SEA-BED LOGGING MODELING USING COMSOL MULTIPHYSICS SOFTWARE:

EFFECT OF DISPERSED CLAY AND BRINE SALINITY TO ELECTROMAGNETIC WAVE

By

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CERTIFICATION OF APPROVAL

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Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS TRONOH, PERAK
May 2011

CERTIFICATION OF ORIGINALITY

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

(AZLIA BINTI AHMAD SUPIAN)

ABSTRACT

This report basically discusses the preliminary research done and basic understanding of the chosen topic,which is **Sea-bed logging modeling using COMSOL multiphysics** from the near surface to as deep below the sea floor.

The objective of the project is to test the simulation using COMSOL multiphysics software to be closed to the actual situation in the offshore rather than use the electromagnetic wave to directly detecting the presence of oil and gas reservoirs in exploration prospects prior to drilling. The challenge in this project is to learn how to use the COMSOL multiphysics software.

The simulation using COMSOL will be done after solid modelling which is reproduce the demonstration of the sea-bed logging modeling and continue to define the properties of the sea-bed logging.For the last step the analysis from the result graph will be determine to get the exact prove that by using the simulation can be similar to the actual situation in the offshore.

The experiment of the salinity of brine in a sand-shale reservoir rock also affects the EM response considerably and studied the effect of varying the brine salinity. Thus, modeling of SBL under control environment using suitable Electromagnetic (EM) modeling technique to differentiate between water, sediment, and hydrocarbon layer plane are needed.

The potential of this integrated modeling approach was demonstrated by calculating the variation in the EM response associated with a petroleum reservoir, due to different clay distributions. .

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INTRODUCTION

1.1 PROJECT BACKGROUND

1.1.1 Sea Bed Logging

Seabed logging (SBL) is a new method employing EM energy to detect and characterize hydrocarbon bearing reservoirs in marine environments. However, compared with other more mature EM methods, the representation of the petroleum reservoir is still rather crude in standard SBL-modeling programs

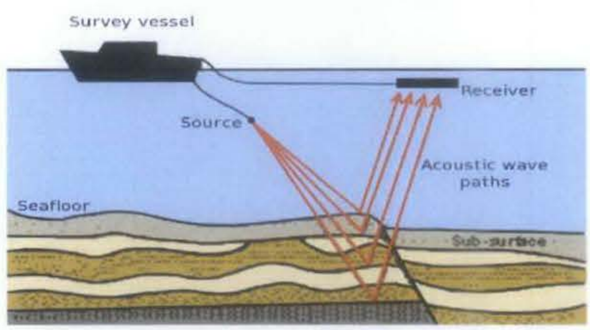

Figure 1: The real condition in sea bed logging (1)

1.1.2 Sand Shale Reservoir

The reservoir zone is often assigned a fixed conductivity value without any link to a rock physics description. However, the actual petroleum reservoir is a complex mixture of fluid, sand, clay and gas. Different formations and structures will give rise to different EM properties and at the end to different measurements. An accurate and efficient EM description of the reservoir zone is therefore necessary to further understand and develop the SBL technique.

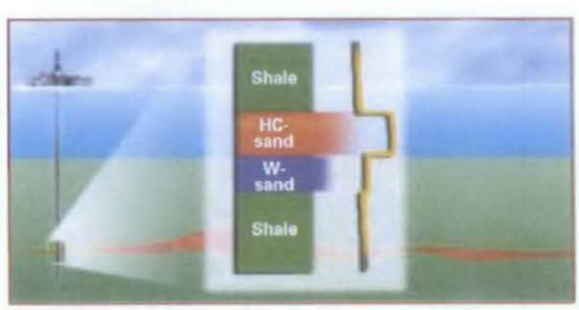

Figure 2:Sand shale in marine sand (2)

1.1.3 COMSOL Multiphysics Sofware

COMSOL Multiphysics is a finite element analysis, solver and simulation software package for various physics and engineering applications, especially coupled phenomena, or multiphysics.The COMSOLMultiphysics simulation software environment facilitates all steps in the modeling process in defining geometry, meshing, specifying physics, solving, and then visualizing results.

1.2 PROBLEM STATEMENT

1.2.1 Problem Identification

- Most seabed logging projects have been used to confirm the presence of hydrocarbon in structures identified from data before drilling. This application using COMSOL multiphysics significantly reduces the drilling risk especially for operators of expensive deepwater wells
- New rock-physics modeling tool was developed to describe the properties of a sand-shale reservoir. All mixing-models are sensitive to the oil layer but the dispersed clay model shows a much larger anomaly than other two mixing model which are coated clay and structural clay The potential of this integrated modeling approach was demonstrated by calculating the variation in the EM response associated with a petroleum reservoir, due to different clay distributions. .
- I have also experiment that the salinity of brine in a sand-shale reservoir rock also affects the EM response considerably and studied the effect of varying the brine salinity. Thus, modeling of SBL under control environment using suitable Electromagnetic (EM) modeling technique to differentiate between water, sediment, and hydrocarbon layer plane are needed.

1.3 OBJECTIVES

The objectives of this project are:

- To study the sea-bed deepwater properties including the electromagnetic wave and the finite element in waveguide
- To reduce the amount of experiment indeed to explore the hydrocarbon reservoirs under the sea-bottom by use the COMSOL software rather than use the electromagnetic sounding method.
- To experiment the effect of clay distribution and the salinity of dispersed clay the in sand shale to the electromagnetic wave in COMSOL multiphysics software
- To determine the effect of airwave to the EM data when parameters such as sea depth, water level, and frequency are varied.

1.4 SCOPE OF STUDY

In order to complete this project, several scope of study had to achieve. The major scopes are as follows:

1.4.1 Understanding Seabed Logging method.

- The Research towards the processes involved in seabed logging technique and the existing issues related to it.
- Research on measurement principle of Seabed Logging to excite the EM waves in a hydrocarbon reservoir.
- The properties of the clay distribution will be tested using simulation in COMSOL software
- The proper ways of handling and processing the data are to be considered.

1.4.2 Developing Seabed logging simulator using COMSOL

- There will be a need to install COMSOL software into personal computer (PC).
- Training on how to use COMSOL software in order to develop the simulator.
- The knowledge on electromagnetic (EM) principle and tools offered in the software will help to achieve the project objective.
- The simulator shall then be used to model the Electromagnetic waves to detect potential hydrocarbon when different parameters are varied.
- Interpret data based on the information gained.
- An analysis will be done based on the result collected from the simulation
- A written report of this project will be produced after all activities has been successfully conducted

1.5 FEASIBILITY OF THE PROJECT WITHIN THE SCOPE AND TIME FRAME

Two semesters will be required to complete this project. For the first semester, author will start the project with research on electromagnetic waves and its application as well as the development of the simulator using COMSOL. Learning the software is an important aspect in Final Year Project (FYP) 1 to prepare for better results in FYP2.

The second semester will focus on the simulation and data collection of the modeling the seabed logging. All the data will then be interpreted for technical report.

With the resources that are available in UTP, the project shall be completed within the given time frame and the author was strongly believed that the project can be completed within the time frame that has been given to the author.

CHAPTER 2

LITERATURE REVIEW

2.1 SEABED LOGGING (ELECTROMAGNETIC WAVE)

2.1.1 Electromagnetic Wave

Electromagnetic methods use the response of the ground to the propagation of incident alternating electromagnetic waves, made up of two orthogonal vector components, an electrical intensity (E) and a magnetizing force (H) in a plane perpendicular to the direction of travel

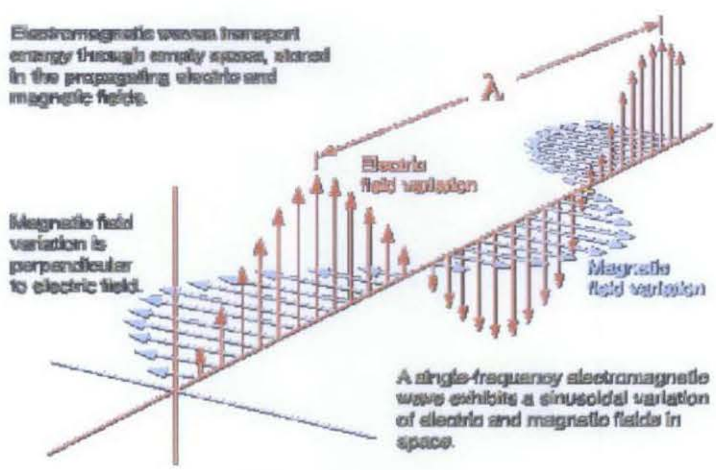

Figure 3: Electric Field Variation (3)

In electromagnetic waves most of the theory is related to Maxwell's equations and it is stated that magnetic field produced (B) is proportionally related to the current and the type of material used. The bigger the current flows inside a conductor and the higher the permeability of the material used, then the bigger the B field is produced [9].

Both magnetic field (B) and electric field (E) are propagating perpendicularly to each other with the same amplitude where the reduction in B field intensity will cause the same amount of reduction in E field as well [9].

Based on Maxwell equation [9]:

$$B = \frac{\mu_0 I}{2\pi r} \qquad [1]$$

Where;

B = Magnetic field,

$\mu 0$ = Permeability

I = Current

r= Distance

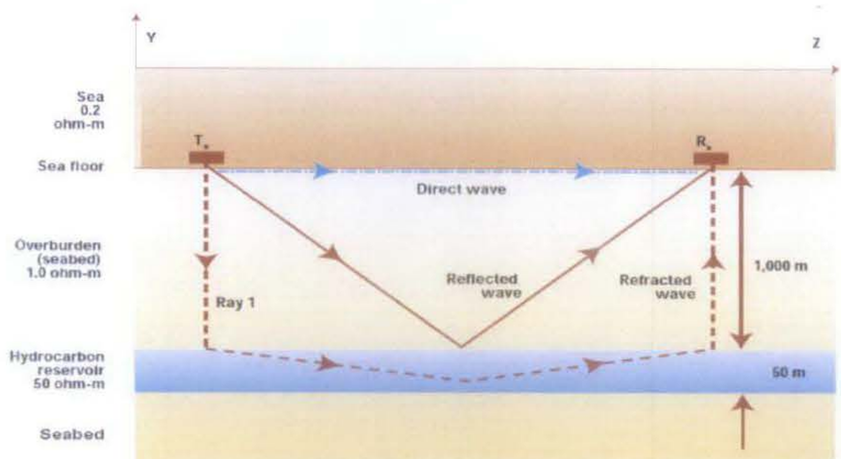

Figure 4 : Wave propagation in path in the hydrocarbon reservoir (4)

A plane wave and a homogeneous medium assumption is of course not valid for the SBL measurement situation in a practice.To approach the reality a bit more,consider a homogeneous seabed model without a hydrocarbon-filled reservoir.Consider horizontal electrical dipole transmitter placed on the sea floor.The complete radial electric field E_ρ in the seawater near the seafloor a radial distance ρ can be written

$$E_\rho = I\, L_t\, e^{jk\rho} \left(1/\rho^3 - jk/\rho^2 - k^2/\rho \right) / (2\pi\sigma_{sea}) \qquad [2]$$

Where I is the transmitter current,Lt is the transmitter antenna effective length.k is the complex wave number of the seabed, **ρ** is the distance to the transmitter antenna and σ_{sea} is the electric conductivity of the sea water.The signal magnitude (V_r) received by a horizontal dipole receiver antenna at a radial distance ρ can be written

$$V_r = I\, L_r\, L_t\, e^{jkt} \left(1/\rho^3 - jk/\rho^2 - k^2/\rho \right) / (2\pi\sigma_{sea}) \quad (3)$$

[3]

Where Lt is the receiver antenna effective length.Both the magnitude and the phase of received signal,as functional of the distance ρ ,are measurble quantities.They are mainly dependant on the seabed wave number k.

2.1.2 Sea Bed Logging Background

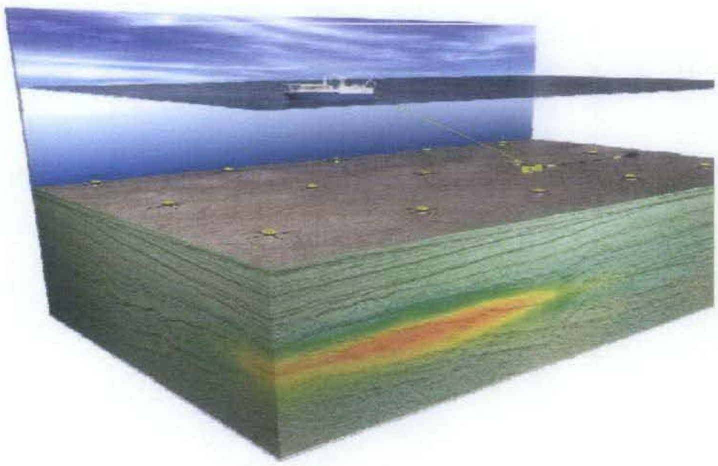

Figure 5: Sea Bed Logging in 3D design (5)

The Sea Bed Logging (SBL) method uses a mobile horizontal electric dipole (HED) transmitter and an array of seafloor electric receivers. The seafloor receivers measure the low frequency electrical field generated by the HED source from different positions. Thus, an observational survey consists of many transmitters and receivers located over the examined sea-bottom area.

All fluid-filled rocks are characterised by electrical conductivity. The difference in conductivity between, for example, shale and sandstone is relatively small when these rocks are water-saturated (resistivity 0.2-5 Ωm). If the sandstone is filled with oil or gas, however, its conductivity falls markedly (resistivity 20 - >200 Ωm). This is the principle applied in well resistivity logging.

With the electromagnetic field generated from a transmitter towed approximately 30m *above* the seabed and registered by a receiver placed on the seabed it is now possible to "view" the reservoir from above and not just from an instrument in a borehole. To achieve deep penetration– several thousands of metres down it is necessary to have a powerful source and low frequencies (typically 0.25-10Hz) in the outgoing signal.

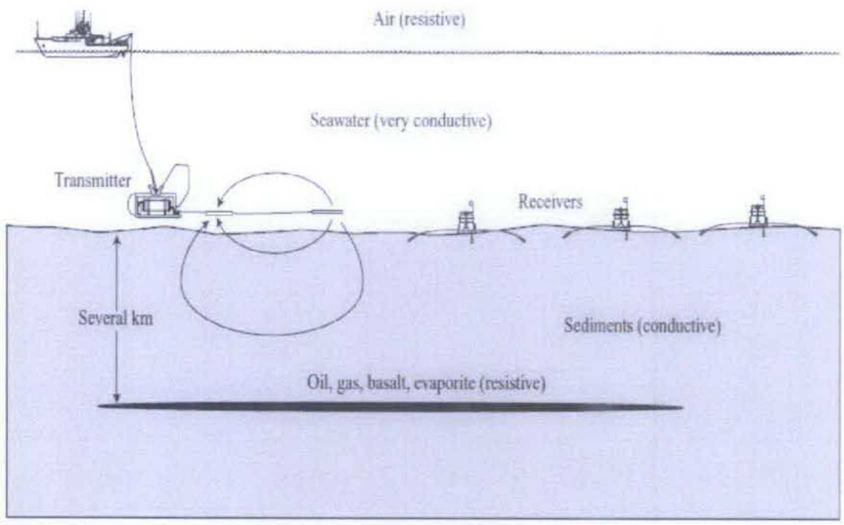

Figure 6: The receivers are first placed on the seabed. Then a vessel with a transmitter passes over them. Signals arrive directly through the water, through air and through the reservoir (6)

The source is an electric dipole consisting of two poles, a lead and a tail electrode, each about 10m long. The two poles are located 300-400m apart and connected by a cable. Passing an oscillating high-power current from the lead to tail electrode creates an electromagnetic field that sends out waves in all directions. When a wave meets a low-resistivity layer, it passes through and becomes slightly weakened or attenuated. Encountering a high resistivity layer, the wave is deflected along it and attenuated to a much lesser degree.

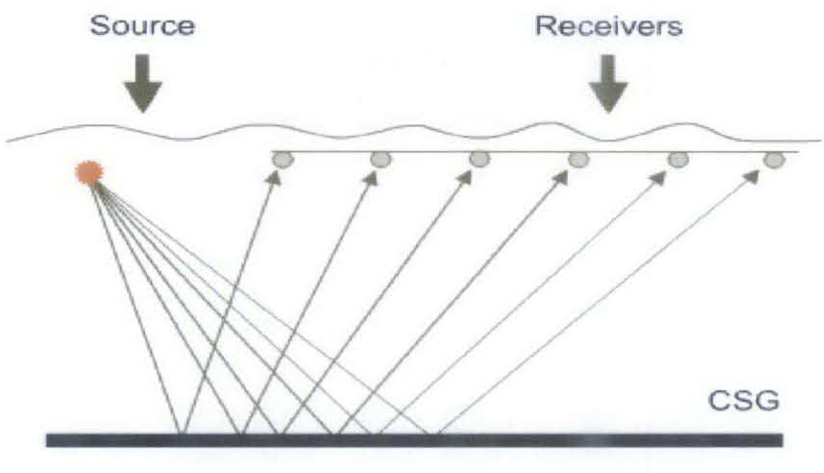

Figure 7 : The electromagnetic source is towed near the seabed, while receivers are placed on the seabed in a regular grid. (7)

The source thus generates a signal that is distorted by resistive bodies in the subsurface. The distorted response shows as anomalous readings that differ from the background. The resistive bodies showing these anomalies could be oil or gas reservoirs. The strength of the electric field, for a specific receiver placed on the seabed, is measured and registered as a function of distance between transmitter and receiver ("offset").

When the distance from the transmitter to the receiver increases (the boat moves away from the receiver), the signals diminish in strength. All measurements above the reservoir are compared with reference measurements outside it. Signal strength from resistive bodies increase with offset up to a point; at offsets approximately equal or greater than 3x the burial depth, the energy from the resistive body dominates all the other energy paths.

Figure 8 : Third-generation seabed-logging receivers record electric and magnetic field components on the seabed. (8)

2.2 CLAY DISTRIBUTION AND BRINE SALINITY IN SAND SHALE RESERVOIR

2.2.1 Dispersed Clays

All mixing-models are sensitive to the oil layer but the dispersed clay model shows a much larger anomaly than other two mixing model which are coated clay and structural clay.In this mixing-model the clay grains fill the pore space between sand grains and assume that the composite medium is built from an initial fixed volume of fluid by adding to it, in steps,infinitesimal amounts of insulating sand grains and clay aggregates. The incremental method solution can be written as (assuming non-conducting core $\sigma sa = 0$):

$$\sigma^* = \sigma_f \phi^{3/2} \left[\frac{1 + (1 - 3p)\,\sigma_c / 2\sigma^*}{1 + (1 - 3p)\,\sigma_c / 2\sigma_f} \right]^{3p/(1-3p)} \qquad [4]$$

where p again is the volume fraction of clay in the solid portion.

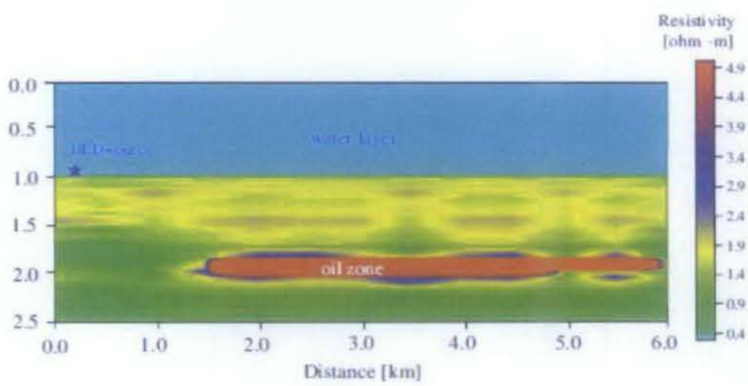

Figure 9: 2D of resistivity model (9)

Clays and shales are hydrated minerals with high porosities and low permeabilities. The minerals themselves may not be very conductive, but their surface causes an excess of cations in the pore fluid immediately adjacent to the clay surfaces. The result is high conductivity near the clay surfaces, which can dominate the overall conductance if the pore water conductivity is low.

The excess conduction along clay mineral-fluid interfaces is called surface conductance, because of being caused by a thin film of material confined to the clay surfaces. When clays are brought in contact with an electrolyte, the negative charges on the clay surfaces attract the positive ions and repulse the negative ions present in it. Generation of an electrical ionic double layer by accumulation of ions near the charged surfaces contributes to the total conductivity of the brine filled rocks. The type, quantity, distribution and morphology of clays affect the excess conductivity caused by the electric double layers.

In the case of clay dispersed in the pore volume, the conducting inclusions are clay particles only. In equations [5] and σ_{clay} represents the conductivity of the clay. In the case of dispersed clay possible alignment (single shape-distribution) is allowed for and either spherical or aligned clay aggregates (fixed shape)

$$m_c = 1/A_q, \quad \sigma_c = \sigma_{clay} \quad \textit{dispersed clay} \tag{5}$$

In the simulations, a dispersed-clay case was assumed with a clay fraction of 20% in the solid part and a clay-conductivity of 1.0 S/m. The grain-shape distribution was now 65% spherical and 35% discs, corresponding to a cementation factor of *m =2.30* (fully water saturated) in equation [6] and the effect of possible saturation changes S_w is included, assuming an initial water saturation of S_{w0}.

$$\begin{aligned}\sigma(s, p, T, S_w) &= [\sigma_w(s_0, T_0) + \Delta\sigma_w] \cdot [S_{w0} + \Delta S_w]^n \\ &\times [\phi(p_0) + \Delta\phi]^m \cdot \\ &\left(\frac{B(s_0, T_0) + l \cdot B(s, T)\sigma_c(s_0, T_0)/\sigma(s, p, T, S_w)}{B(s_0, T_0) + l \cdot B(s, T)\sigma_c(s_0, T_0)/(\sigma_w(s_0, T_0) + \Delta\sigma_w)}\right)^n .\end{aligned} \tag{6}$$

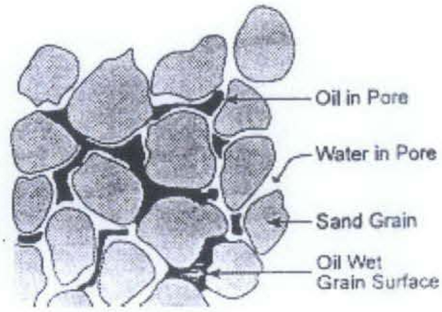

Figure 10 : Dispersed-clay features in the sediment (10)

2.2.2 Brine Salinity

Electrical-conductivity measurements in boreholes are used to determine the volume of hydrocarbons present in oil and gas reservoirs. The method is based on the fact that hydrocarbons do not conduct electrical current, whereas saline formation water does. The formation conductivity therefore decreases with increasing hydrocarbon saturation.

Reservoir production causes changes in saturation over time. As an example, water can be injected to squeeze out more hydrocarbons and hence, water is replacing oil/gas as a pore fluid. The salinity can also change during production if steam injection is employed to enhance the recovery rate. In such a case, the salinity is diluted and the conductivity will decrease due to dissolved salts being depleted. Steam condensation will increase the conductivity due to increased water saturation in the pore space.

Different salts in water have a different ability to conduct electricity. This is because of the differences in charge and size / weight and mobility of the different ions. This difference is quantified as a property called the specific conductance. The specific conductance is a value based on the theoretical conductivity of ions at very low concentrations.

Although it is possible to calculate the conductivity for any electrolyte at any temperature and concentration, the exact contribution of individual ions is difficult to determine due to interactions between the ions. This means that it is difficult to work out what the conductivity of a particular salt mix should be, and hence it is difficult to establish the theoretical relationship between conductivity and TDS for a given mixture.

It is well-known that the brine conductivity σw in equation (7) varies both with temperature and salinity.

$$\sigma = \sigma_w (S_w \phi)^m \left(\frac{1 + l\sigma_c / \sigma}{1 + l\sigma_c / \sigma_w} \right)^n, \qquad [7]$$

Traditionally, Arps' formula has often been used in combination with Archie's law to predict the temperature dependent effective conductivity for the sand at a given salinity. Based on empirical data, Sen and Goode proposed a more general relationship, taking into account the molality of the brine. Making use of their results (and converting from molality to salinity), the following relationship is employed here

$$\sigma_w(s, T) = \sigma_w(s_0, T_0) + \Delta\sigma_w, \qquad [8]$$

where T_0 and s_0 represent initial temperature and salinity, respectively temperatures are measured in degrees Celsius and salinity in kppm.

Salinity is a measure of the amount of salts in the water. Because dissolved ions increase salinity as well as conductivity, the two measures are related. Salts that dissolve in water break into positively and negatively charged ions. Conductivity is the ability of water to conduct an electrical current, and the dissolved ions are the conductors. The major positively charged ions are sodium, (Na+) calcium (Ca+2), potassium (K+) and magnesium (Mg+2). The major negatively charged ions are chloride (Cl-), sulfate (SO4-2), carbonate (CO3). The salts in sea water are primarily sodium chloride.

(NaCl). $2\ NaCl(aq) + 2\ H_2O(l) \rightarrow 2\ NaOH(aq) + H_2(g) + Cl_2(g)$ [9]

Ionic conductance is not so well understood. Current flow though a conductive ionic medium (salt water) requires the actual movement of charged ions (Such as Na+ and Cl-) through the medium (water) However, when an alternating current is induced in the medium, the direction of the potential is constantly reversing. The Cations and Anions are still in motion but their behaviour is different. Thus, it can be seen that the conductance in the formation is due to the ability of charged ions to migrate through the water within the pore spaces.The presence of hydrocarbon impedes the movement of charged ions

2.3 SIMULATION USING COMSOL MULTIPHYSICS

COMSOL Multiphysic Software has developed a new technique for 3-D interpretation of the sea-bottom electrical profiling data, collected with a mobile horizontal electric dipole (HED) transmitter and an array of the seafloor electric receivers (Seabed Logging Method).

Figure 11 : COMSOL Multiphysic software

The method is allows simultaneous inversion of multitransmitter data. This method will do the interpretation of the synthetic EM data simulated for the model of a sea-bottom petroleum reservoir. The results demonstrate that the SBL method with the 3-D interpretation can be effectively used for sea-bottom reservoir detection.

COMSOL Multiphysics (formerly FEMLAB) is a finite element analysis and solver software package for various physics and engineering applications, especially coupled phenomena, or multiphysics. COMSOL Multiphysics also offers an extensive and well-managed interface to MATLAB and its toolboxes for a large variety of programming, preprocessing and postprocessing possibilities. In addition to conventional physics-based user-interfaces, COMSOL Multiphysics also allows for entering coupled systems of partial differential equations (PDEs).

Based on the Finite Element (FE) Method:

- FE can handle complex geometries and boundary conditions with ease. FD is basically restricted to rectangular shapes.
- FD only tries to minimize error at discrete points, whereas FE tries to minimize the error over the entire element (line segments in 1-D, triangles in 2-D)
- The mathematics behind FE are more involved than FD

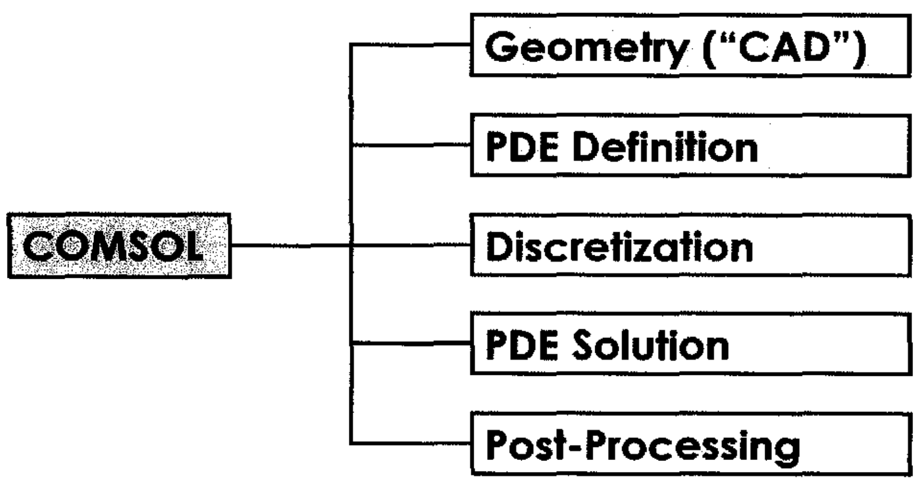

Figure 12: Typical modeling steps in COMSOL Multiphysics

Necessary Assumptions for the methods that had studied so far:

- 2-D problems, in plan view generally
- Horizontal-only flow (Dupuit-Forchheimer assumption)
- Isotropic, homogeneous domain
- Steady-state conditions (no change in time)
- Darcy's law applies in the full domain
- To get approximate solutions to problems that cannot be solved analytically, for example:
  - Problems with complicated geometries and/or boundaries
  - Problems with difficult to solve PDEs

- To test the applicability of a simple rule under a variety of conditions (for example, the Ghyben-Herzberg relation)
- To verify the correctness of an analytical solution

Compared with other methods of modeling:

- Relatively easy to use graphical interface
- Uses state-of-the-art solvers and optimizers. Runs well on a suitably-equipped (lots of RAM) desktop PC.
- Lots of default options / hidden parameters
- Interface changes based on what type of physics you are solving for. "Multiphysics" gets even more cumbersome.

CHAPTER 3

METHODOLOGY

3.1 RESEARCH METHODOLOGY

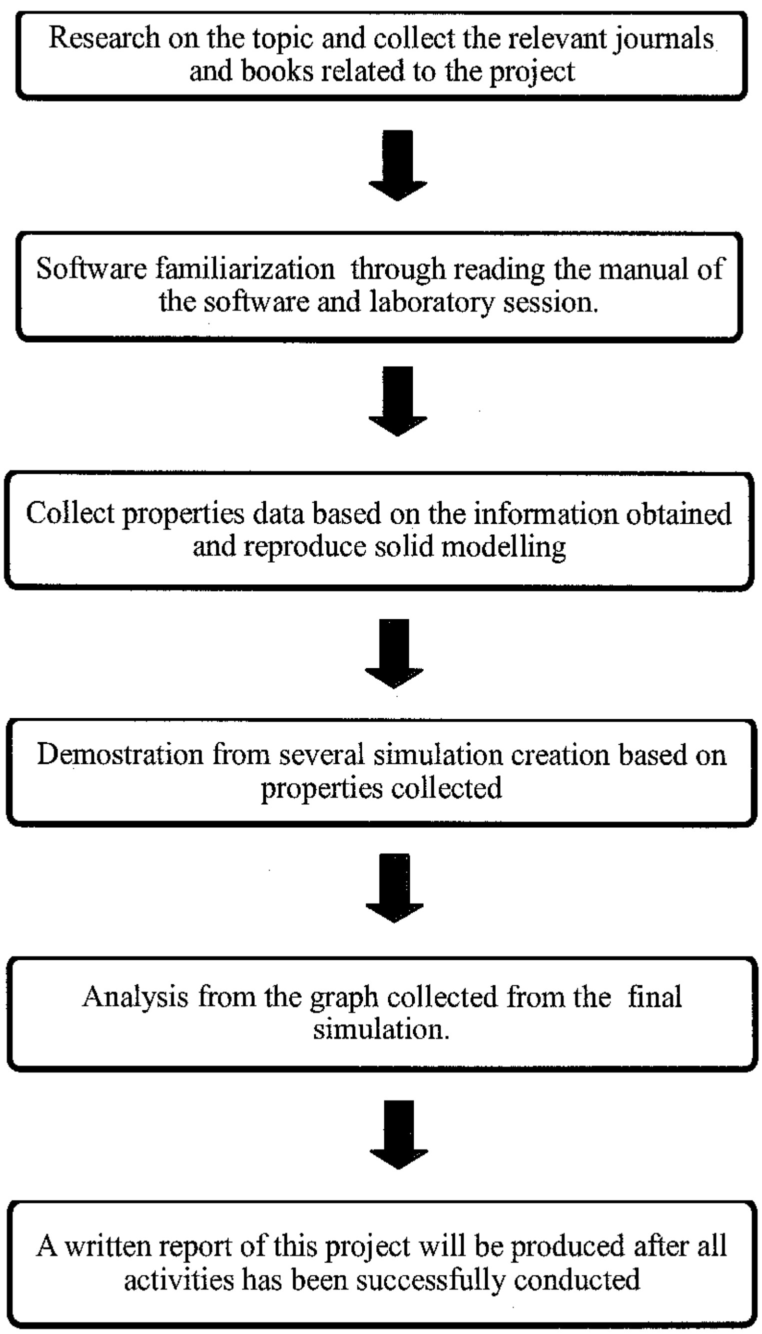

Figure 13: Research Methodology of the Project

3.2 FLOWCHART/PROCEDURE OF PROJECT DEVELOPMENT

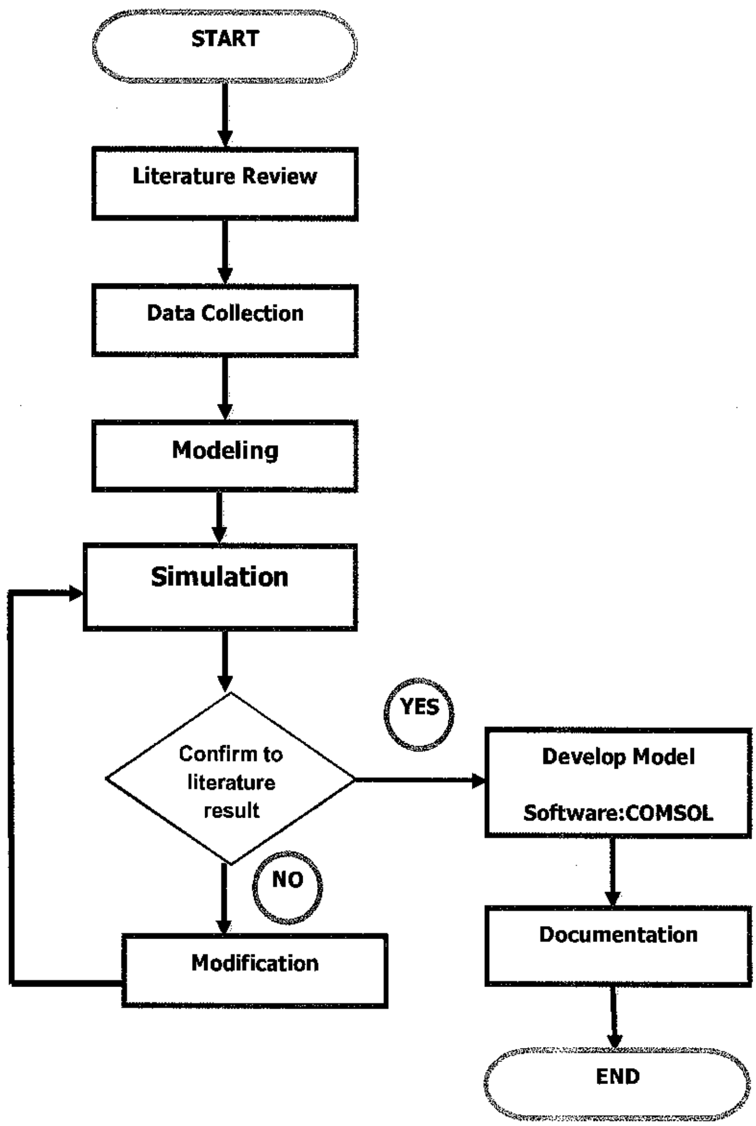

Figure 14: Flowchart of the Project Procedure/Development

3.3 WORK SCOPE

3.3.1 Data Gathering and Research

Data gathering and research to acquire the theoretical equations for model development is done via articles, journals and papers regarding SBL and EM wave to ensure the accuracy of collected data.

3.3.2 Developing SBL Simulator

Seabed Logging 3D Simulator was developed using COMSOL software based on forward modeling technique. The simulator was developed under ideal or equilibrium situation which was not considering noise, seawater density, temperature and others. Each component of received signals was processed as part of data representation in three-dimensional view. Finally, the working model was verified by conducting experiment regarding the study requirements that were affecting on changing the source frequency and variation of hydrocarbon reservoir thickness.

3.3.3 Parameters Variation

Changing parameters in SBL using COMSOL software can affect hydrocarbon detection and mapping. Parameters that have been varied were:

- The location with hydrocarbons and without hydrocarbon.
- Frequency of the transmitter.
- Hydrocarbon thickness.
- The depth of the seawater

Received waves components were observed and analyzed to be used for future study.

3.4 TOOL AND EQUIPMENT REQUIRED

3.4.1 COMSOL 3.5a

As stated in Section 2.4.5, SBL Simulator was developed using Comsol software. RF module was used as a medium for this simulator because it provides a unique environment for the simulation of electromagnetic waves in three dimension modeling. Figure 5shows Comsol's model navigator used to select the application module to be used which is the RF module.

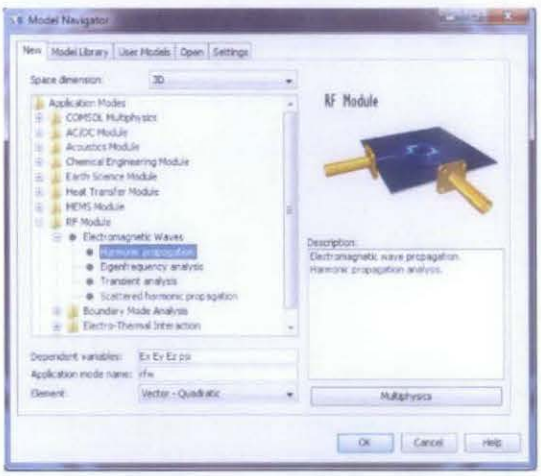

Figure 15: Model Navigator

The environment used for this simulator was based on data gathered from research of a real seabed logging environment. Comsol Multiphysics also provide user with GUI which help user to easily create a model by using all the tools given. Figure 6 show Comsol Multiphysics GUI to develop the SBL model.

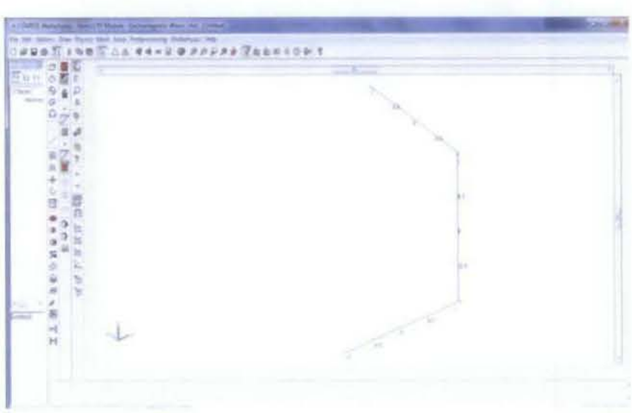

Figure 16: COMSOL Graphical User Interface (GUI)

3.5 DEVELOPING SBL SIMULATOR

SBL simulator was developed to generate plane layer model and EM field of the waves received by the receivers based on ideal environment. Users are able to key in desired parameters through the simulator.

When creating a model in Comsol Multiphysics, the typical modeling steps include:

- Creating the geometry
- Defining the physics on the domains
- Meshing the geometry
- Solving the model
- Postprocessing the solution
- Performing parametric studies

Before started with all the steps user need to complete some setting by click on COMSOL Multiphysic 3.5a and Comsol's model navigator will appear as in figure 15 and then Select **New** at the tab menu. From the tab select 3D for the space dimension, select **Harmonic Propagation**, and then click **"OK".**

3.5.1 Geometry Modeling

"Sphere" tool was use to create block for air, seawater, sediment and hydrocarbon. This tool allow user to set the length and axis base point of the block as illustrated in figure 17 and then click "**OK**" the sphere will appear .

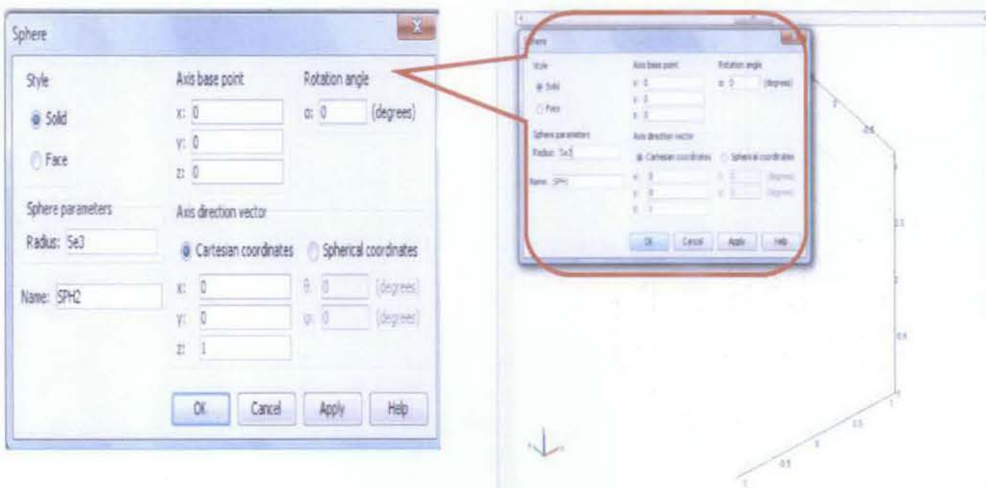

Figure 17: Creating sphere for air, seawater and sediment

Then,use the **"Cylinder"tool** to create a cylinder which is represent air and seawater to create with parameter **Radius** 6e3 and **Height** 1e3 and then click "**OK**"

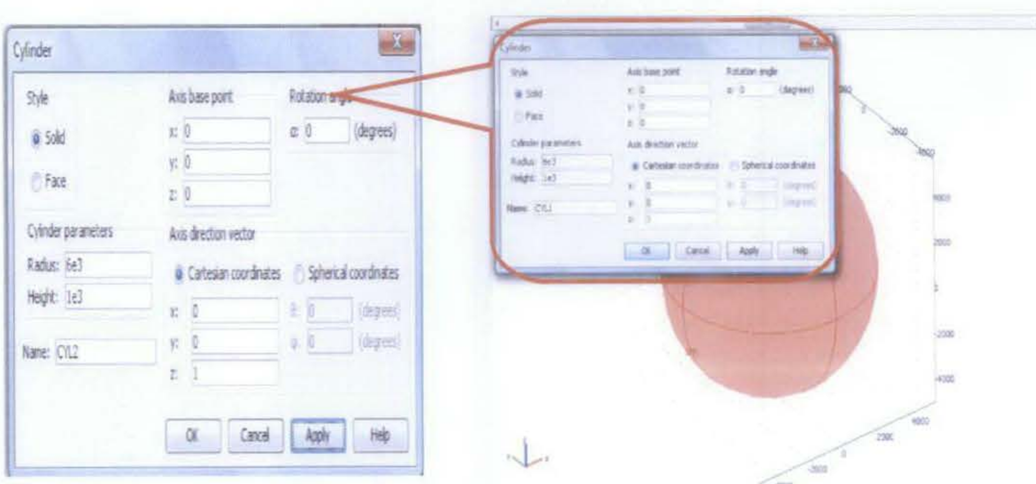

Figure 18 : Creating cylinder for air and sea water

After the cylinder created, select all object by pressing **Ctrl+A** and click the **Intersection** button on **Draw tool bar** and cylinder represent seawater will appear as intersection with the sphere.

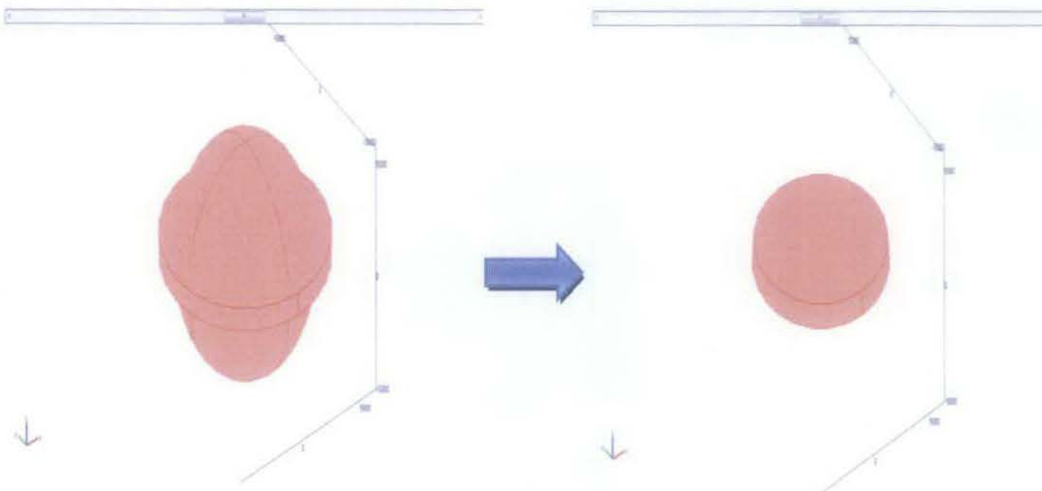

Figure 19 :Intersection sphere and cylinder for seawater

Then, create a new sphere with a **Radius** of 5e3 in order to create block of hydrocarbon in the next step.

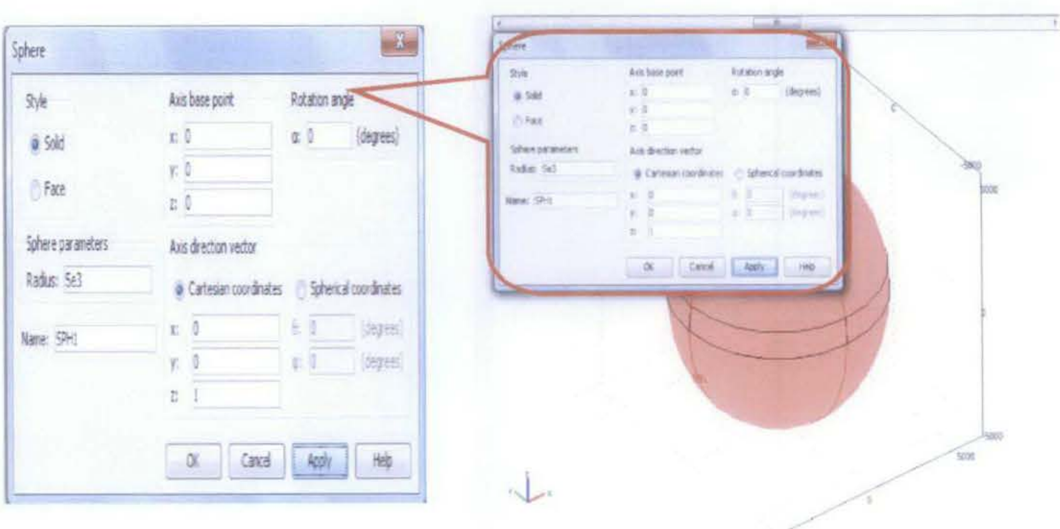

Figure 20 : Creating a new sphere

After create the sphere, click the block symbol an define a block as hydrocarbon with the parameter

- **Base** : Center
- **Length x**: 4e3
- **Length y**:1e3
- **Length z**:100
- **Axis base point** z:-250

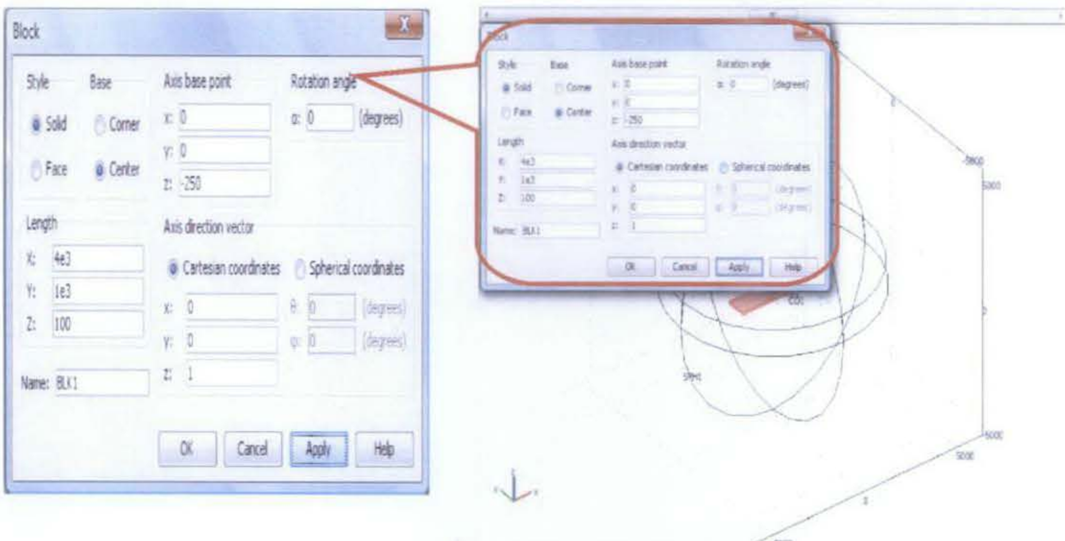

Figure 21 : Creating block for hydrocarbon

"Line" tool was use to create the transmitter and also receiver of the seabed logging environment. This tool allow user to set the coordinate of the line as illustrated in figure 22 and then click the line symbol and define a Polyline with parameter represent transmitter:

- **Coordinates x**: -10 10
- **Coordinates y**:0 0
- **Coordinates z**:150 150

click "**OK**" when line of block will appear.

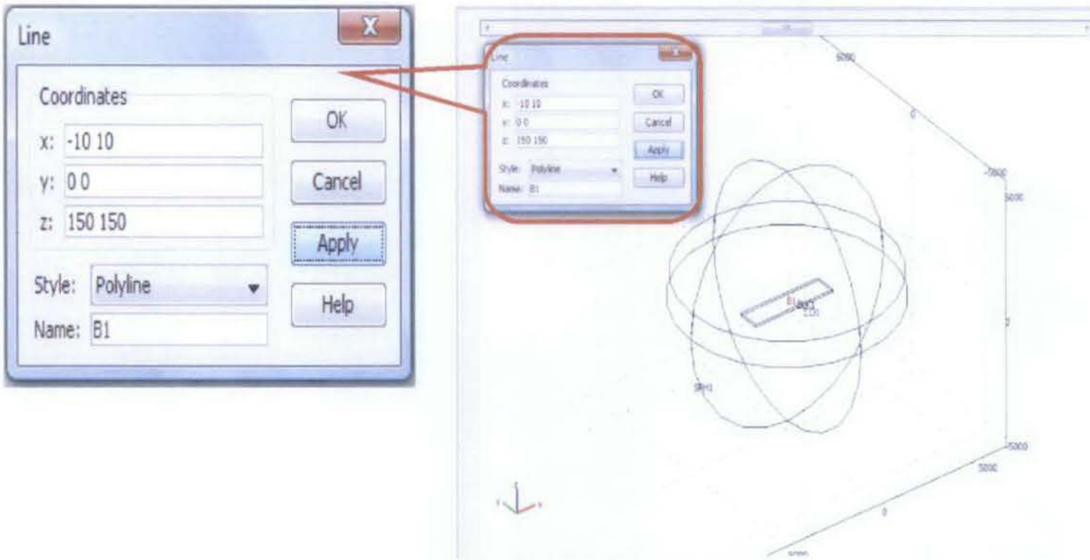

Figure 22 : Creating line with the coordinate for transmitter

Then, click the line symbol again and define a Polyline 2 with parameter represent receiver :

- **Coordinates x**: -5e3 5e3
- **Coordinates y**:0 0
- **Coordinates z**:0 0

click "**OK**" when the red line will appear.

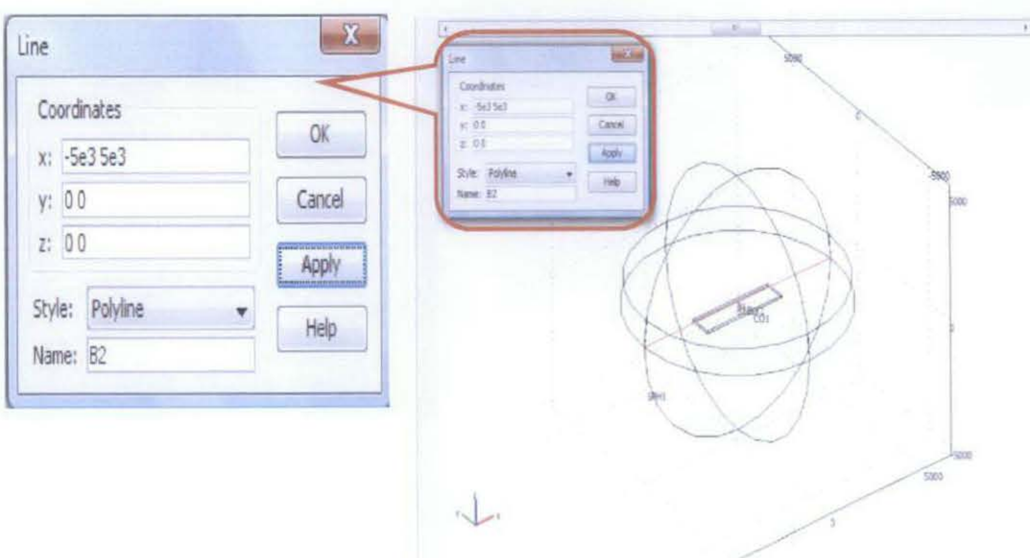

Figure 23 : Creating line for receiver using Line tool

3.5.2 Physic Setting

User can find the **"Physic"** menu at the menu bar with the same row as **File**, **Edit**, **Plot Processing** and **Mesh**. In physic menu there are four setting that need to be set which are:

- Subdomain setting
- Boundaries setting
- Edge setting
- Scalar variable setting.

"Subdomain" setting as being illustrate in figure 24 is to set the material properties and for the seabed logging application. User need to set up the relative permittivity and electric conductivity of the seabed environment.Table 1,Table 2 and Table 3 shows the setting parameter for this environment.

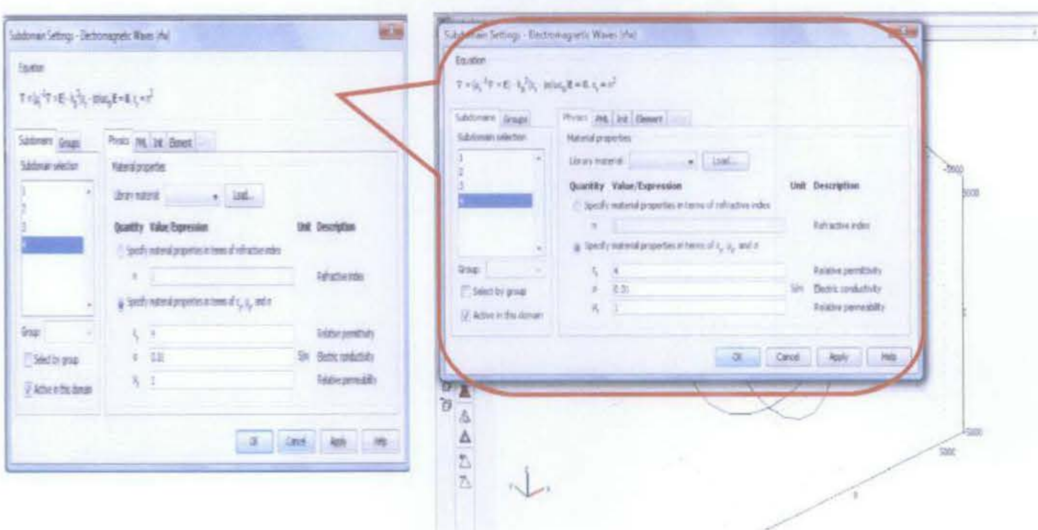

Figure 24 : Subdomain setting

SETTING	SUBDOMAIN 1	SUBDOMAIN 2	SUBDOMAIN 3	SUBDOMAIN 4
Relative Permittivity	80	30	1	4
Conductivity	5.2632(σ_w)	0.014979(σ^*)	0.001	0.01

Table 1: Subdomain setting parameters for model with hydrocarbon for 30 kppm

SETTING	SUBDOMAIN 1	SUBDOMAIN 2	SUBDOMAIN 3	SUBDOMAIN 4
Relative Permittivity	80	30	1	4
Conductivity	15.3846(σ_w)	0.039676(σ^*)	0.001	0.01

Table 2: Subdomain setting parameters for model with hydrocarbon for 100 kppm

SETTING	SUBDOMAIN 1	SUBDOMAIN 2	SUBDOMAIN 3	SUBDOMAIN 4
Relative Permittivity	80	30	1	4
Conductivity	27.7778(σ_w)	0.066(σ^*)	0.001	0.01

Table 3: Subdomain setting parameters for model with hydrocarbon for 250 kppm

"Boundaries" setting as being illustrate in figure 25 is to set the different dielectric regions in the rectangular waveguides. From boundaries tab select the region by group and click on the boundary selection list. At condition tab select scattering boundaries condition and spherical wave type.

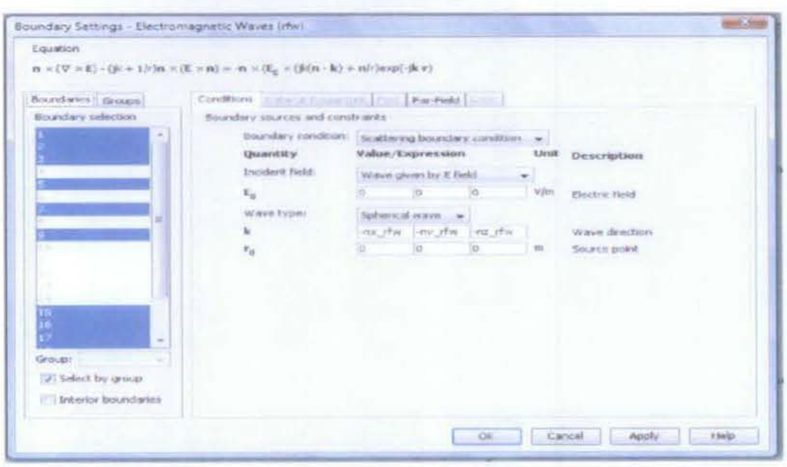

Figure 25 : Boundaries setting

"Edge" setting as being illustrate in figure 26 is to describe the physics on a model's main domain and work similar way as the point settings. On edge selection, select point that being assign to be the transmitter point. Than at coefficients tab, select current in edge segment direction and key in the value for the transmitter current. Based on research, transmitter current used for seabed logging are 1e4.

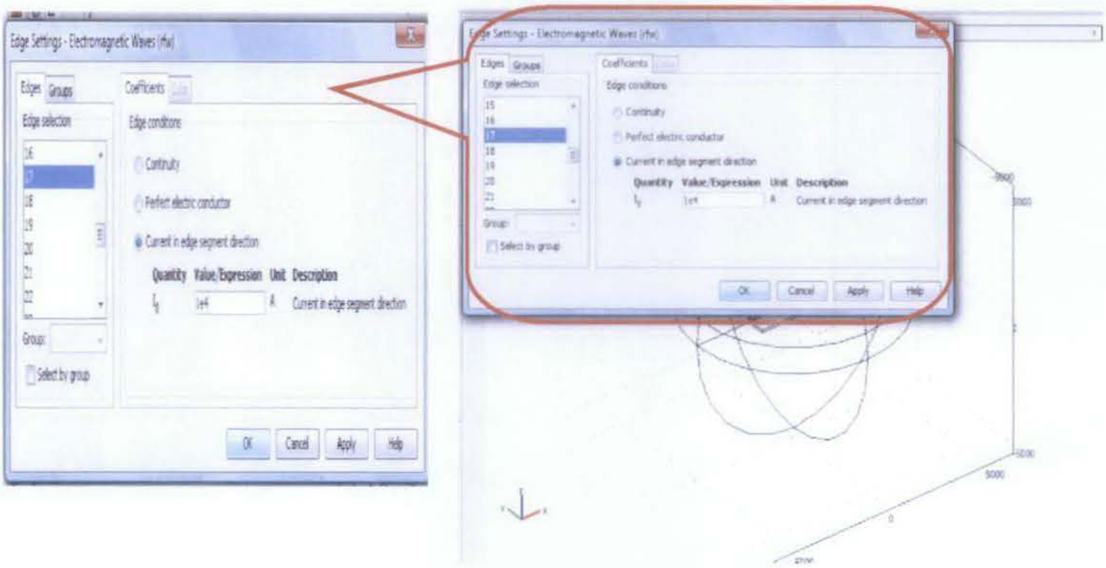

Figure 26: Edge setting

"Application Scalar Variable" setting as being illustrate in figure 27. The values of each scalar variable can be changed by making an entry in the edit field in the Expression column. Hence, for this seabed model user need to change the Expression of frequency description only.

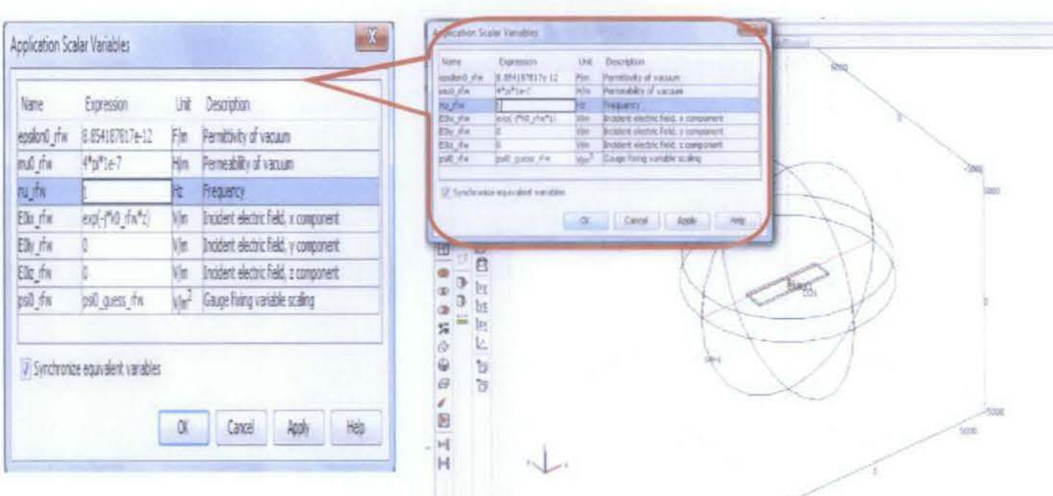

Figure 27: Application scalar variable setting

3.5.3 Meshing Geometry

User can find the **"Mesh" menu** at the menu bar with the same row as **File**, **Edit**, **Plot Processing** and **Physic**. Inside the mesh menu user need to set for the Free Mesh Parameters only. **"Free Mesh Parameters"** setting as being illustrate in figure 28 is being set up. From Global tab select the custom mesh size and set the maximum element size. For this model the maximum element size is set to be 1e3.

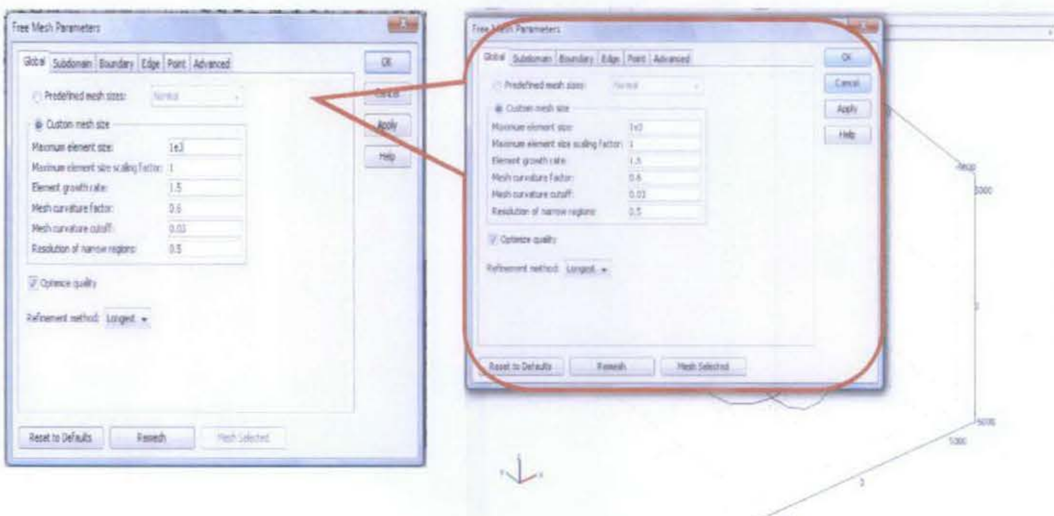

Figure 28: Free mesh parameter setting

Creating a free mesh containing tetrahedral elements, or a swept mesh containing prism elements or hexahedral elements can be chosen. a 3D mesh can be created by extruding 2D mesh. When a 2D mesh are extruded into 3D mesh, triangular element and quadrilateral elements in the 2D mesh are extruded into prism (wedge) elements and hexahedral (brick) element, respectively, as illustrated in figure 29. After meshing user need solve it by clicking on the solve icon " = ".

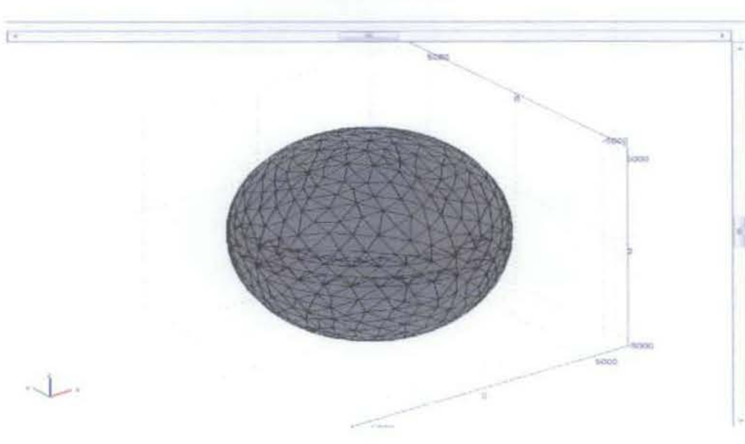

Figure 29: Mesh Model

3.5.4 Post Processing the Model

User can find the **"Post Processing" menu** at the menu bar with the same row as **File**, **Edit**, **Mesh** and **Physic** as being illustrated in figure 30.

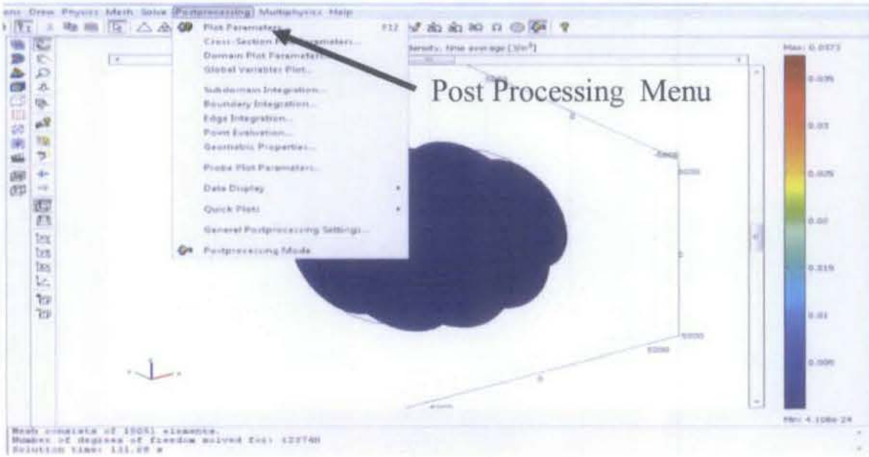

Figure 30: Post Processing Menu

"Boundaries" setting as being illustrate in figure 31 is to **Plot parameters** is to get visualizations on the solution domain using the common plot types. From plot parameter select on the slice tab and key in **20*log10(normE_rfw)** in the expression. Number of levels for **x=0**, **y=1**, and **z=0**. The slice plot is default type and it displays a quantity as a set of colored slices through geometry.

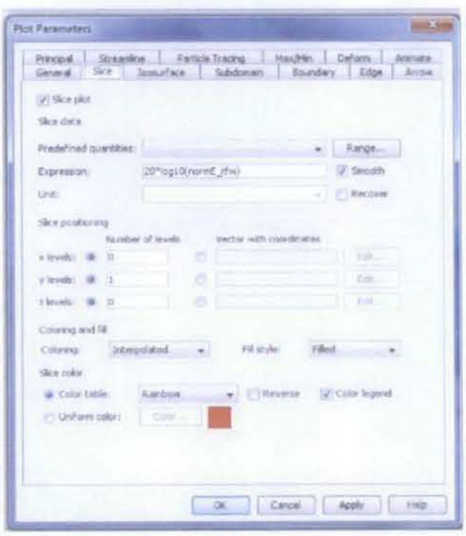

Figure 31: Plot Parameter setting

"Domain Plot Parameters" setting as being illustrate in figure 32 is to visualize on one or several surfaces as a quantity in time or along a parameter range. On surface tab key in **20*log10(normE_rfw)** in the Expression edit field and select the boundary to plot in the boundary selection list. Select Edge 5 in the **Edge selection** list and set the **x-axis data** to **x**.

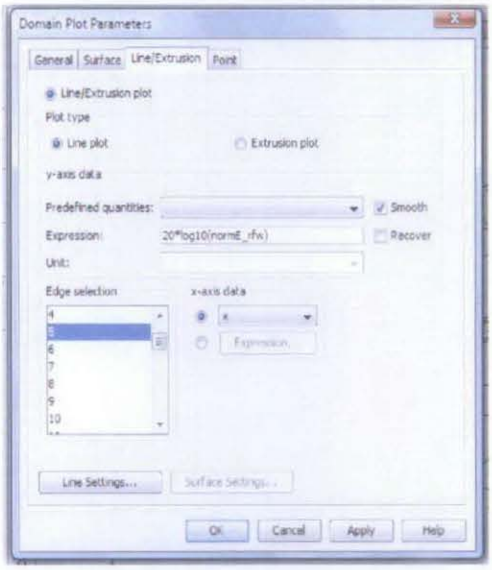

Figure 32: Domain Plot Parameter Setting

Figure 33 shows result of the domain plot parameter for model with hydrocarbon

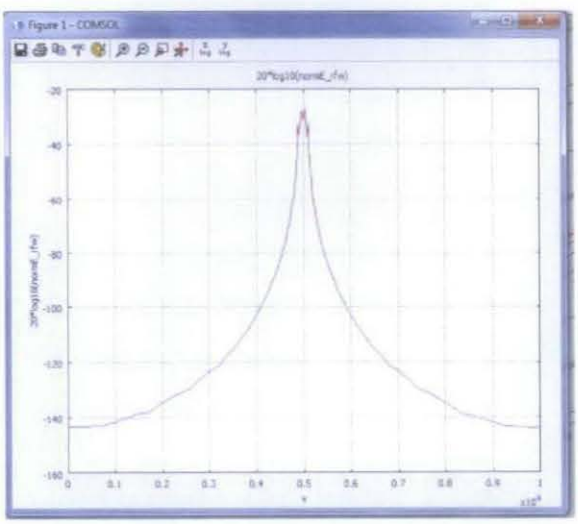

Figure 33: Result of Domain Plot Parameter for model with

3.5.5 Simulator Without Hydrocarbon

For simulator model without hydrocarbon user need to repeat procedure from the **"Physic Subdomain" setting** as being illustrate in figure 34.The material properties for this model need to be set up again as in the table 2 that shows the setting parameter. Then user need to mesh the model again and solve it by click on the mesh and solve symbol.

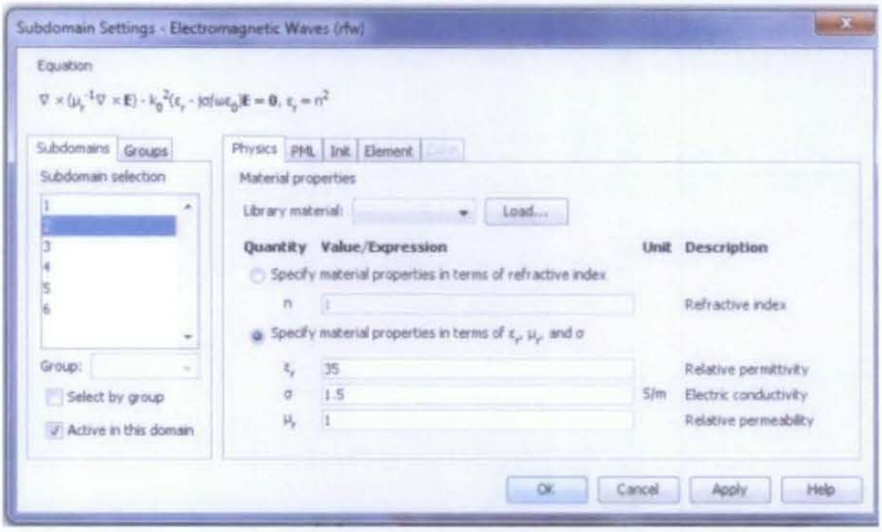

Figure 34 : Subdomain Setting for model without hydrocarbon

SETTING	SUBDOMAIN 1	SUBDOMAIN 2	SUBDOMAIN 3	SUBDOMAIN 4
Relative Permittivity	80	30	1	30
Conductivity	5.2632(σ_w)	0.014979(σ^*)	0.001	0.014979

Table 4 : Subdomain setting parameters for model without hydrocarbon for 30 kppm

SETTING	SUBDOMAIN 1	SUBDOMAIN 2	SUBDOMAIN 3	SUBDOMAIN 4
Relative Permittivity	80	30	1	30
Conductivity	15.3846(σ_w)	0.039676(σ^*)	0.001	0.039676

Table 5 : Subdomain setting parameters for model without hydrocarbon for100kppm

SETTING	SUBDOMAIN 1	SUBDOMAIN 2	SUBDOMAIN 3	SUBDOMAIN 4
Relative Permittivity	80	30	1	30
Conductivity	27.7778(σ_w)	0.066(σ^*)	0.001	0.066

Table 6: Subdomain setting parameters for model without hydrocarbon for 250kppm

In post processing menu select the **"Domain Plot Parameter"** and as in figure 35 at **Line/Extrusion** tab select the boundary to plot which is boundary number 5. Change the line color from the **"Line Setting"** and at General tab tick on the **"keep current plot"** as shown in figure 35.

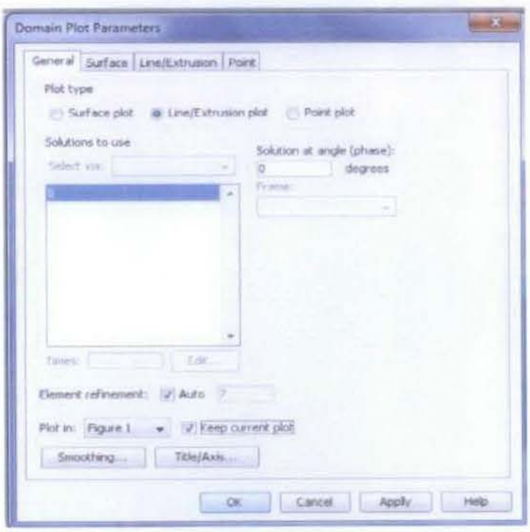

Figure 35 : Domain Plot Parameters Setting for model without hydrocarbon

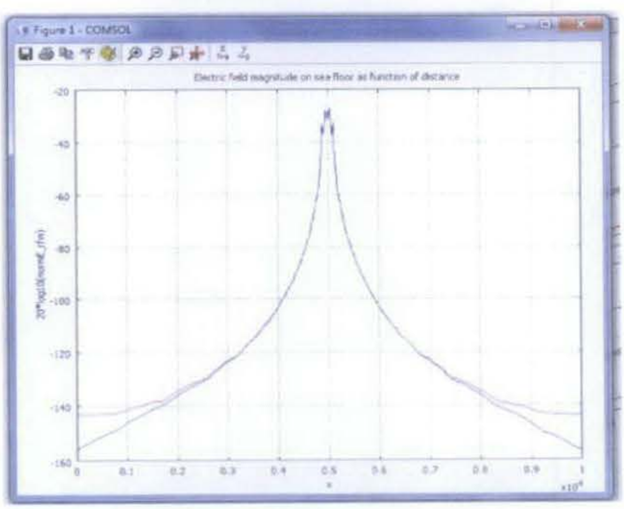

Figure 36 : Result for model with and without hydrocarbon

3.5.6 Seabed Logging Model

Figure 37 show the seabed logging model that had been developed using Comsol and specification for each layer. As stated in Section 3.4.2, subdomain setting is to set the material properties and for the seabed logging application. Hence, in table 3 and 4 shows the material property for air, seawater, sediment, and hydrocarbon.

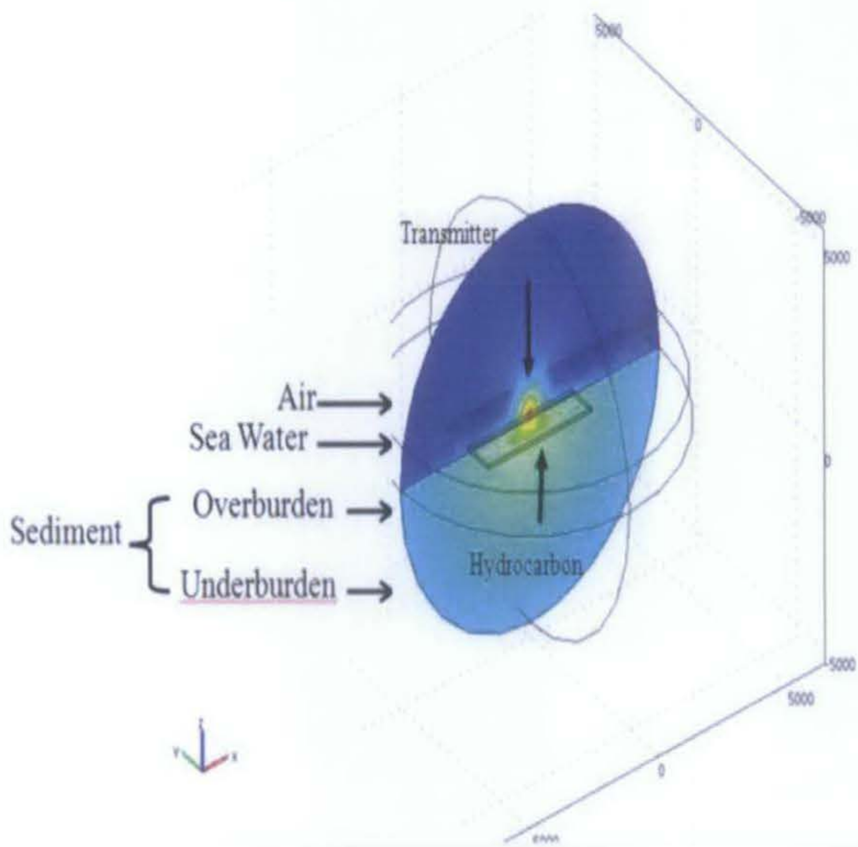

Figure 37: Seabed Logging 3D Model using COMSOL Multiphysic

3.6 PARAMETER VARIATION

Some models have been developed by using COMSOL that reflect the seabed logging 3D simulation. However, the simulator has been modified to observe the differences on the results by changing the following parameters:

3.6.1 The location with hydrocarbons and without hydrocarbon

For location with hydrocarbon and without variation, the model and other parameters are fix accept for the parameter for brine salinity which is:

- 30 kppm
- 100 kppm
- 250 kppm

3.6.2 Frequency of the transmitter

For frequency variation, the model and other parameters are fix for each brine salinity accept frequency of the transmitter. The frequency of the transmitter is varied as below:

- 0.5 Hz
- 1 Hz
- 2 Hz

3.6.3 Hydrocarbon thickness.

For hydrocarbon thickness, the model had been modified while other parameters are fix for brine salinity 30 kppm. The hydrocarbon thickness is varied as stated below:

- 50 m
- 100 m
- 200 m

3.6.4 The depth of the seawater

For the depth of seawater, the model had been modified while other parameters are fix for brine salinity 30 kppm. The depth of seawater is varied as stated below:

- 1000 m
- 2000 m
- 3000 m

CHAPTER 4

RESULT AND DISCUSSION

4.1 SEA BED LOGGING MODEL

Figure 38 show the slice view of each sub domain in seabed logging model and specification for each layer. As sub domain setting is to set the material properties and for the seabed logging application and shows the material property for air, seawater, sediment (overburden), and hydrocarbon.

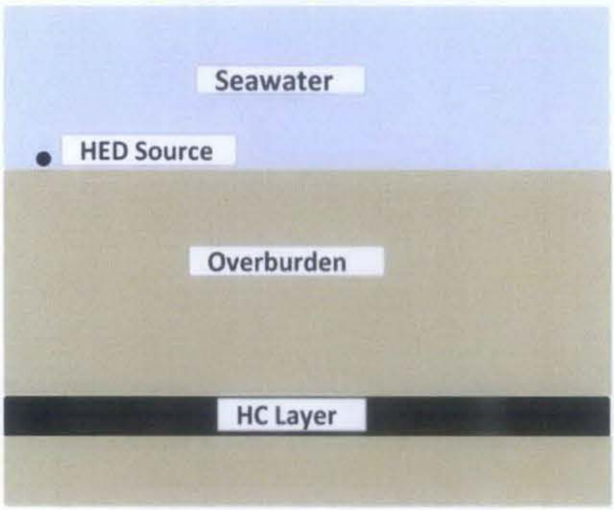

Figure 38: Slice View of Each Sub Domain in Sea Bed Logging

4.2 DATA RESULT FROM SIMULATION IN COMSOL MULTIPHYSICS SOFTWARE

4.2.1 Model Detention For Dispersed Clay And Brine Salinity

- The computational domain sphere = 5 km radius.
- Amount of receiver = 100 receivers
- Thickness of overburden = 1000 m
- Thickness of half space = ∞
- Water saturation, Sw = 0.15
- Variation brine salinity (dispersed clay) (kppm) = 30 kppm,100 kppm,250 kppm

Conductivity (S/m)	Salinity (kppm)		
	30	100	250
Water conductivity ,σ_w	5.2632	15.3846	27.7778
Clay conductivity,σ^*	0.014979	0.039676	0.066

Table 7 : Variations in the effective conductivity of the reservoir rock and water conductivity due to different brine salinities.

4.2.2 Plot Parameter with Hydrocarbon and without Hydrocarbon for 3 Different Brine Salinity

As stated, following are the results obtained after varying the hydrocarbon obtaining in the seabed logging. As in figure 39 the hydrocarbon was in a shape of sphere and it is located under transmitter which could be seen in the middle of the SBL model. For this parameter varying the brine salinity for dispersed clay for both with hydrocarbon and without hydrocarbon which is:

- 30 kppm
- 100 kppm
- 250 kppm

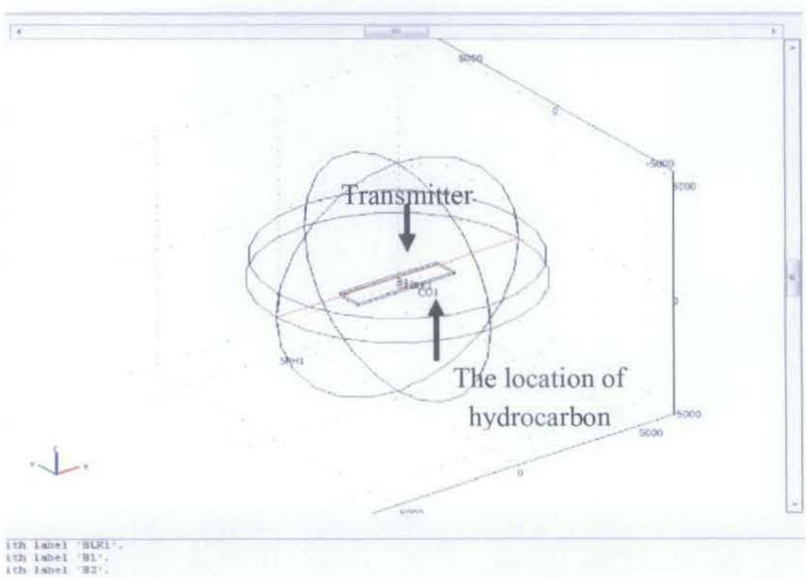

Figure 39: Location of hydrocarbon

Figure 40 shows the guiding effect of the hydrocarbon layer where as red color in the middle of the model shows the area that have the highest total energy density.

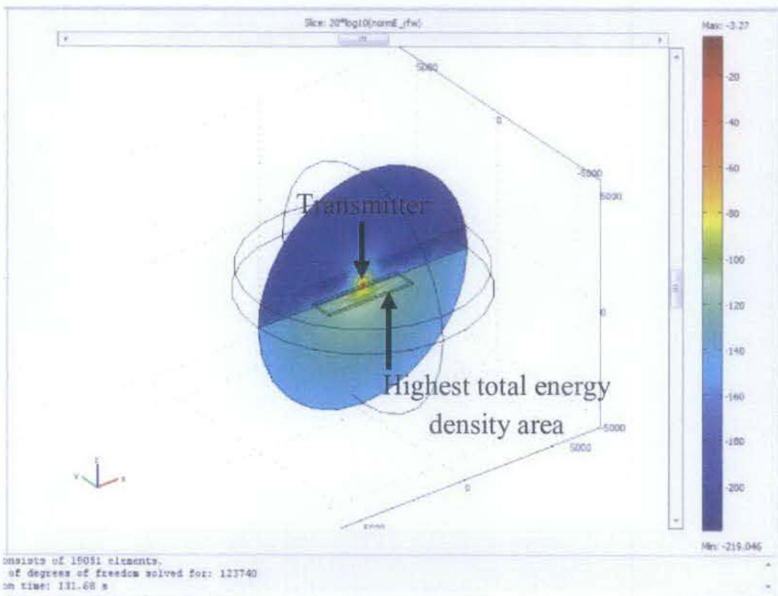

Figure 40: Total energy density on linear scale

Result:

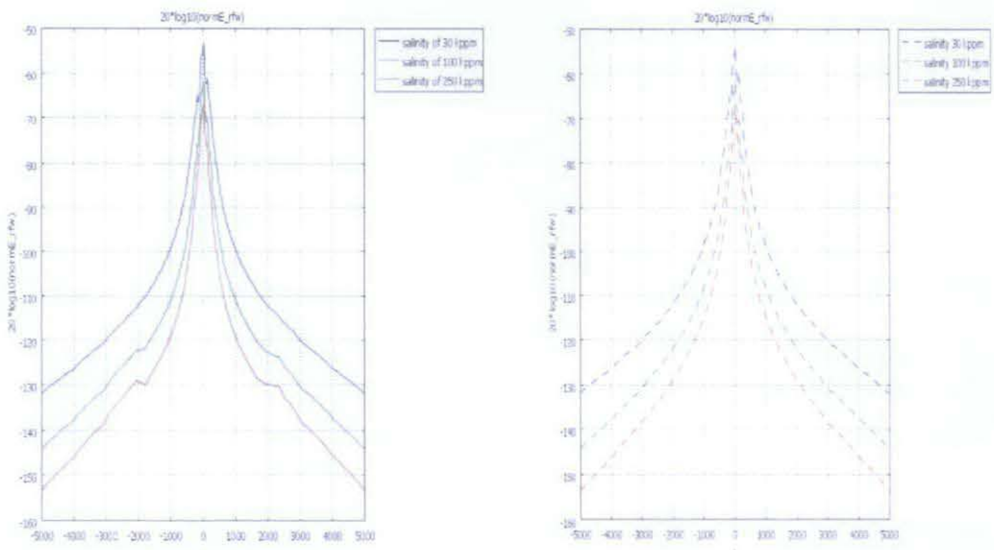

Figure 41: Result of Domain Plot Parameter for model with hydrocarbon (left) and without hydrocarbon (right)

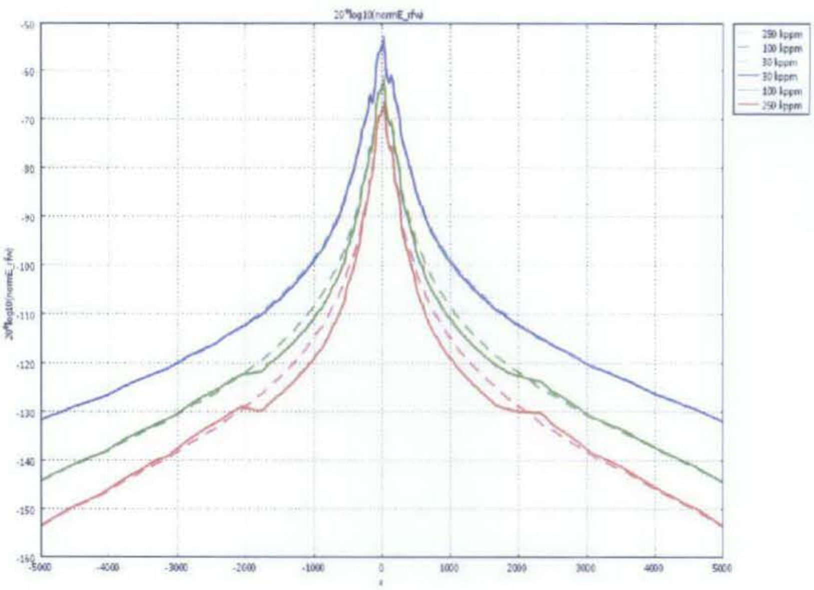

Figure 42: Result of Domain Plot Parameter for both model with hydrocarbon and without hydrocarbon

Discussion:

Result from figure 42 show the magnitude of received electric field (E-Field) from model with hydrocarbon and without hydrocarbon. Magnitude of E-field from model with hydrocarbon is higher than the Magnitude of E-field from model without hydrocarbon for each variation in brine salinity. The result also show that the brine salinity for 30 kppm give the highest EM detection compared to brine salinity for 100 kppm and 250 kppm. As the result,30 kppm is used in varying the other parameter since the salinity is the lowest compared to 100 kppm and 250 kppm.

4.2.3 Plot Parameter in Varying the Transmitter Frequency for 3 Different Brine Salinity

As stated before, the transmitter frequency variations will only vary frequency and other parameters are fix. Hence, seabed model in figure 43 shows that the hydrocarbon location is fix.

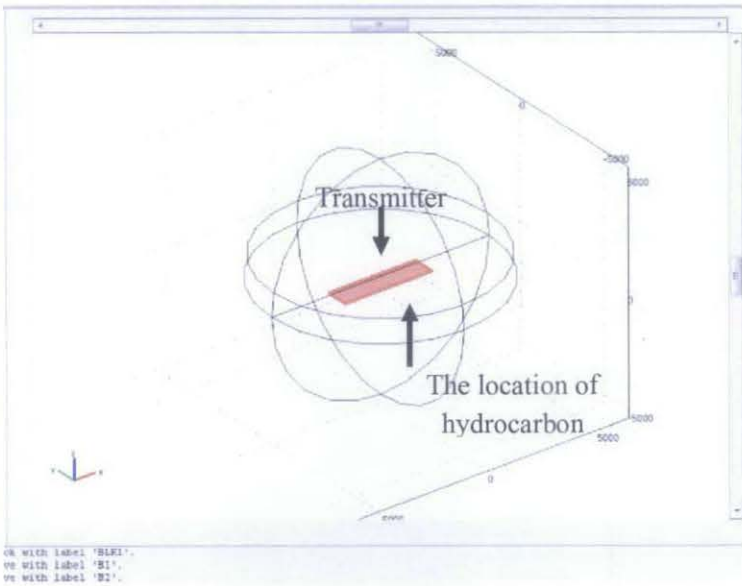

Figure 43: Seabed Model with fix hydrocarbon position

4.2.3.1 Transmitter with frequency of 0.5 Hz,1 Hz and 2 Hz was used in the set up for brine salinity 30 kppm

Result figure 44 shows the highest total energy density area for SBL model with transmitter frequency of 0.5 Hz,1 Hz and 2 Hz for salinity 30 kppm. Wearers, in figure 45 shows the result differences of electric field magnitude on seafloor as function of distance between model with hydrocarbon and without hydrocarbon.

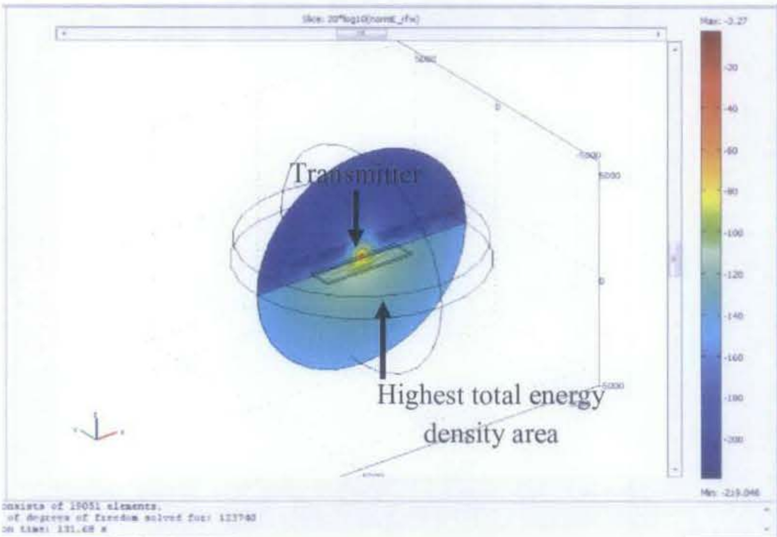

Figure 44: Total energy density on linear scale

Result:

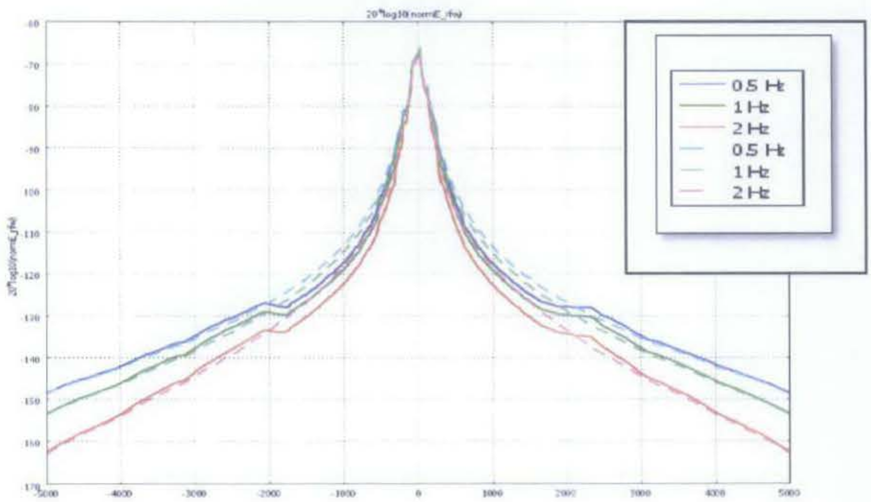

Figure 45: Result of Domain Plot Parameter for brine salinity 30 kppm for each frequency

4.2.3.2 Transmitter with frequency of 0.5 Hz, 1 Hz and 2 Hz was used in the set up for brine salinity 100 kppm

Result figure 46 shows the highest total energy density area for SBL model with transmitter frequency of 0.5 Hz,1 Hz and 2 Hz for salinity 100 kppm. Wearers, in figure 47 shows the differences of electric field magnitude on seafloor as function of distance between model with hydrocarbon and without hydrocarbon.

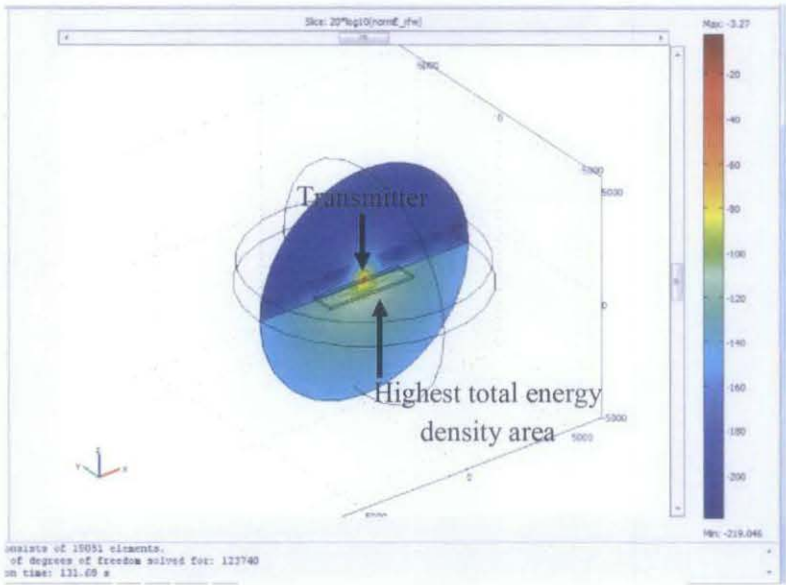

Figure 46: Total energy density on linear scale

Result:

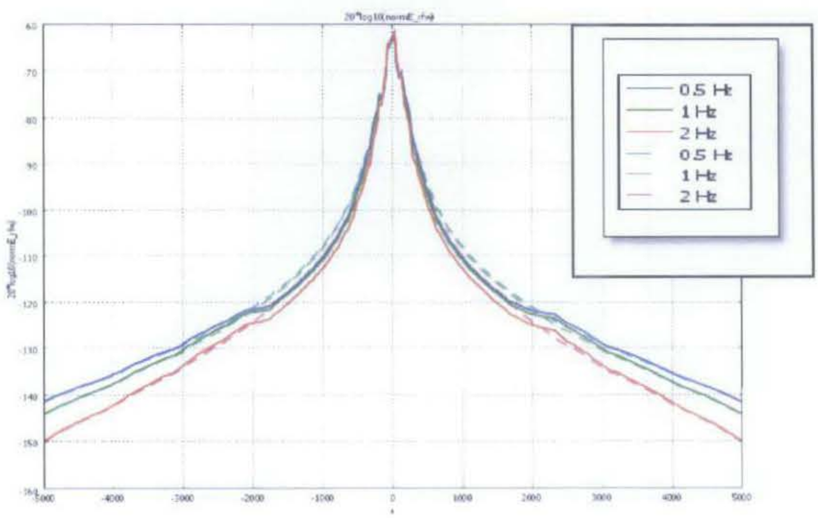

Figure 47: Result of Domain Plot Parameter for brine salinity 100 kppm for each frequency

4.2.3.3 Transmitter with frequency of 0.5 Hz,1 Hz and 2 Hz was used in the set up for brine salinity 250 kppm

Result figure 48 shows the highest total energy density area for SBL model with transmitter frequency 0.5 Hz,1 Hz and 2 Hz for salinity 250 kppm. Wearers, in figure 49 shows the differences of electric field magnitude on seafloor as function of distance between model with hydrocarbon and without hydrocarbon.

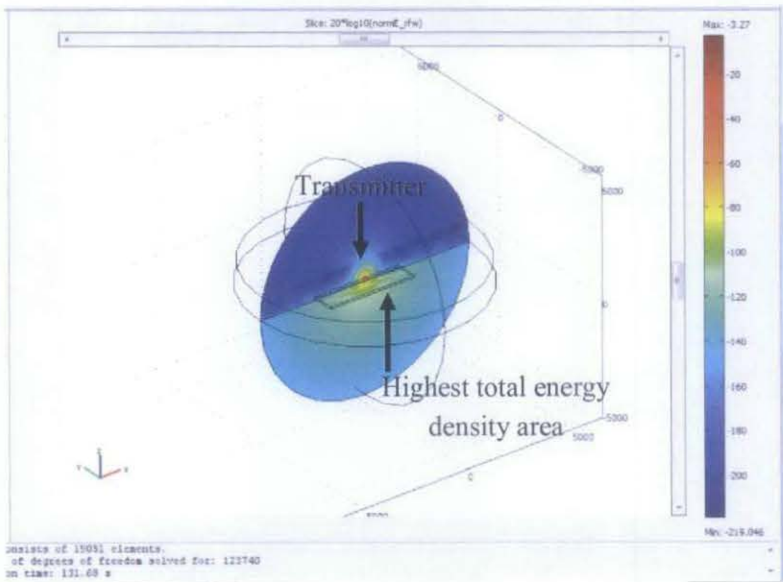

Figure 48: Total energy density on linear scale

Result:

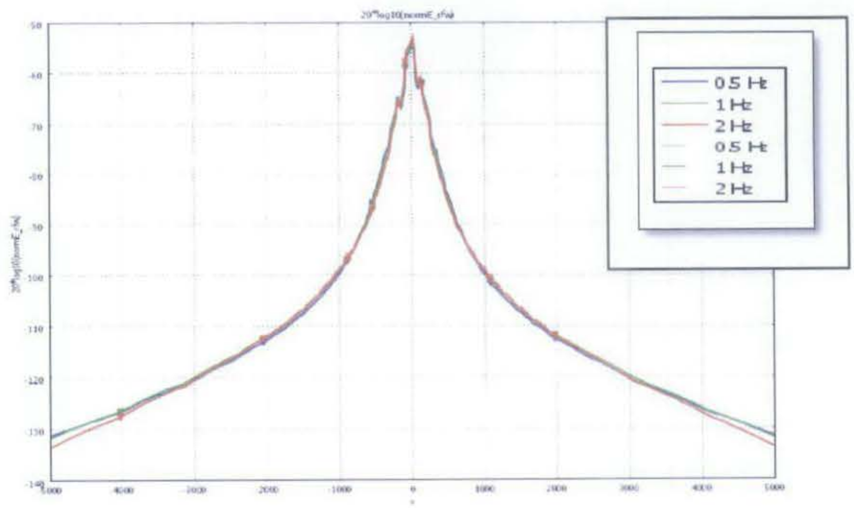

Figure 49: Result of Domain Plot Parameter for brine salinity 250 kppm for each frequency

Discussion:

From figure 45, figure 47 and figure 49 are shown that model of SBL with 0.5Hz of frequency receive the highest magnitude of E-field compared to model with 1 Hz and 2 Hz of frequency for each brine salinity. Therefore, the smaller the frequency gives the higher the magnitude of the electric field. Brine Salinity for 30 kppm which is the lowest salinity give the highest E-field compared to salinity for 100 kppm and 250 kppm.

4.2.4 Varying the Hydrocarbon Thickness for Brine Salinity 30 kppm

Then continued with varying the hydrocarbon thickness to 50 m, 100m and 200m using brine salinity 30 kppm only since the brine salinity for 30 kppm giving the highest EM detection compared to 100 kppm and 250 kppm. From figure 50, it shows the guiding effect of SBL model with hydrocarbon thickness of 50 m

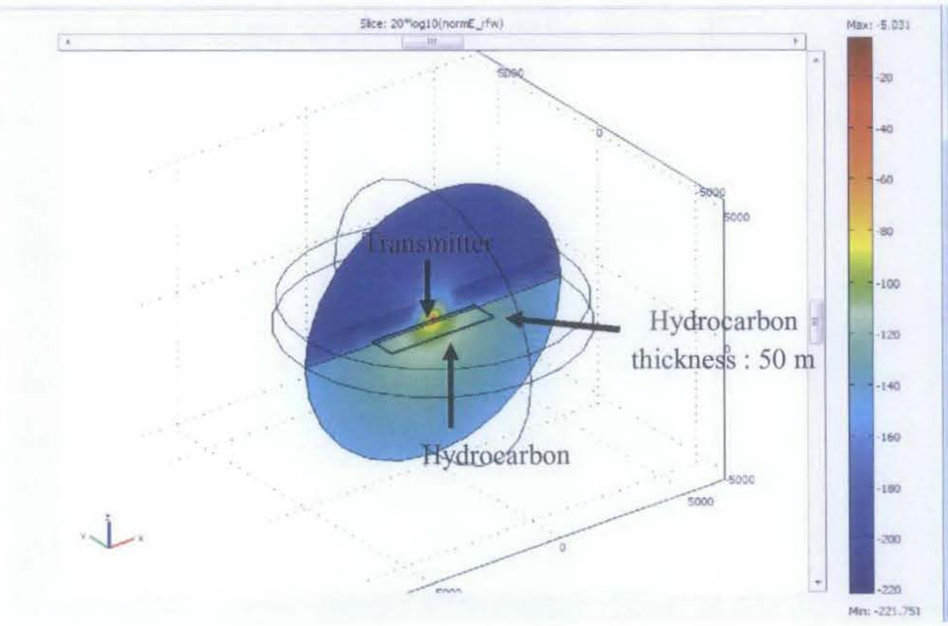

Figure 50: Guiding effect for 50 m hydrocarbon thickness

Result:

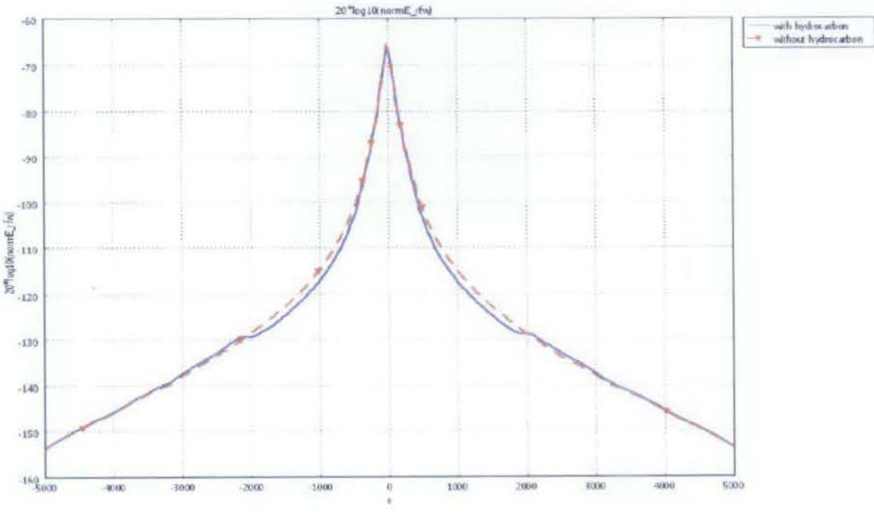

Figure 51: Graph for 50 m hydrocarbon thickness

From figure 52, it shows the guiding effect of SBL model with hydrocarbon thickness of 100m.

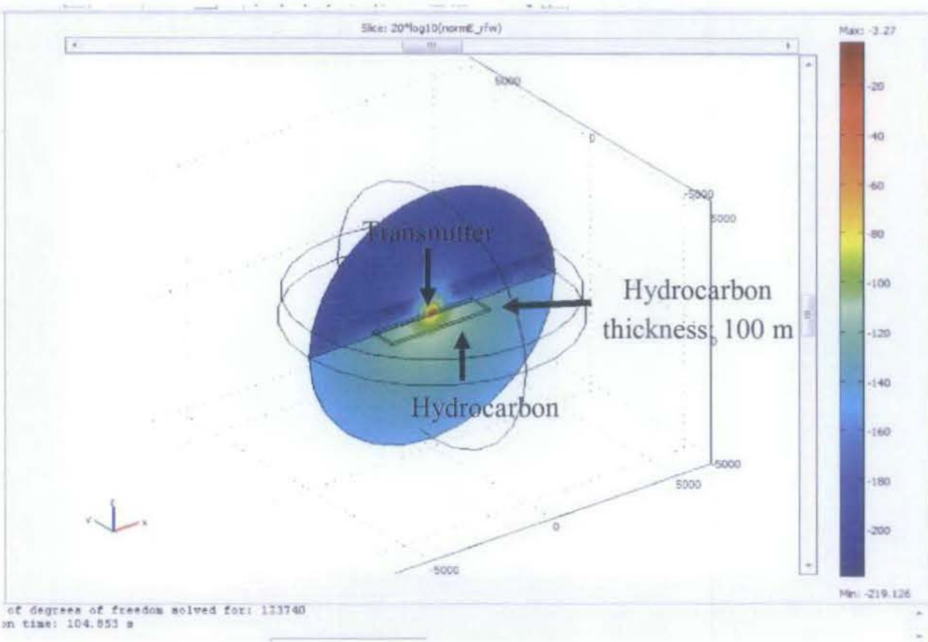

Figure 52: Guiding effect for 100 m hydrocarbon thickness

Result:

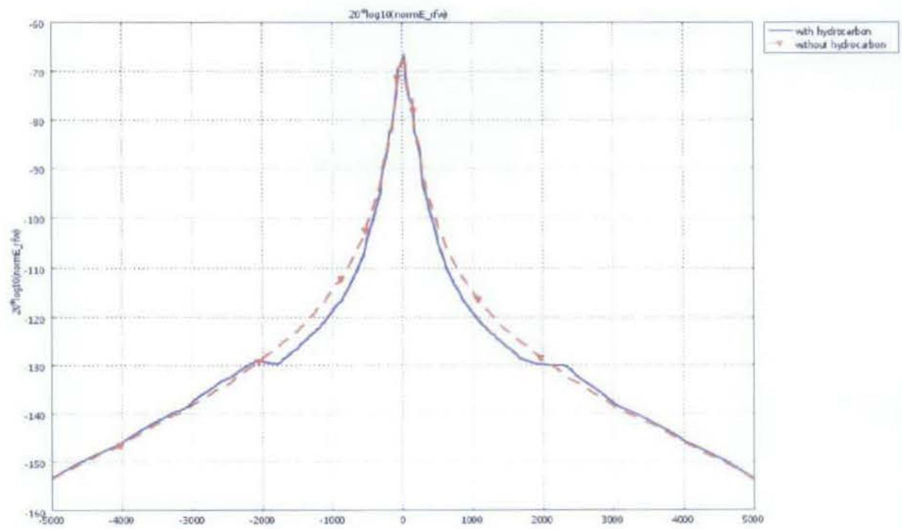

Figure 53: Graph for 100 m hydrocarbon thickness

From figure 54, it shows the guiding effect of SBL model with hydrocarbon thickness of 200m.

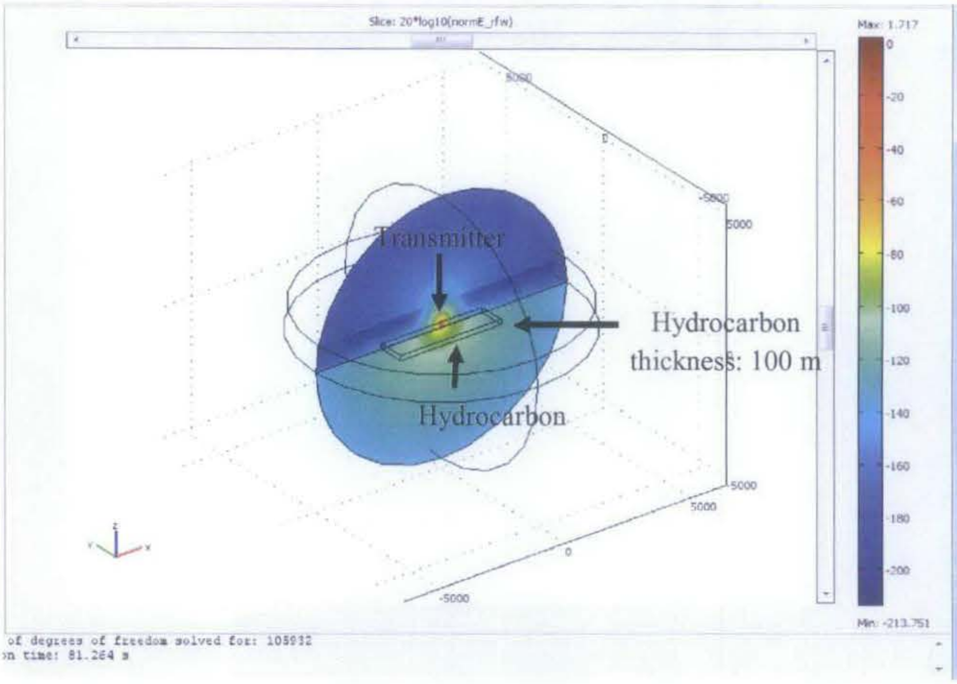

Figure 54: Guiding effect for 200 m hydrocarbon thickness

Result:

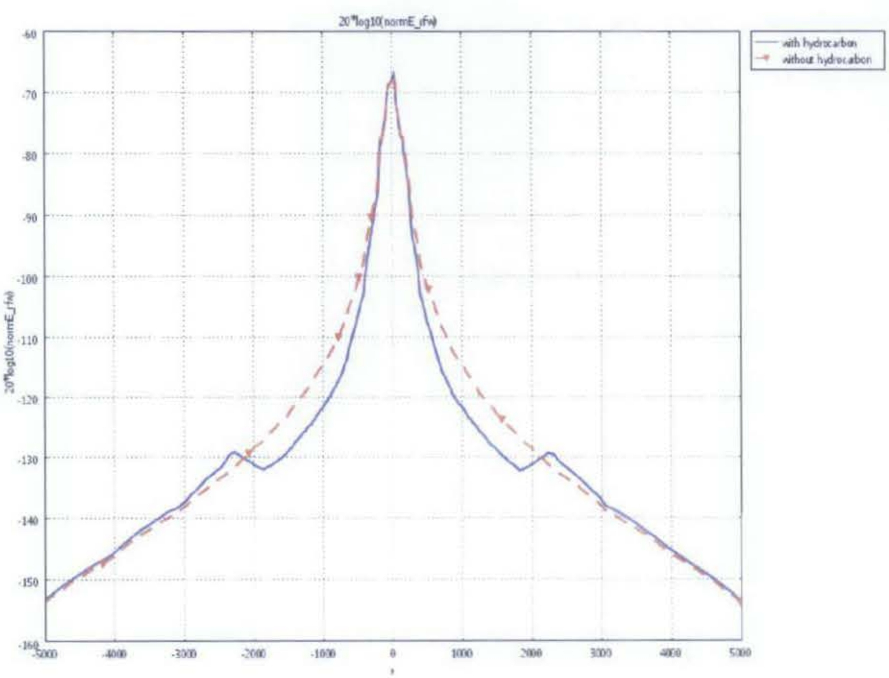

Figure 55: Graph for 200 m hydrocarbon thickness

Discussion:

When hydrocarbon thickness is 50 m,100 m and 200 m, there is a different shown on the graph between model with hydrocarbon and without hydrocarbon. Thus, it is shown that the reflected EM waves reach receiver after varied thickness of hydrocarbon in the highest EM wave detection salinity which is 30 kppm.The thicker the thickness of the hydrocarbon, the smaller the effect of the E-field at the receiver which is mean that the EM wave receive by receiver from the transmitter experience the transport energy wave to the empty space in hydrocarbon surrounding and give a smaller reflection to each surface and give result of smaller effect of E-field.

4.2.5 Varying the depth of Seawater for Brine Salinity 30 kppm

Then continued with varying the depth of seawater for 1000 m, 2000 m and 3000 m using brine salinity 30 kppm only since the brine salinity for 30 kppm giving the highest EM detection compared to 100 kppm and 250 kppm. From figure 56, it shows model parameter of SBL model with depth of seawater for 1000 m.

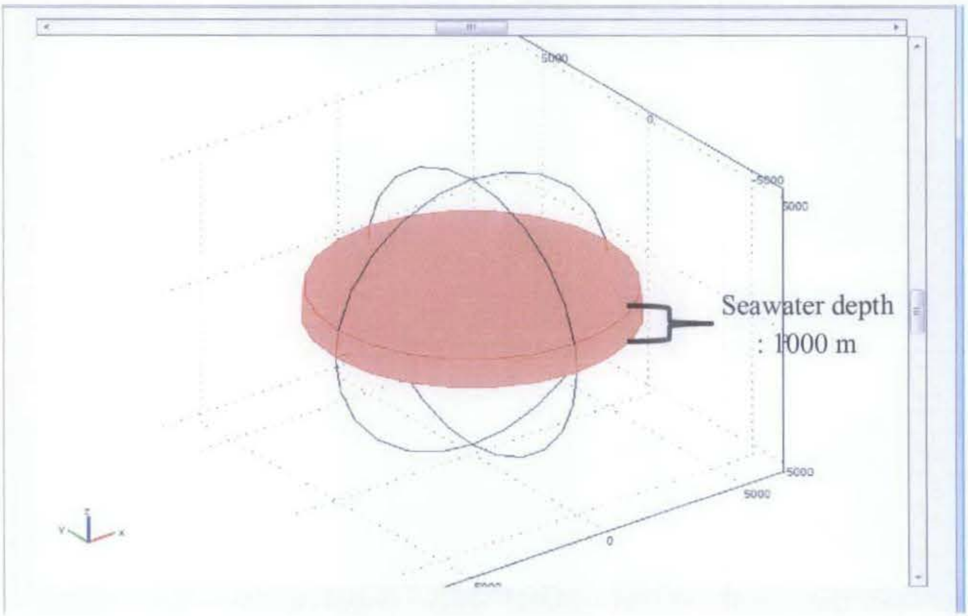

Figure 56: Model of seawater depth for 1000 m

Result:

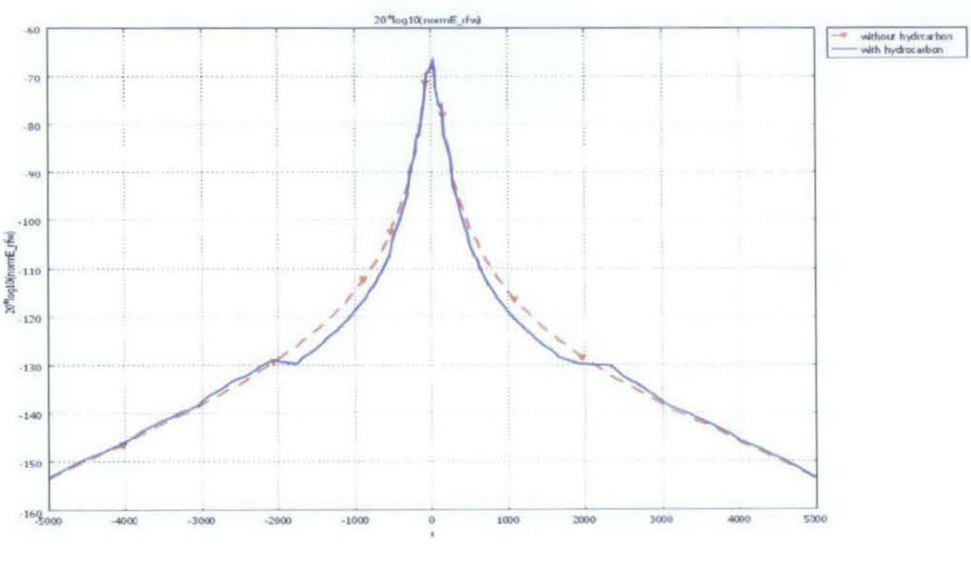

Figure 57: Graph for 1000 m depth of seawater

From figure 58, it shows the model parameter of SBL model with depth of seawater for 2000 m

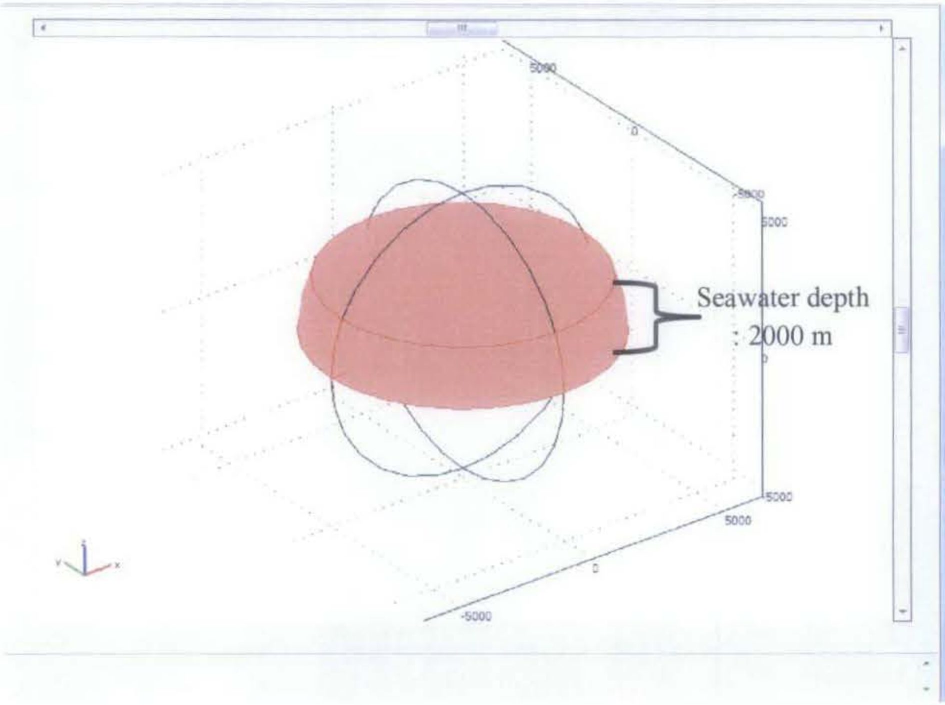

Figure 58: Model of seawater depth for 2000 m

Result:

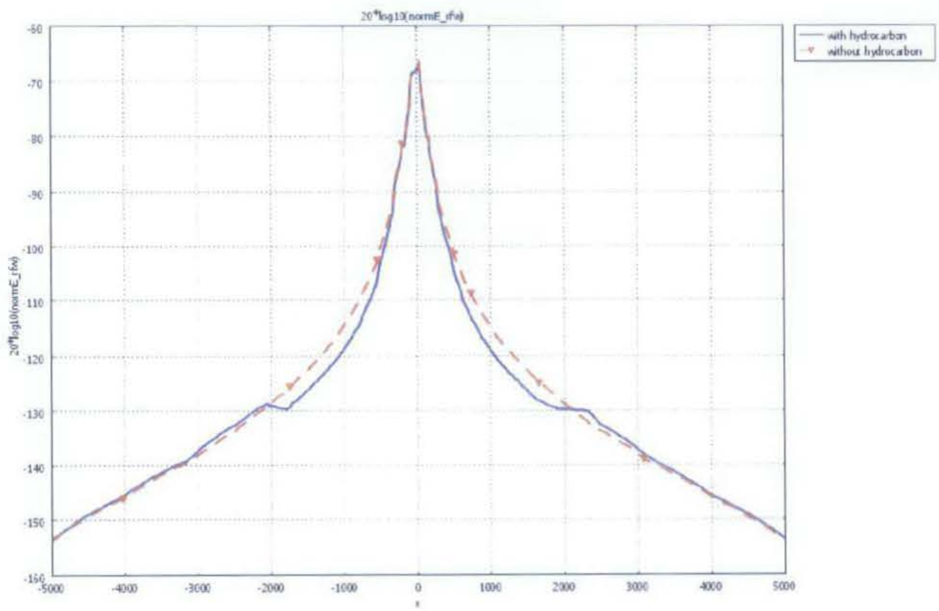

Figure 59: Graph for 2000 m depth of seawater

From figure 60, it shows the model parameter of SBL model with depth of seawater for 3000 m

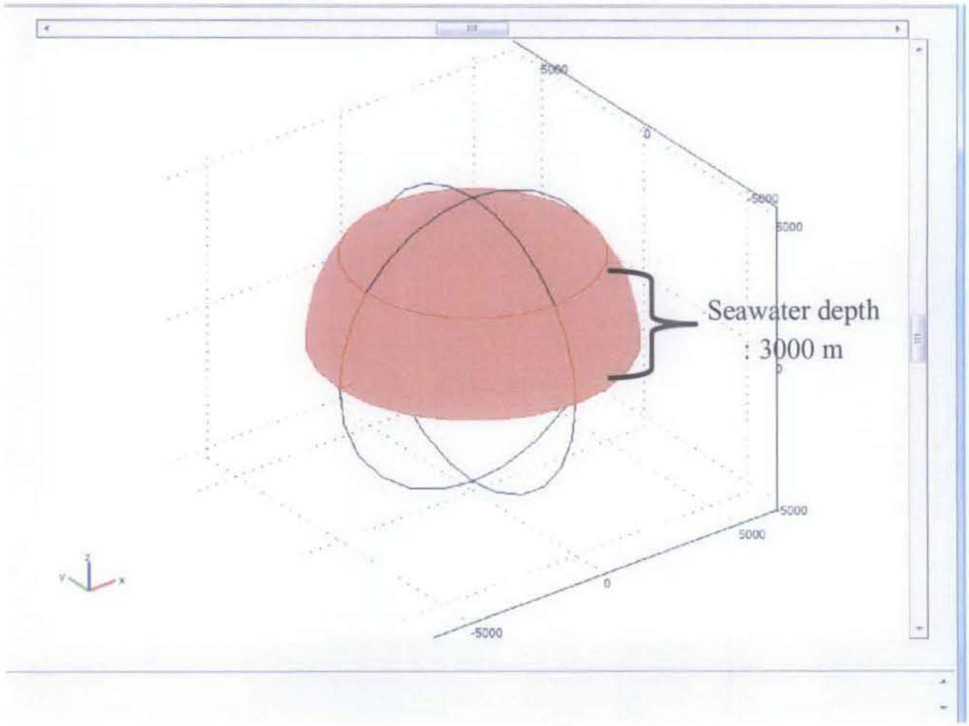

Figure 60: Model of seawater depth for 3000 m

Result:

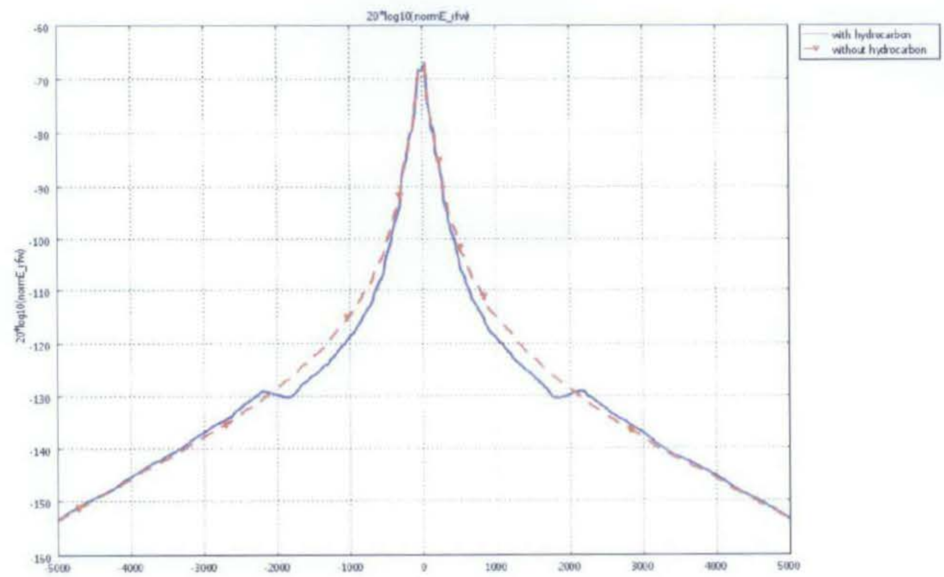

Figure 61: Graph for 3000 m depth of seawater

Discussion:

From the result in figure 57, figure 59 and figure 61, the shown graph between model with hydrocarbon and without hydrocarbon. From all the graph shown, there no changes of E-field detection even with or without hydrocarbon with the variation parameter of seawater depth 1000 m, 2000 m or 3000 m.Thus,the variation in the depth of seawater is not effecting the E-field detection and giving the detection for the hydrocarbon from the distance at 2000 m from the left to 2000 m from the right because of variation is significantly beyond the sea water limit.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSIONS

In a nutshell, authors conclude that this project will bring a lot of benefit to the future and can be applied to a multinational oil and gas company. By modeling 3D simulator of EM waves for seabed logging application using COMSOL hopefully it can interpret data from the receiver and give an accurate result for user easy understanding. This simulator can also improve the difficulty to predict the existing of hydrocarbon underneath the sea floor because it will show user figures of hydrocarbon layer plane, water, and sediment.

Furthermore, it can also determine the effect of airwave to receiver when different variables are varied. Finite element method is a powerful tool to solve problems regarding on arbitrary geological structures without much trouble. As the evident that different brine salinity, keeping the volume fraction of clay constant, give rise to very different effective conductivities of the reservoir rock, and hence affects the EM response considerably even with or without hydrocarbon.

In reality a hydrocarbon reservoir is more complex than the models discussed in this paper. However, we feel that the reservoir rock physics description introduced here will make EM-modeling more realistic offering useful information for further development of the SBL technique as well as for interpretation of SBL data.

5.2 RECOMMENDATION

Improvement on developed SBL simulator can be done by including more inputs parameter option that considers bathymetry effect, temperature, pressure, and all sizes of hydrocarbon reservoir.

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APPENDICES

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	Seabed Logging model development and modification work																				
2	Submission of Progress Report							M	●												
								I													
3	Project work continues							D													
																S	E				
4	Testing and Validation work							S								T	X				
								E								U	A				
5	Pre-EDX							M				●				D	M				
								E								Y					
6	Finalize results and findings							S													
								T								W	W				
7	Submission of Draft Report							E						●		E	E				
								R								E	E				
8	Submission of Final Report and Technical paper.														●	K	K				
								B													
9	Oral Presentation							R								●					
								E													
								A													
								K													