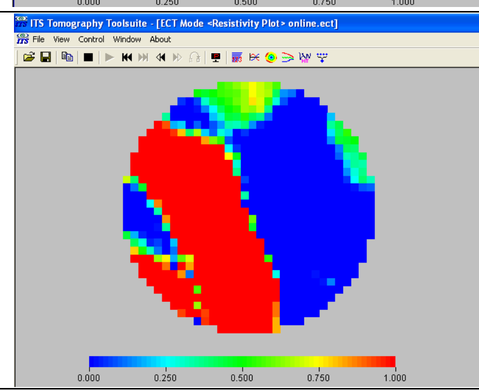
<table>
<tr><th>Condition</th><th>Run 1</th><th>Run 2</th></tr>
<tr><td>Full</td><td>
</td><td>
</td></tr>
<tr><td>Half Full</td><td>
</td><td>
</td></tr>
<tr><td>Empty</td><td>
</td><td>
</td></tr>
</table>

Figure 4.15: Round Pixel Map for Drilling Fluid

4.3.2 Capacitance Measurements

- **Run 1**

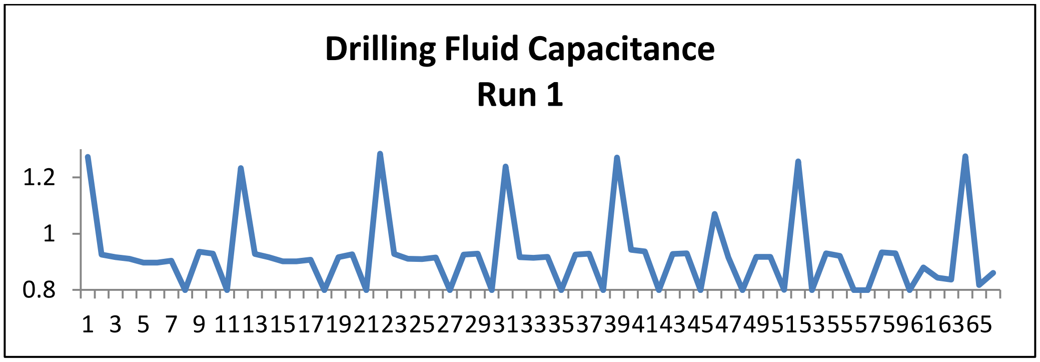


Figure 4.16: Drilling Fluid capacitance measurement for Run 1

- **Run 2**

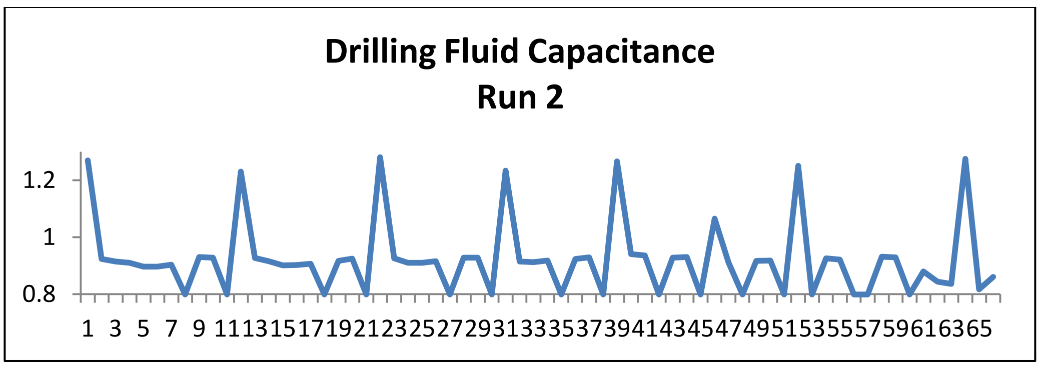


Figure 4.17: Drilling Fluid capacitance measurement for Run 2

4.3.3 Voltage Measurements

- **Run 1**

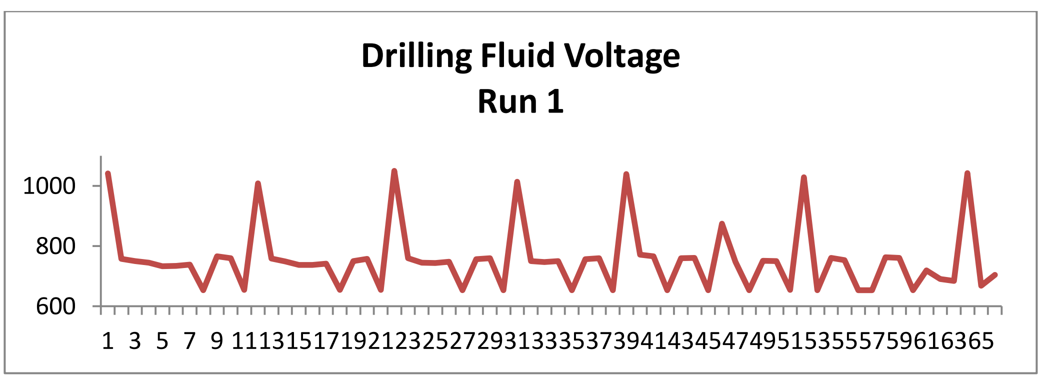


Figure 4.18: Drilling Fluid voltage measurement for Run 1

- **Run 2**

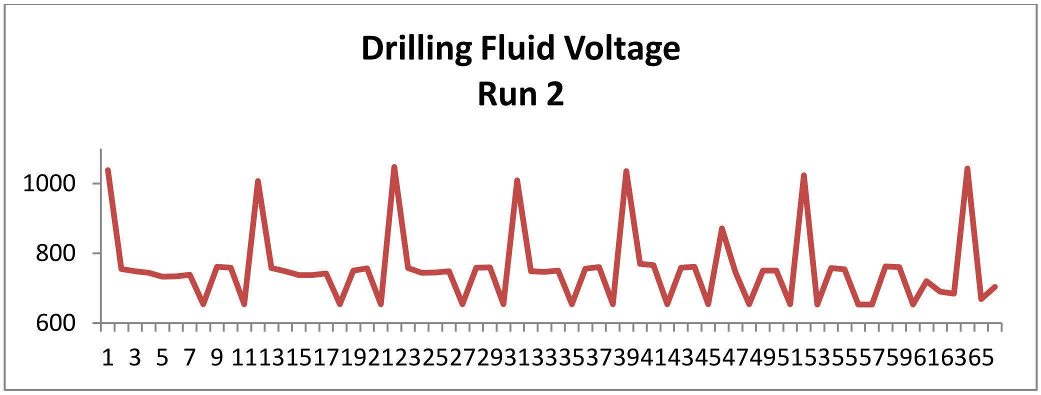


Figure 4.19: Drilling Fluid voltage measurement for Run 2

4.3.4 Pixel Permittivity

- **Run 1**

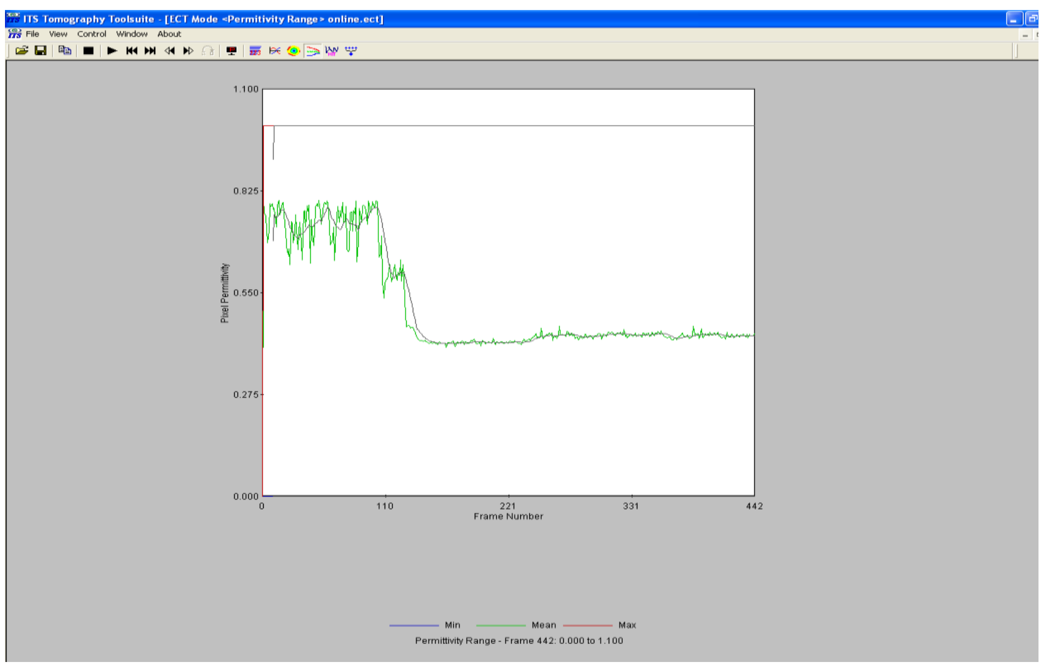


Figure 4.20: Drilling Fluid pixel permittivity for Run 1

- **Run 2**

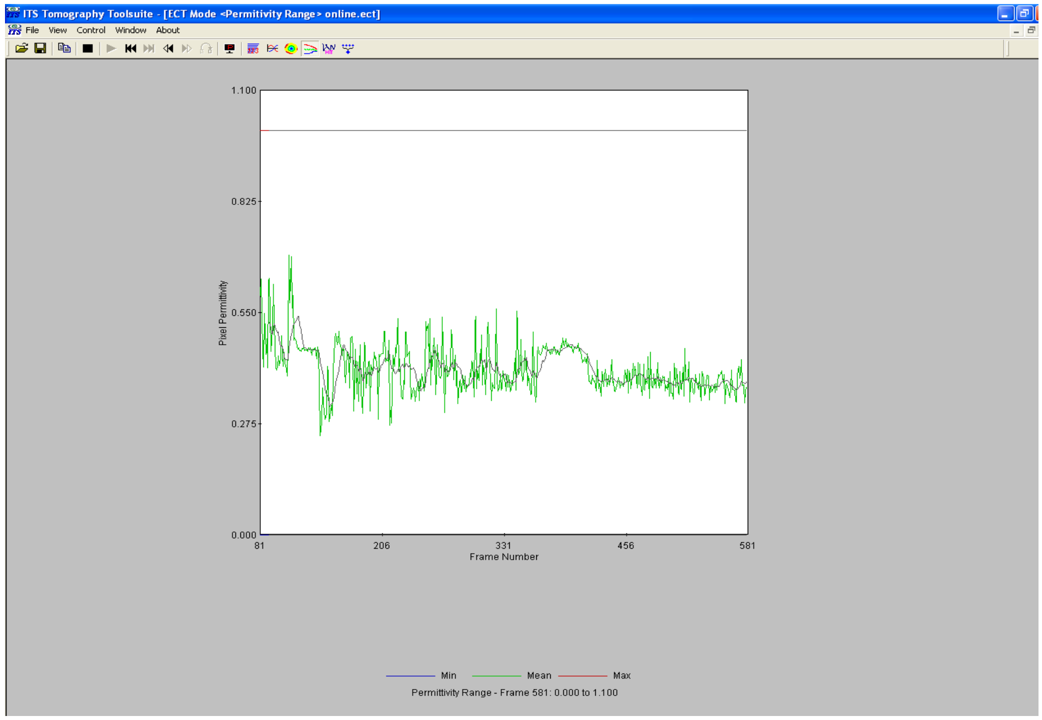


Figure 4.21: Drilling Fluid pixel permittivity for Run 2

4.4 DRILLING FLUID + NUT PLUG TESTING RESULT

4.4.1 Round Pixel Map

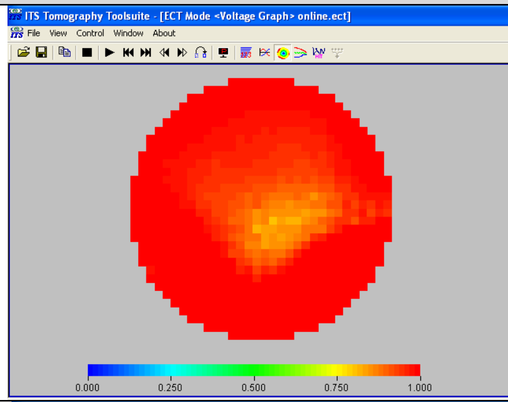
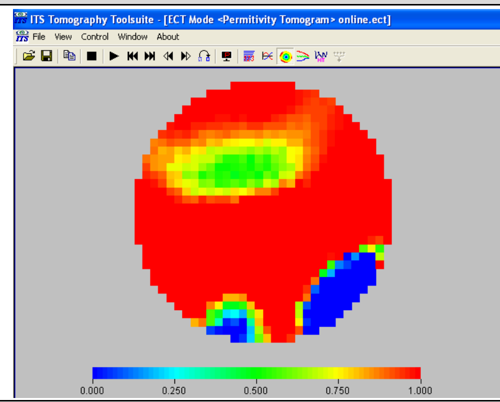
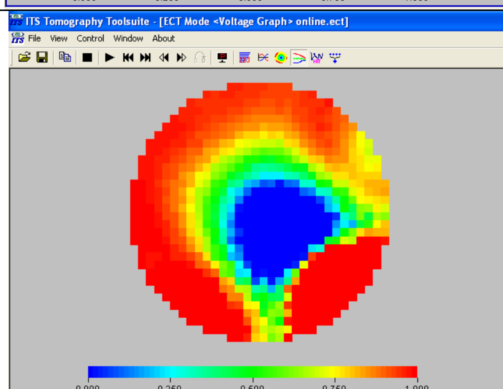
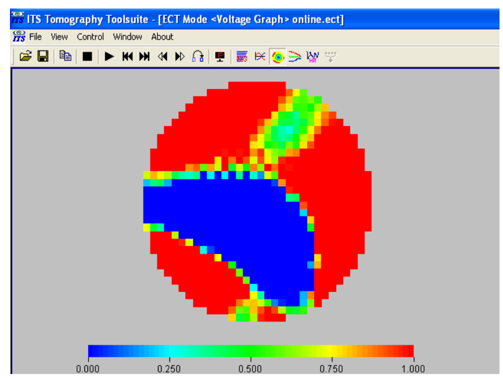
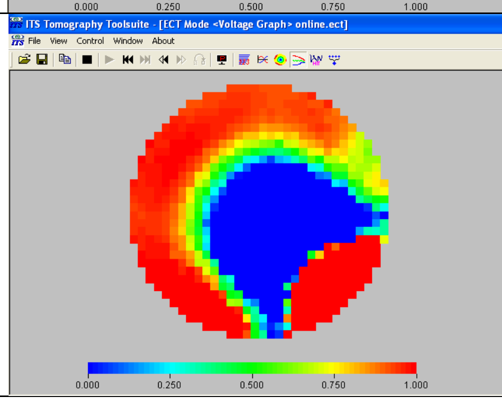
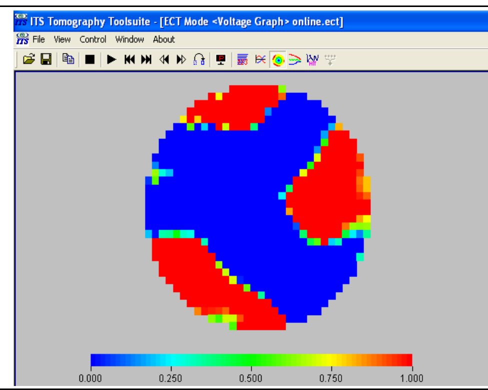
<table>
<tr><th>Condition</th><th>Run 1</th><th>Run 2</th></tr>
<tr><td>Full</td><td>
</td><td>
</td></tr>
<tr><td>Half Full</td><td>
</td><td>
</td></tr>
<tr><td>Empty</td><td>
</td><td>
</td></tr>
</table>

Figure 4.22: Round Pixel Map for Drilling Fluid + Nut Plug

4.4.2 Capacitance Measurements

- **Run 1**

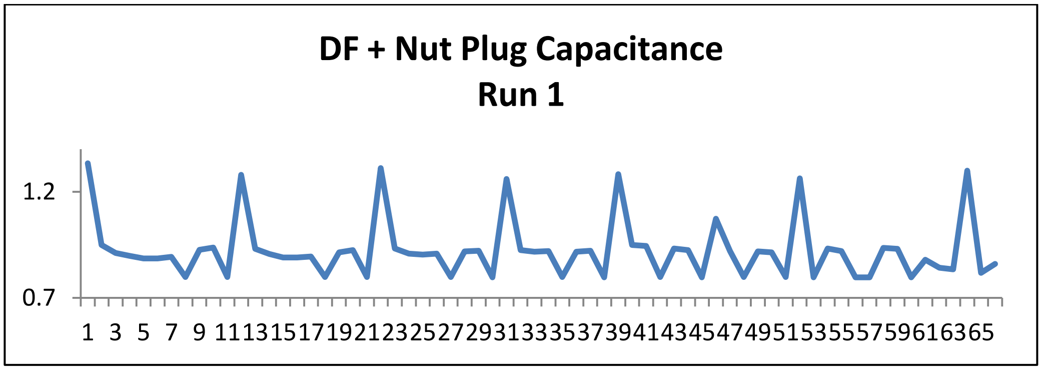


Figure 4.23: Drilling Fluid + Nut Plug capacitance measurement for Run 1

- **Run 2**

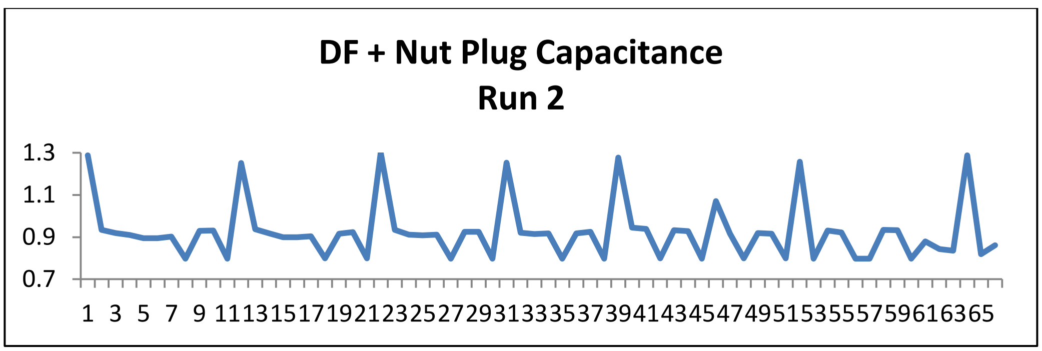


Figure 4.24: Drilling Fluid + Nut Plug capacitance measurement for Run 2

4.4.3 Voltage Measurements

- **Run 1**

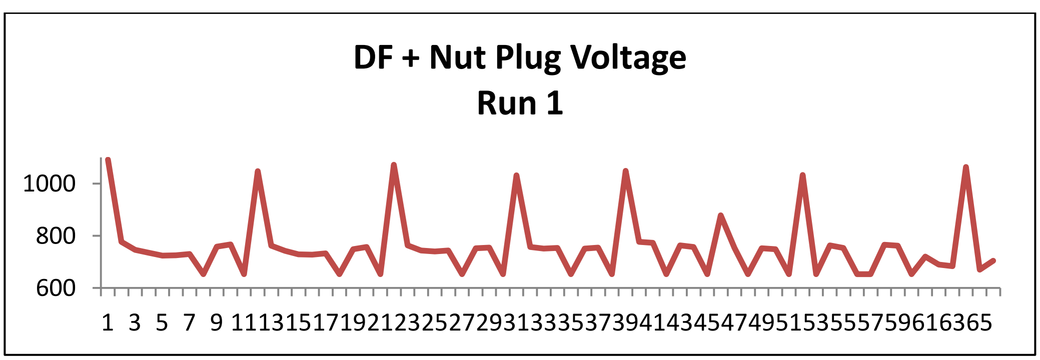


Figure 4.25: Drilling Fluid + Nut Plug voltage measurement for Run 1

- **Run 2**

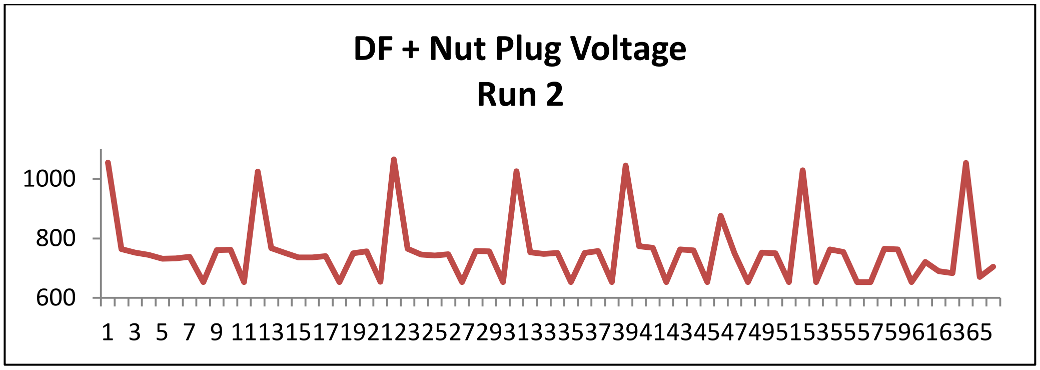


Figure 4.26: Drilling Fluid + Nut Plug voltage measurement for Run 2

4.4.4 Pixel Permittivity

- **Run 1**

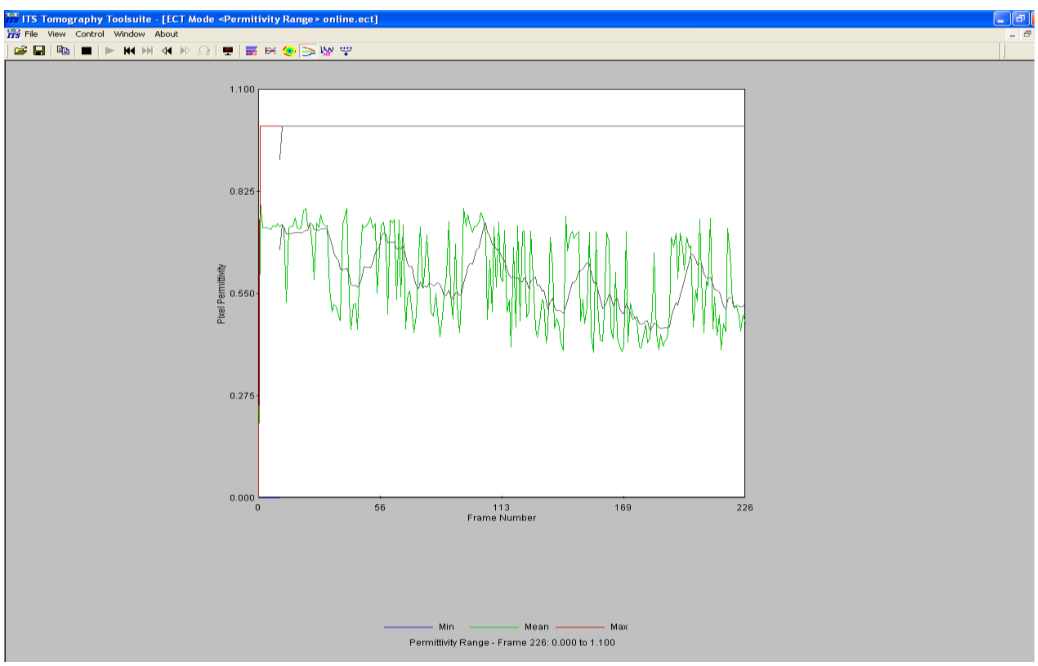


Figure 4.27: Drilling Fluid + Nut Plug pixel permittivity for Run 1

- **Run 2**

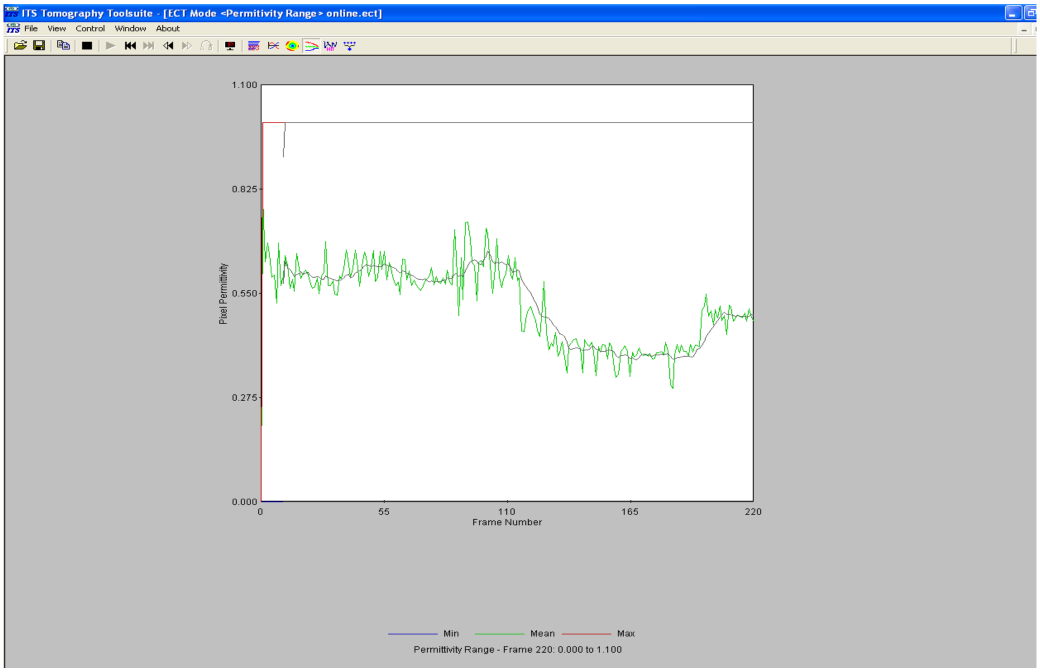


Figure 4.28: Drilling Fluid + Nut Plug pixel permittivity for Run 2

4.5 DRILLING FLUID + PINEAPPLE TESTING RESULT

4.5.1 Round Pixel Map

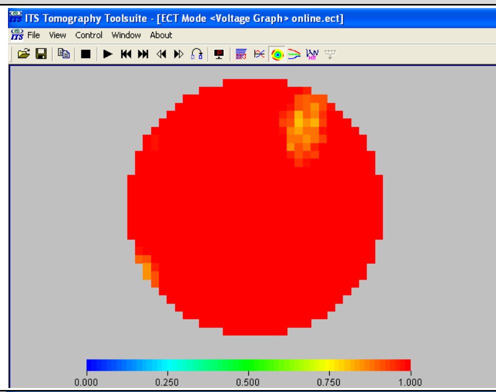
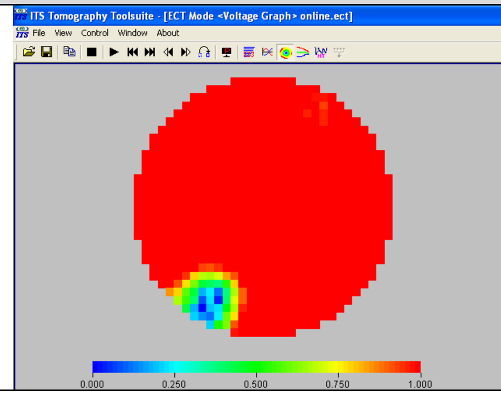
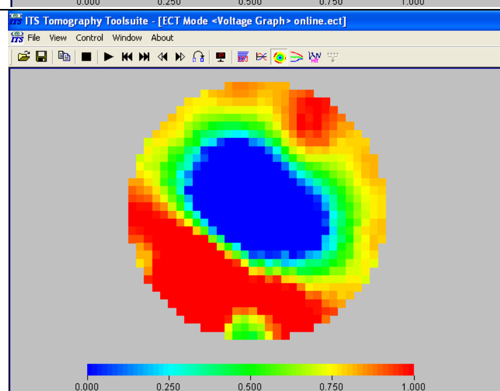
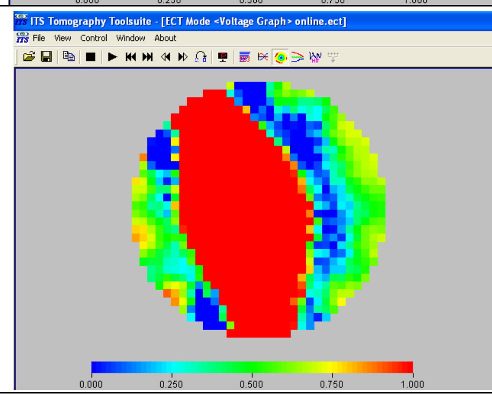
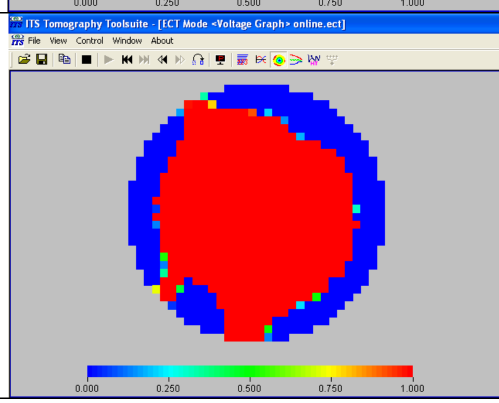
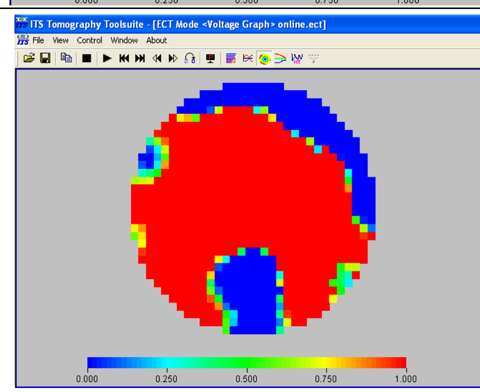
Condition	Run 1	Run 2
Full		
Half Full		
Empty		

Figure 4.29: Round Pixel Map for Drilling Fluid + Pineapple

4.5.2 Capacitance Measurements

- **Run 1**

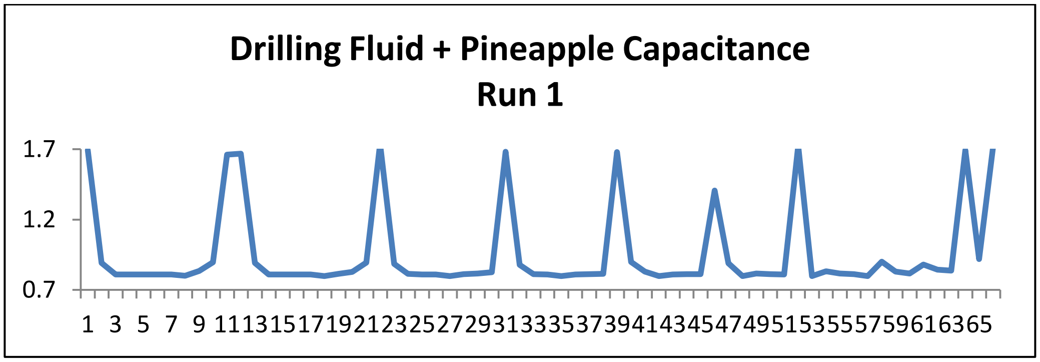


Figure 4.30: Drilling Fluid + Pineapple capacitance measurement for Run 1

- **Run 2**

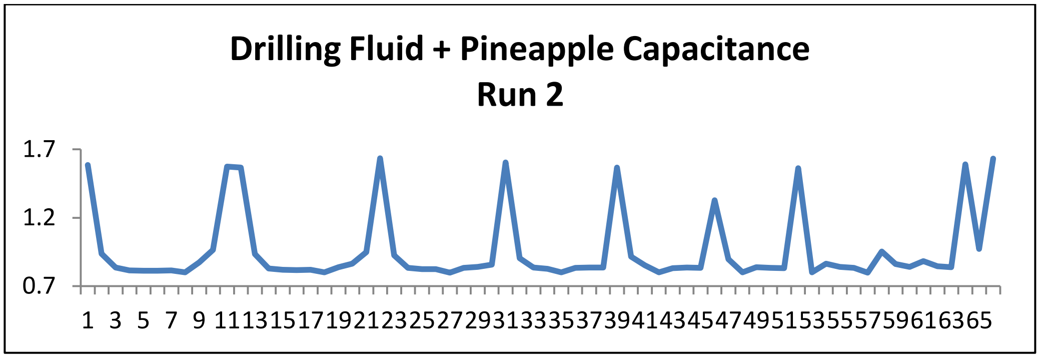


Figure 4.31: Drilling Fluid + Pineapple capacitance measurement for Run 2

4.5.3 Voltage Measurements

- **Run 1**

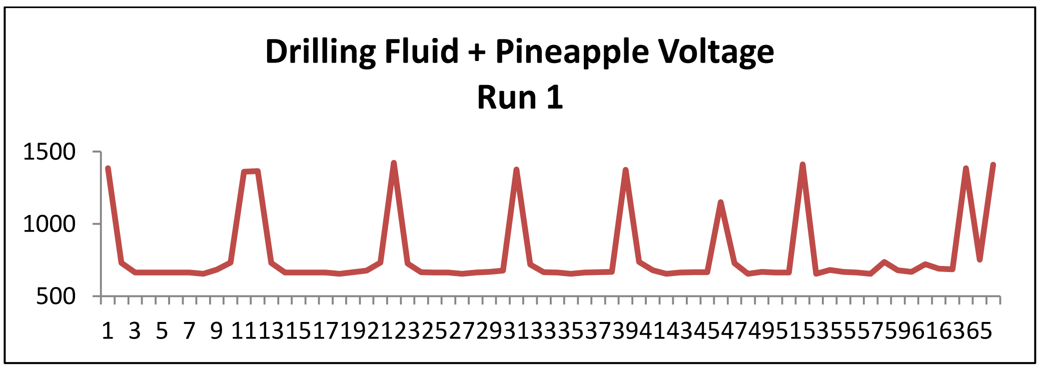


Figure 4.32: Drilling Fluid + Pineapple voltage measurement for Run 1

- **Run 2**

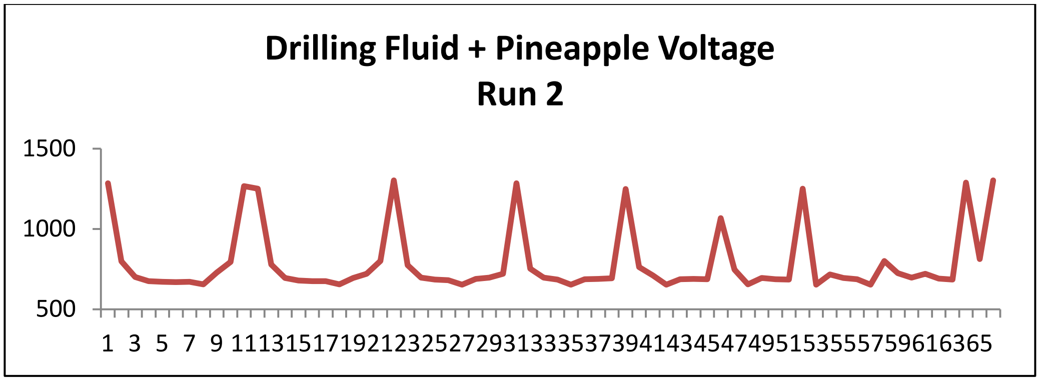


Figure 4.33: Drilling Fluid + Pineapple voltage measurement for Run 2

4.5.4 Pixel Permittivity

- **Run 1**

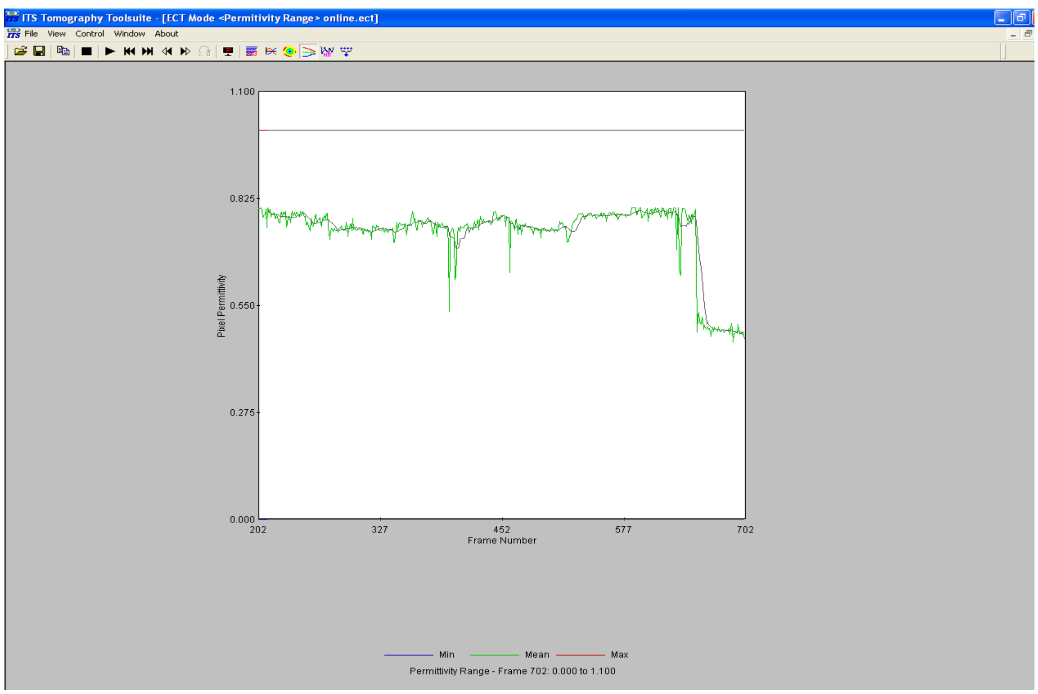


Figure 4.34: Drilling Fluid + Pineapple pixel permittivity for Run 1

- **Run 2**

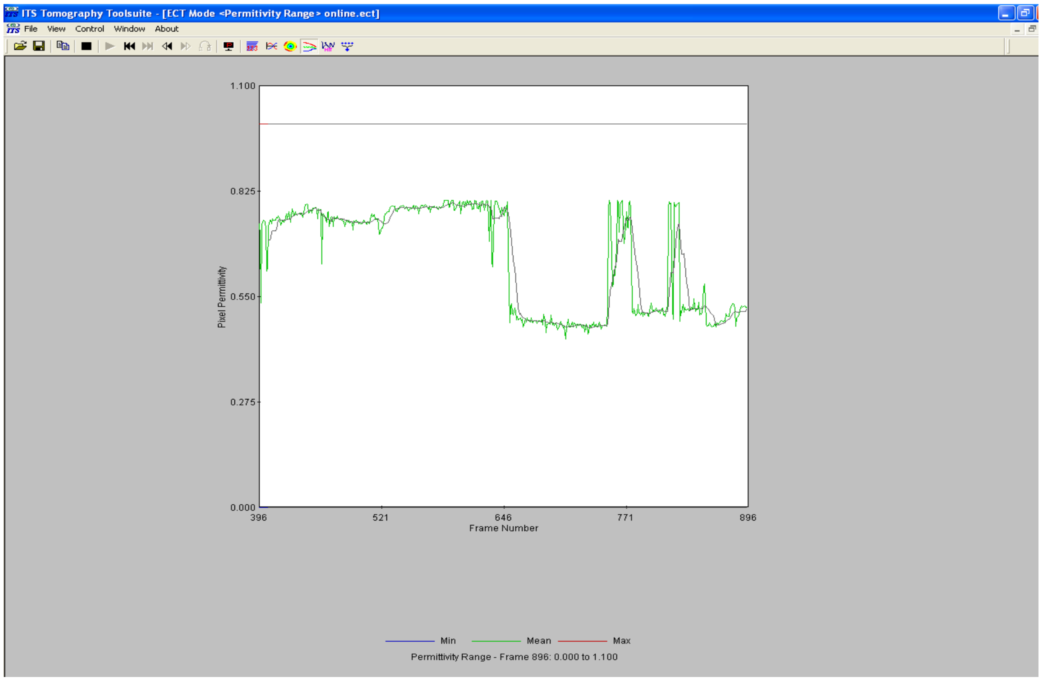


Figure 4.35: Drilling Fluid + Pineapple pixel permittivity for Run 2

4.6 RESULT DISCUSSION

4.6.1 Discussion on PVC and Water Results

1) Round Pixel Map

Based on the result obtained, unfortunately, it does not show the accurate results as predicted. In the beginning, given full condition, round pixel map is all in red colour because it shows that the container is full with the material. However, when half of the material was remove, the round pixel map should shows half red at bottom and another half blue at top since the upper area is now filled with air and it had been set as the lower case during the calibration process. Similarly during the empty condition, the round pixel map should show a full blue colour to represent the material inside it which is air.

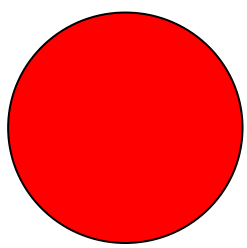
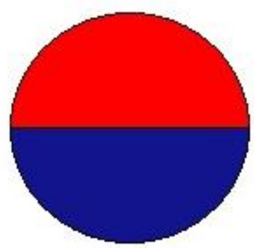
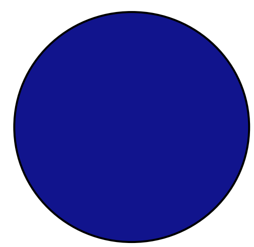
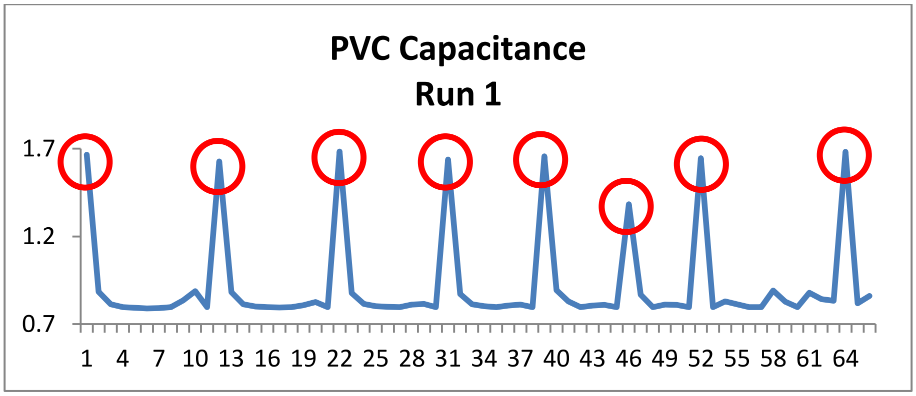
Condition	**Full**	**Half full**	**Empty**
Expected Result			

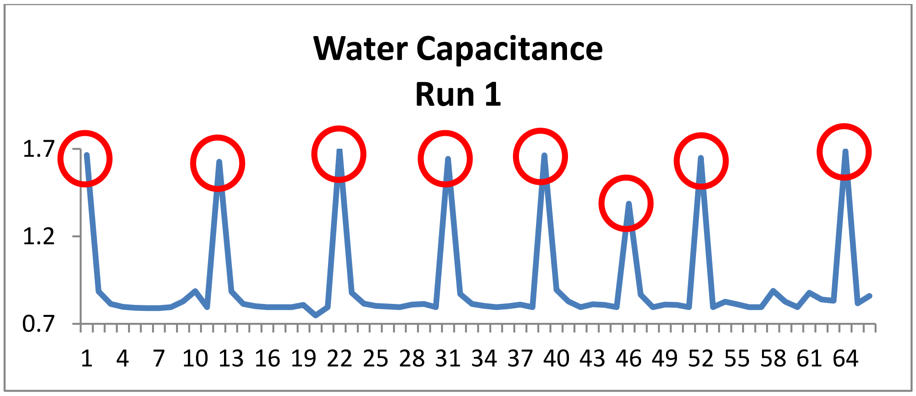
Figure 4.36: Expected Result

2) Capacitance and Voltage Measurements

Both measurements show the same pattern of graph despite there were different values obtained as the capacitance measurements ranging between 1.7 F to 0.7 F and the voltage measurements range from 1400 mV to 600 mV. The reason behind this situation is because both measurements derive from a same sensor used. In other words, it is a matter of converting from capacitance to voltage values or vice versa (1).

However, the error from the round pixel map are most likely the colour distribution at given conditions which were not the same as expected result and this deficiency can also be detected in the graph of capacitance and voltage measurements. Since one electrode has been used as a source and others as a detector, there should have 11 peaks to represent the detector sensors. Unfavorably, there are only 8 peaks in the graph of both measurements.

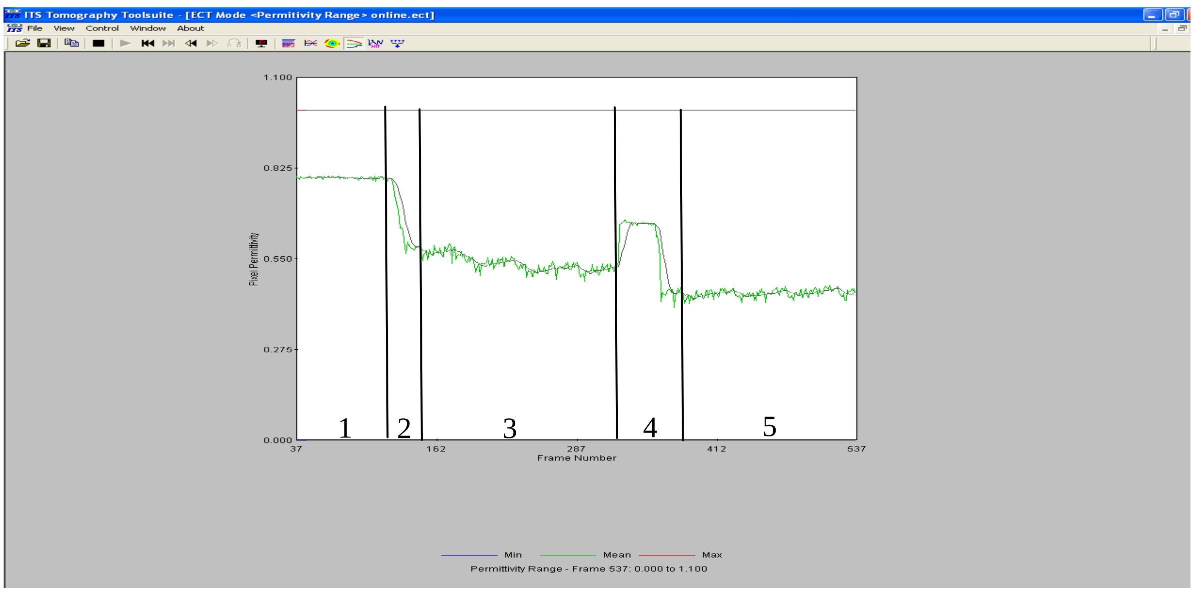




This might be due to few electrode sensors malfunction and most probably two or three electrode sensors were not performing their intended function in voltage measuring.

3) Pixel Permittivity

The pixel permittivity graph showed the maximum, minimum and average conductivity and permittivity values of the pixels from the conductivity and the permittivity tomogram. For layman term, the pixel permittivity graph is like a story teller. Without looking at round pixel map itself, we still could identify what was happening during the process.



There are 5 phases occurred during this process:

- Phase 1:

  It shows high permittivity which means the container was fully filled by the material.

- Phase 2:

  It shows a huge drop line, hence it gives an indicator that almost half or more of the material was removed from the container.

- Phase 3:

  The graph shows slightly up and down line. The possible cause is as the container was shaking, the material inside also moving around.

- Phase 4:

  During this phase, it shows that the graph move upward and constant before another slick drop. Thus, it gives a hint that the material was accumulated for a while before it was removed from the container.

- Phase 5:

  In this final phase shows relatively linear pattern at bottom which means the container was empty and filled by the air.

4.6.2 Discussion on Drilling Fluid, Drilling Fluid + Nut Plug and Drilling Fluid + Pineapple Results

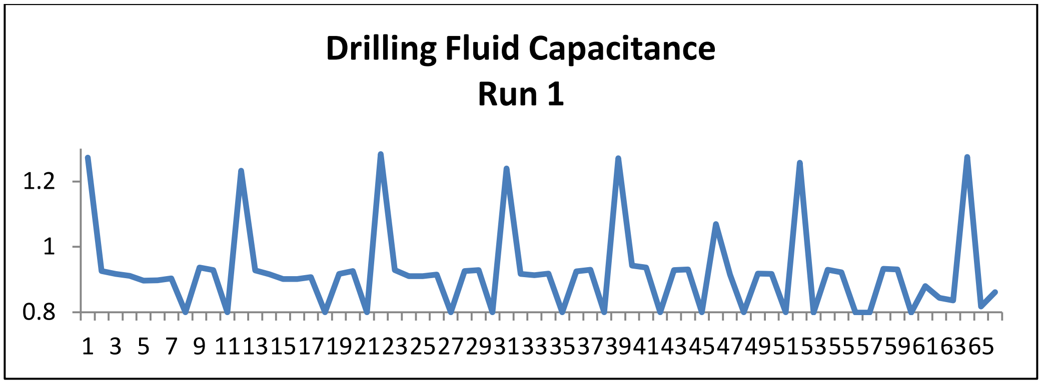
1) Round Pixel Map

The outcome obtained from the round pixel map shown also not as predicted. Moreover, the results were even worst compare to PVC and water's round pixel map. It is supposed to show full solid red colour during full condition (refer Figure 4.6) but the round pixel map showed a blue spots somewhere in the middle and at aside. For half full condition, the round pixel map still react randomly regardless the conditions set in the container. These situations also continue to happen during empty condition.

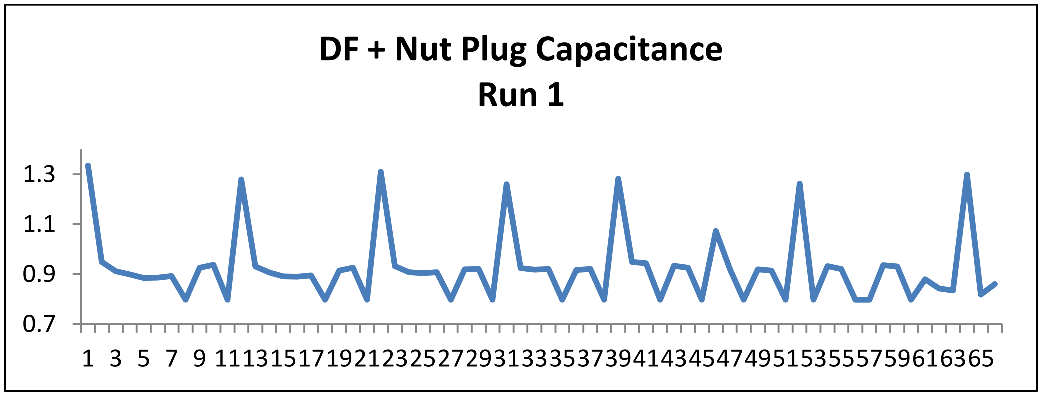
2) Capacitance and Voltage Measurements

Only the drilling fluid + pineapple showed similar pattern of graph in PVC and water which used as benchmark. The others have shown different pattern whereby there have downward peaks in the graph. This might due to sensor errors as later on you would see the erratic pattern in the pixel permittivity graph drilling fluid and drilling fluid with nut plug.

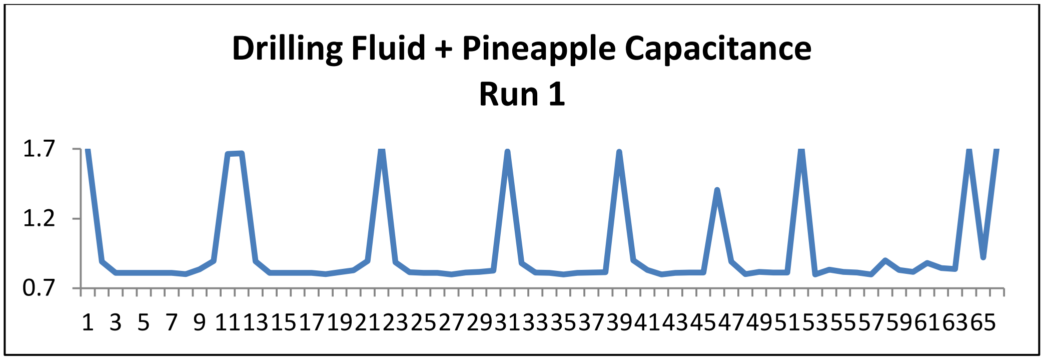
- **Drilling Fluid**



- **Drilling Fluid + Nut Plug**



- **Drilling Fluid + Pineapple**



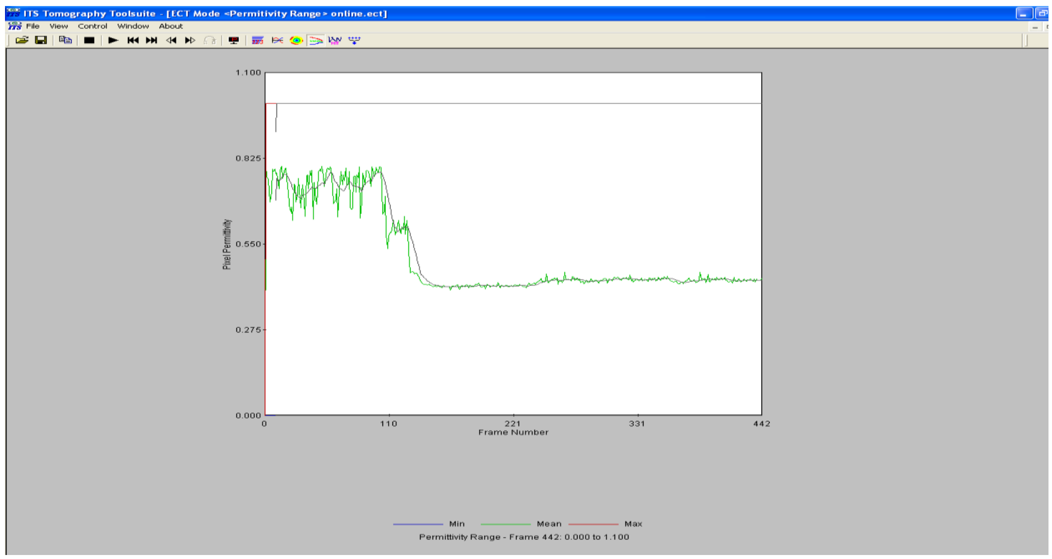
Another reason of this unusual pattern is because of the properties inside the drilling fluid itself. Since it was a mix of many substances, there have some possibilities that voltages could not enter through and reach at detector sensors. In fact, most of the researches were using only two different properties such as mixture of water and oil or water and air. This kind of test has never been done before.

However, it gives an indication that if the data acquisition is stable; the testing can be carry on to the next stage of research. Hence, major service and maintenance on the data acquisition is required in order to obtain better yet accurate result.

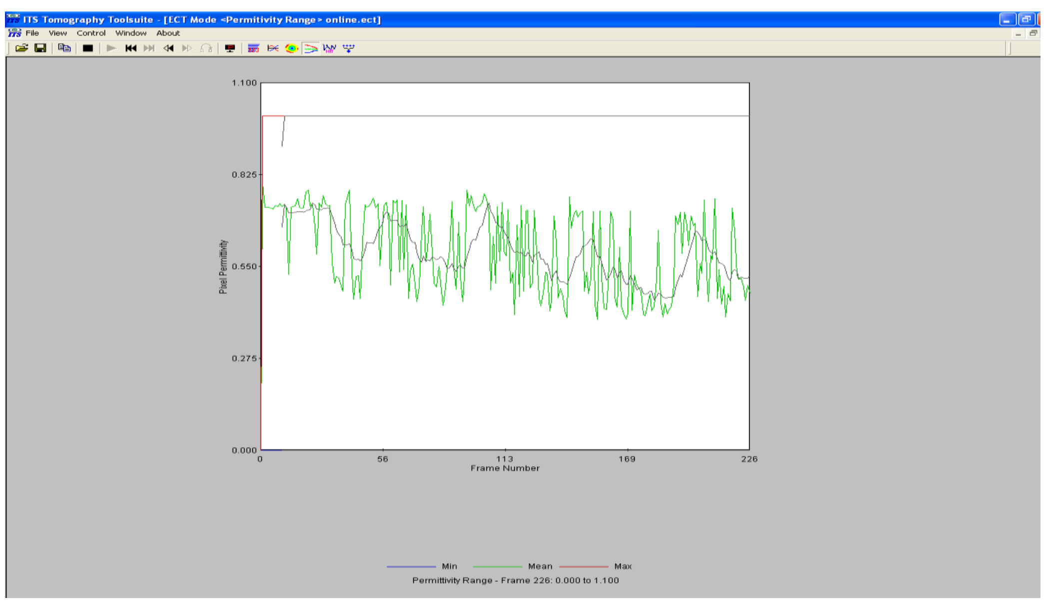
3) Pixel Permittivity

Definitely, the unusual graph pattern of drilling fluid and drilling fluid with nut plug will be affected at pixel permittivity projection. As a result, a very erratic pattern of pixel permittivity was recorded.

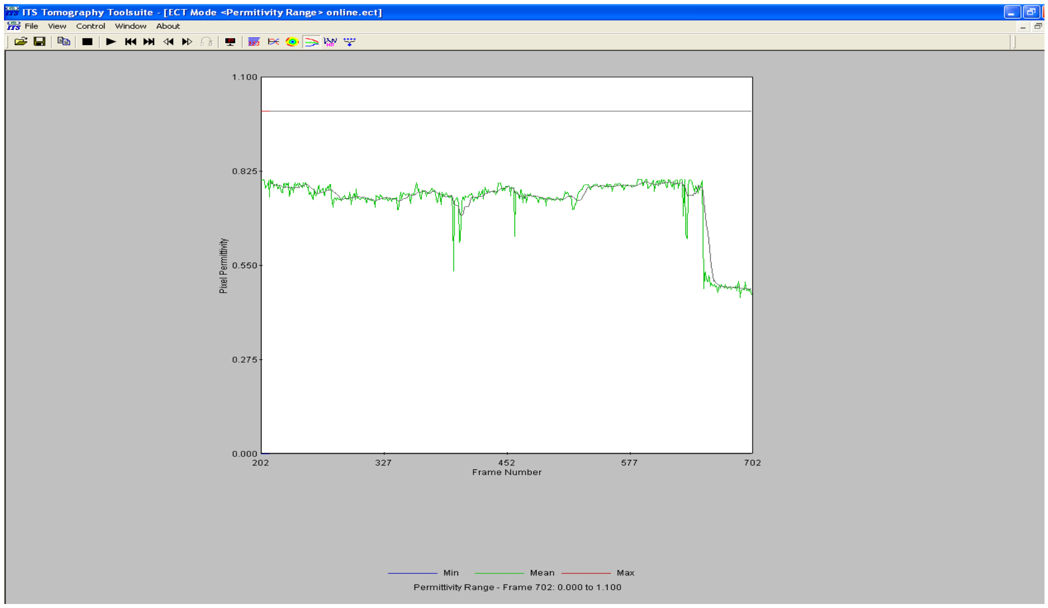
- **Drilling Fluid**



- **Drilling Fluid + Nut Plug**



- **Drilling Fluid + Pineapple**



Based on the figures above, a very erratic pattern was projected and it means the round pixel map was randomly showing blue and red colour and not adhere to the condition inside the container. Only the drilling fluid with pineapple shows relatively stable pattern despite there has similar pattern in drilling fluid at the end of it. As a matter of fact, the container was actually empty during that time. And yet, during the drilling fluid with pineapple testing was conducted, a considerably good result was recorded with literally stable pattern.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

As a conclusion, the objective of this project was not achieved. Only one out of three types drilling fluid provides a relatively accurate data. Others were not even close with the expected result. Due to lack of understanding about ECT's operation in the beginning, this project has forces the author to spend more time to learn about ECT's operation instead of conducting the experiments. This is because most of the research papers available only shared the outcome of the experiment but not on the procedures they had conducted.

Hence, the author had provided a detail procedure on how to operate the ECT equipments. In order to make learning process easier, a screen shot of every step were taken to show where or which button needed to be press on.

The results from this project must be verified through another research in future. As mention before, it is mainly due to the data acquisition malfunction. By performing a servicing or upgrading on the data acquisition unit may provides better data accuracy. Thus, the data is more meaningful and useful to be as reference for other similar experiments.

5.2 RECOMMENDATIONS

Since the first day the equipment arrived in 2006, ECT equipments have never been undergoing a major service**.** Usually, an electronic machine required regular calibration activities to ensure the system provides the most accurate result. This is a reason behind the errors occurred during the experiment.

Second recommendation is to provide training to technician or appointed person in charge for taking a responsibility towards the ECT. Currently, only a few students have knowledge on ECT's operation and able to interpret the data. If these students leave the campus, there are no competent people to guide a newbie to conduct an experiment.

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