# Simulation Overall Heat Transfer Coefficient in Surface Pipeline System

by

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13898

Dissertation submitted in partial fulfilment of

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CERTIFICATION OF APPROVAL

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(PETROLEUM)

Approved by,

____________________

(Dr. Masoud Rashidi)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2014

## CERTIFICATION OF ORIGINALITY

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

____________________________________

(Nur Amirah Binti Zahta Amini)

# ABSTRACT

Flow assurance issues are critical and difficult problem in oil and gas industry especially in estimating and predicting the wax formation as well as its physicochemical characteristics. Wax deposition occurs as the fluid heat can be rapidly lost to the surrounding if there is no thermal insulation layer surrounding the pipe wall and the temperature drops below the crude oil cloud point temperature.

This study will be focusing on determining and explain the new effective way of eliminating paraffin deposition based on its thermal conductivity by utilizing a novel polymer which called Ethylene-TetraFluoroEthylene (ETFE). Furthermore, comparisons on the characteristic of heat transfer are carried out between four types of pipes materials – steel pipe, PVC pipe, PolyTetraFluoroEthylen (PTFE) and ETFE plastic pipe coated.

Comparatively, most of the methods can be used to prevent and remove the paraffin deposition. However, insulation systems gave better performance as it was found helping in prevent heat loss and solid deposition during flow conditions.

# ACKNOWLEDGEMENTS

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Last but not least, I would like to express my gratefulness to my colleague, family for being very reassuring and giving me a plenty of guidance to compete this project successfully. Their presence is highly respected. The entire platform certainly brought us together to raise the value of friendship and family.

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## ABBREVIATIONS AND NOMENCLATURES

| | |
|---|---|
| C | Heat capacity |
| $C_p$ | Specific heat |
| P | Density |
| d | Pipeline diameter |
| $h_i$ | Inner heat transfer |
| $h_o$ | Outer heat transfer |
| k | Thermal conductivity |
| $k_{i-1}$ | Thermal conductivity of the wax between two radii |
| $\dot{m}$ | Mass flow rate |
| $N_{Re}$ | Renold number |
| $N_u$ | Nusselt number |
| P | Pressure |
| Q | Flow rate |
| $r_i$ | Inner radius |
| $r_o$ | Outer radius |
| T | Temperature |
| Ta | Ambient temperature |
| Tin | Inlet temperature |
| U | Overall heat transfer coefficient |

# CHAPTER 1

# INTRODUCTION

## 1.1 BACKGROUND OF STUDY

One of the most common problems in the oil production is formation of paraffin deposition. Paraffin is a molecular substance that frequently found in crude oil. Paraffin is belongs to the chemical family that made up of carbon and hydrogen atoms with high molecular weight. It can be everything of carbon chains $C_{18}$ and above. Physical properties of paraffin normally white in colour, odourless, tasteless and waxy solid.

The deposition of paraffin can cause clog the tubing in the well and flow-lines on the surface. Paraffin depositions occur in the production equipment as the temperature fall below the cloud point. Therefore, it starts to crystallize and deposit where could cause a reduction in the permeability and wettability. In fact, it wills results inefficiency of production operation which cost millions to billions of fixing cost.

Therefore, several method have been carried out to removed the paraffin deposition such as mechanical, chemical, thermal and combination of all these three methods. But none of the methods worked effectively in the oil and gas field. Moreover, the methods are quite expensive and cause some side effects. Therefore, it is more desirable to focus on the prevention methods rather than removing the paraffin deposition.

In this project, the studies will be focusing on the simulation on overall heat transfer coefficient in surface pipeline system. During the simulation, effect of temperature change will be study and compare with different coating materials to control the paraffin deposition. All the basic data and relevant information will be used into PVTsim and OLGA in order to run the simulation. The results obtains will be analyze and the best coating materials can be find out to overcome this problem.

## 1.2 PROBLEM STATEMENT

Paraffin is one of the flow assurance issues in production system. The present of these paraffin deposit bring a big impact to the oil and gas industry especially in reducing the oil production and increasing cost of the project. Formation of paraffin deposition occur when the temperature drop below the cloud point in the wellbore zone, tubing, pipeline and in surface equipment. Therefore, various types of method have been operated in order to encounter this problem. However, none of the above method successfully removed the paraffin deposit due to spreading the problem to the other wells, lead to environmental problem, decreasing oil production and increasing the operation cost. Besides, once the treatment done, maximum production is achieved but the output will decrease until the next treatment.

## 1.3 OBJECTIVE

Following are the objectives to be achieved at the end of the final year project:

- To study and compare the temperature loss to the surrounding with paraffin deposition inside different pipe coated.
- To investigate the overall heat transfer coefficient in surface pipeline system.
- To study the effect of heat transfer at different coating material on paraffin deposition control.

## 1.4 SCOPE OF STUDY

The scope of study for this project is divided into two which is to observe the effect of thermal efficiency or heat exchange of paraffin deposition in pipeline system, and to study the effect of different coating material pipe on paraffin deposition by doing experiment and simulation process.

## 1.5 RELEVANCY OF STUDY

The significance of the project is to determine the suitability of using different coating material other than using conventional method to remove the paraffin deposition in pipeline system. As different coating material can be used to enhance production of oil and work as stimulation agent, the reliability of the different coating material will be determined. If the reliability of the different coating material is proven to be outstanding, the coating material can be used widely for any field in Malaysia depending on well conditions.

## 1.6 FEASIBILITY OF THE STUDY WITHIN THE SCOPE AND TIME FRAME

This project is feasible to be done within 9 months which comprises of Final Year Project 1 and Final Year Project 2 from January until September 2014. This project has been divided into two scopes of studies in order to achieve the objective and complete this project. The pipe materials and OLGA software to be used for the experiment and simulation process are all based on the availability of the facilities in the Production Engineering laboratory in UTP. There are no experiments carried out on the dynamic condition since it will consume a lot of time. Both of the project scopes were carried out from March until September 2014, where the experiments and simulations were done within the time frame before performing the discussion on the results. All precautions and efforts are taken to ensure that any delay is minimized.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 INTRODUCTION

One of the main problems in the oil producing and transportation area is paraffin deposition. These paraffin deposit in the wellbore zone, tubing, downhole pumping equipment, pipelines and in surface equipment. [14] Paraffin occurs due to temperature below the cloud point, flow rate in flow system as well as the pipeline surface properties. Therefore, several methods have been carried out to overcome this issue.

## 2.2 CHEMICAL AND PHYSICAL PROPERTIES OF PARAFFIN DEPOSITION

The paraffin is found as white, odourless, tasteless, waxy solid and follows the general formula of $C_nH_{2n+2}$. Paraffin can be classified into three which is macro crystalline, intermediate crystalline and microcrystalline. Its melting point is between 47 $^0$C and 64 $^0$C with having a density approximately around 0.9 g/cm$^3$. [5]

Paraffin basically in the chemical family mainly contains carbon and hydrogen atoms. It also refers to alkane where the simplest alkane is methane, $CH_4$. [11] Paraffin is considered with everything of carbon chains $C_{18}$ and above. As mention by James B. Dobbs, 1999, paraffin with 6 to 12 carbon atoms ($C_6$ to $C_{12}$) are liquids, from 16 to 25 carbon atoms ($C_{16}$ to $C_{25}$) in forms of soft mushy and 25 to 30 or more carbon atom ($C_{25}$ to $C_{30}$), we can see hard crystalline wax forms. [10]

## 2.3 MECHANISM OF PARAFFIN WAX CRYSTALLIZATION, PRECIPITATION AND DEPOSITION

Paraffin is completely dissolved in the crude oil in equilibrium condition. As result of the temperature, *T* and pressure, *P* drop during mitigation of oil, paraffin will start to crystallize, precipitate and adhere to surface of the pipeline system. [10, 11, 12] There will be the formation of paraffin deposition as the temperature of the oil fall below the cloud point. Cloud point is defined as the temperature at which wax crystals start to form in a crude oil. [5, 12]

As the temperature drop below the cloud point, the wax becomes less soluble, solidifies and separates from the liquid phase. Therefore, the crystals form will accumulate and adhere and deposits grow. [10] These clearly show that temperature us the primary factor of paraffin deposition in production equipment such as pipeline. Besides, a mechanism such as shear dispersion, Brown diffusion, gravity, thermophoresis and turbophoresis helps to drive the wax molecule particle to deposit on the pipeline wall. [1, 13]

## 2.4 FACTOR AFFECTING THE FORMATION OF PARAFFIN DEPOSITION

There are three main factors affect to paraffin wax deposition in flow systems, which are flow rate, temperature differential and cooling rate, as well as surface properties. [2, 4]

### 2.4.1 Effect of Flow Rate on Paraffin Deposition

Basically, paraffin deposition depends on the rate of fluid flow. Flow regime can be categories into three which are laminar, transition and turbulent. Reynolds number is used as a parameter to distinguish between flow regimes. For Reynolds number less than 2000, it is laminar flow, if Reynolds number lay between 2000 and 4000, the flow type is transition and Reynolds number more than 4000, and it is called turbulent flow. Rate of paraffin deposition will decrease rapidly as the velocities increase and change the flow from viscous to turbulent. [6]

### 2.4.2 Effect of Temperature Differential and Cooling Rate on Paraffin Deposition

The main factor that cause paraffin deposition is temperature. The solubility of paraffin starts to change as the temperature drop below the wax appearance temperature (WAT) or cloud point. [18] The paraffin deposition not only functions of temperature gradient but also the rate of cooling of the oil where it occurs near the wall. [4] As the oil travel near the wall, it cools rapidly. But as the distance of oil and wall increase, its cooling rate becomes very small.

### 2.4.3 Effect of Surface Properties on Paraffin Deposition

Surface properties or condition also play a role in paraffin deposition. From the research outcome, it show that on the rough metal surface, it helps to increase the deposition of paraffin rapidly compare to the smooth surface area. Therefore, solution of improving the surface roughness has been carried out by reducing the surface energy. These help to lower the adhesive ability of the paraffin deposited in the material's surface. [16]

## 2.5 TEMPERATURE MODEL FOR THE PIPELINE

In the transportation or flow of the wax containing oil, the rate of heat play an important role which is from the oil to through the pipe wall and to the environment or vice versa depending on the time of year or location of the pipeline. [7] The amount of wax deposit will increase as the temperature drop below the cloud point.

A pipeline temperature can be calculate at a certain position (example position x) by divided the pipeline into sections by using energy balanced. A temperature profile can be calculated with present of parameter of the mass flow rate $\dot{m}$, the specific heat $C_p$, pipeline diameter $d$, and the overall heat transfer coefficient $U$.

$$Tx = Ta + (Tin - Ta)\exp(\frac{-\pi dU}{Cp\dot{m}}\ x)$$

Where, $T_a$ = ambient temperature, $T_{in}$ = inlet temperature

### 2.5.1 Overall Heat Transfer Coefficient

The basic understanding of overall heat transfer coefficient, *U* is net resistance to heat flow offered by fluid inside the tubing, the tubing wall, fluids and solids in the annulus and the casing wall. [9, 17] The overall heat transfer can effect of radiant heat transfer from tubing to the casing and resistance to heat flow caused by wax deposition on the tubing or casing.

The overall heat transfer coefficient takes into account the inner, $h_i$, and the outer heat transfer, $h_o$, coefficient as well as the thermal conductivity, $k$, of the pipeline. It can be well explained on the following equation: [9]

$$U = \frac{1}{ri}\left(\sum_{i=1}^{n} \frac{ln_{ri-1}^{ri}}{ki-1,1} + \frac{1}{roho}\right)^{-1}$$

where,

$r_i$ = inner radius

$r_o$ = outer radius

$k_{i-1}$ = thermal conductivity of the wax between the two radii $r_{i-1}$ and $r_i$

### 2.5.2 Inner and Outside Heat Transfer Coefficient

From the study [9], factor of flow regime and Nusselt number must be taking into account to determine the inner heat transfer coefficient. The flow regime can be in laminar, transitional or turbulent. Correlation of Sieder-Tate was used as a default in Depowax modeling to calculate the inner heat transfer coefficient. If,

***Table 1: Relationship between Reynolds number and Nusselt number***

| Renolds Number, Re | Nusselt Number, NU |
|---|---|
| Re > 10 000 (Turbulent) | $Nu = 0.027\ Re^{0.8}\ Pr^{1/3} \left(\frac{\mu b}{\mu w}\right)^{0.25}$ |
| 2 300 > Re > 10 000 (Transitional) | $Nu = 0.027\ Re^{0.8}\ Pr^{1/3} \left(1 - \frac{6x10^5}{Re^{1.8}}\right)\left(\frac{\mu b}{\mu w}\right)^{0.25}$ |
| Re < 2 300 (Laminar) | $Nu = \max(0.184(GrPr)^{1/3}$ |

The outer heat transfer coefficient is a specified value that remains constant for a given section of pipeline. For free or forced convection in air or water, the heat transfer coefficient can be specified. [7, 9]

## 2.6 METHOD OF CONTROLLING THE PARAFFIN DEPOSITION

In oil field, four methods have been performing to remove paraffin deposition. The methods are mechanical, thermal, chemical and combination of these three methods. [2, 3, 6, 19] However, from the studies obtained, none of the methods mention managed to remove the deposition of paraffin. [2, 6]

Firstly, mechanical methods worked by using cutting, pigging and scrapper can be used to removed paraffin deposit when flow-line have been pressurised and stopped. However, this method required more manpower as the system contain large quantities of paraffin deposit and it is not applicable to flows of multiphase systems. [2]

Second, the thermal methods involved steam injection, bottomhole heaters and circulation of hot oil and hot water. When there is no packer, hot water will be pumped down the tubing and casing. [3] However, these methods are not effective in elimination of paraffin and the most harmful as they cause crisis from well to well, plugging of pump and flow lines, loss production and others.

Third, chemical control can be classified into three which are solvents, wax crystal modifiers and paraffin dispersants. Solvents are commonly applied to dissolve paraffin deposits until its power is exhausted. For dispersants, it is used to break down paraffin deposition into smaller particle. Paraffin wax crystal growth will changed when using crystal modifiers. [2] However, all of these methods can be very expensive for continues used as the chemical become more complex during winter time and impossible to pump because of high pour point value of crude oil.

Therefore, from the result study, it was suggested to focus on prevention methods rather than removing the paraffin deposition, crystallization and precipitation completely. Another solution to overcome these problem is tested several types of pipes including Rigid PVC plastic pipe and PTFE plastic coating. An experiment to investigate the effect of velocity on paraffin deposition rate have been carried out by coated the Rigid PVC pipe with ¾ and 2-in nominal diameter and 5 ft in length. [6] From the results obtained, it shows that the amount of paraffin adhere on the pipe surface is small due to the reduced surface roughness. However, there are some disadvantages of this Rigid PVC plastic pipe where:

- Cannot withstand at cold and frozen environments
- Easily cracking and splitting due to solidity
- Limited high pressure and temperature above 158$^{\circ}$ F
- Vulnerability to ultra violet rays affect to alter of chemical contracture of plastic, hence this type of plastic pipes not suitable for outdoor application
- Strength and durability of plastic may reduce with influencing in high temperature

Further studies have been carried out to discover the effective way in preventing and mitigating paraffin deposition. The studies found out the used of PolyTetraFlouroEthylene (PTFE) material are proven to have been highly successful in other fields. Therefore, PTFE material will be utilize in petroleum production operations for preventing and solving paraffin deposition problems. PTFE plastic pipe coating is approached due to its advantages: [16]

- Very good chemical resistance
- Anti-adhesive surface
- Safety due to the best possible flame retardant
- Good at wide range of temperature
- Less friction coefficient

Besides, PTFE plastic pipe coating is distinguished by its ability to improve the surface roughness and reduce surface energy which reduces the adhesive ability of paraffin deposition.

However, Ethylene-TetraFluoroEthylene (ETFE) is a completely new innovation as it has been used only in the fields of infrastructure, health care, telecommunications and in certain other industries such as the football stadium Allianz Arena and Beijing National Aquatics centre.

ETFE is a fluorine based plastic which melts at high temperature and it was synthesized in order to be highly resistant to corrosion and high temperatures. Moreover, its advantageous characteristics include excellent durability and long life expectancy, cost effectiveness, flexibility, inherent fire safety, endurable nature in both very high and very low temperatures and so on. In addition, it is very light so it can be easily shifted and convenient to joint, which is necessary in petroleum field. [11]

Due to the above mentioned advantages of ETFE pipe coating, it has been chosen for this project probably as a better solution for paraffin deposition, precipitation and crystallization on flow lines, tubing, pumps and surface equipment.

# CHAPTER 3

# METHODOLOGY

## 3.1 PROJECT METHODOLOGY

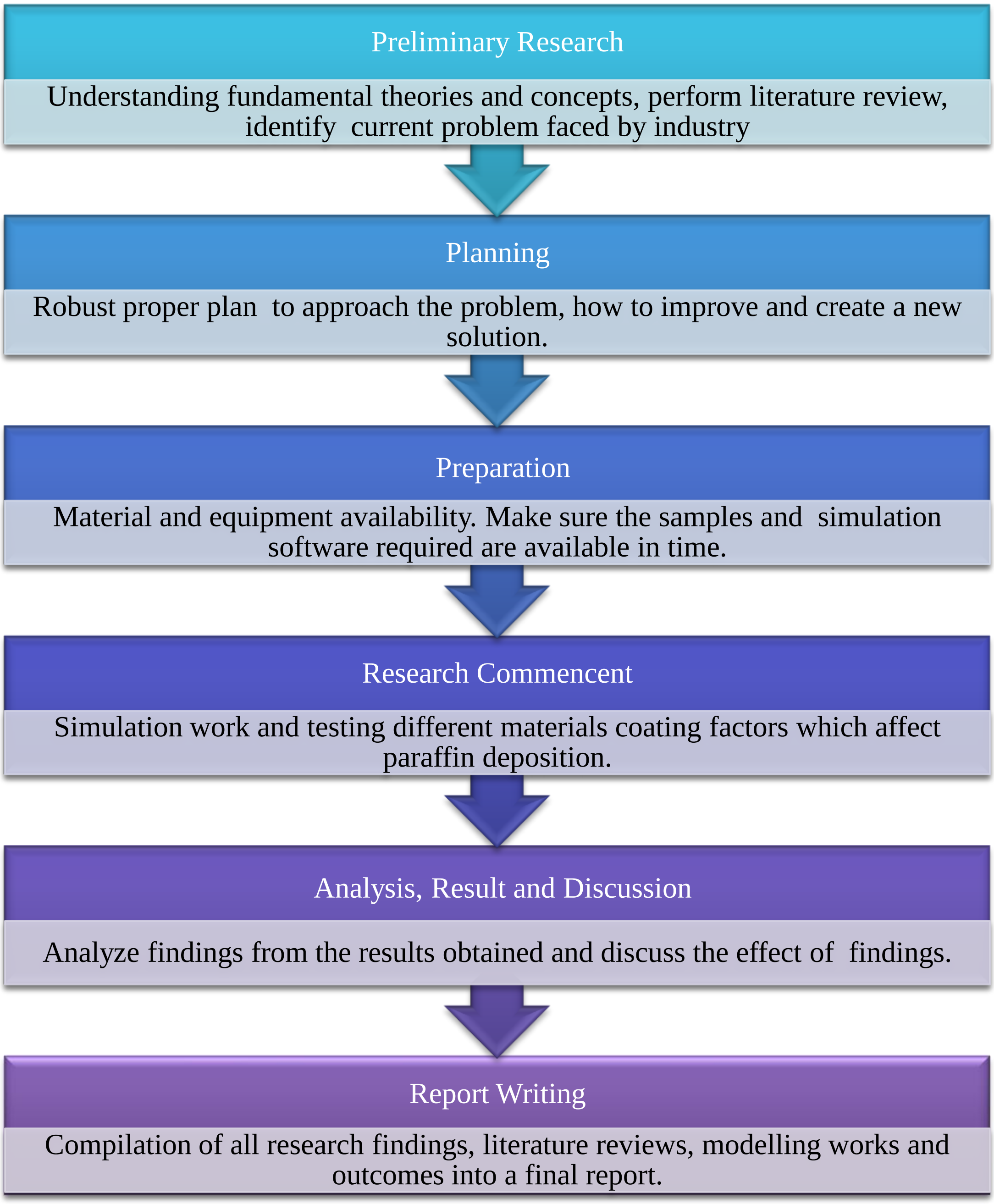
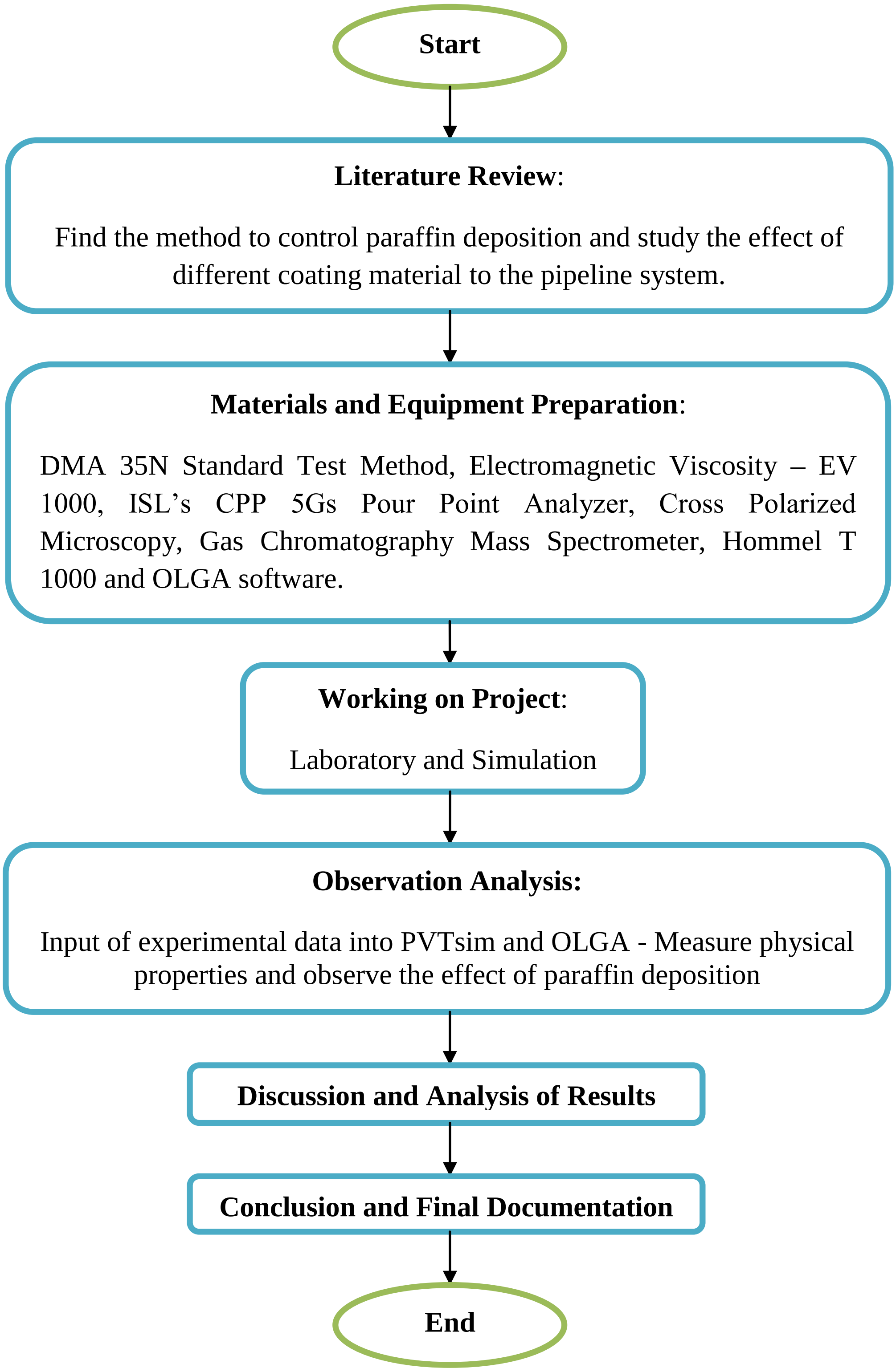



***Figure 1: Process of Final Year Project***

## 3.2 PROJECT ACTIVITIES



### 3.3 MATERIALS AND METHODS

The materials for the study are listed as below:

- 2x2 inch of Steel pipe, PVC pipe and PTFE plastic coated pipes
- 0.5 liter of Dulang crude oil
- Thermometer
- Timer
- Weight scale

Experiments method is described using the following tool(s):

A. Hot water bath
B. Cool water bath

### 3.4 EXPERIMENTAL SETUP

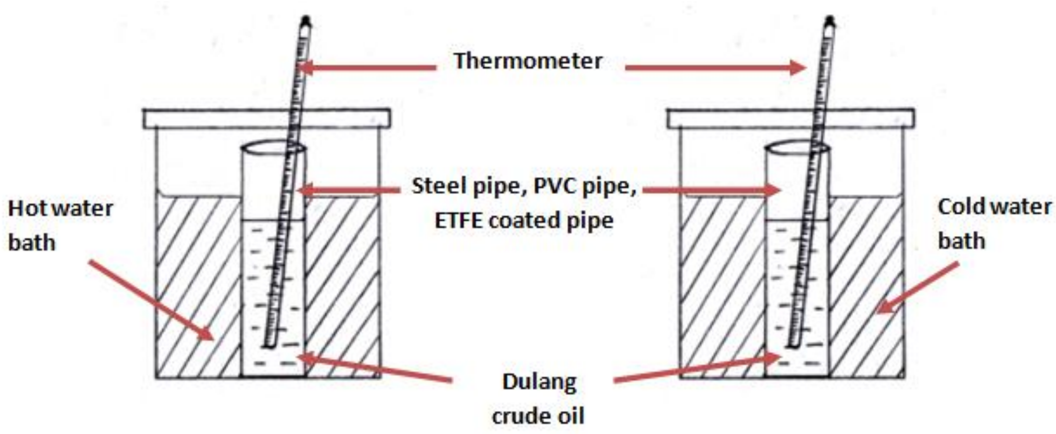



*Figure 2: Schematic Diagram of Paraffin Deposition Experiment Set Up*

## 3.5 EXPERIMENTAL PROCEDURE

Paraffin deposition apparatus was used in order to investigate the paraffin wax formation mechanisms. Detailed experimental procedures as well as parameters are shown below:

1. Prepare hot water bath, cold water bath and 2 inch x 12 inch of Steel pipe, PVC pipe and PTFE coated pipe.
2. Pour water in the hot water bath and keep it heating until temperature of the water reach 85°C.
3. For the cold water bath, pour water and keep the temperature constant at 10°C.
4. Then measure the weight of each steel pipe, PVC pipe and PTFE coated pipe and pour 0.5 liters of Dulang crude oil into it.
5. Take the steel pipe and immerse it in the hot water bath. Measure temperature of crude oil until its reach 50°C.
6. After that, take out the steel pipe from hot water bath and immerse it into the cold pot for 10 minutes.
7. Then remove the steel pipe from the cold water bath and measure it temperature.
8. After that, remove the crude oil liquid remain in the pipe and calculate the weight of the paraffin deposition in the steel pipe.
9. Clean the steel pipe.
10. Repeat step 5 to 9 for every increment of 5 minutes. (e.g. 10, 15, 20, 25… minutes)
11. Then, repeat the same procedure by using the PVC pipe and PTFE plastic coated pipe.

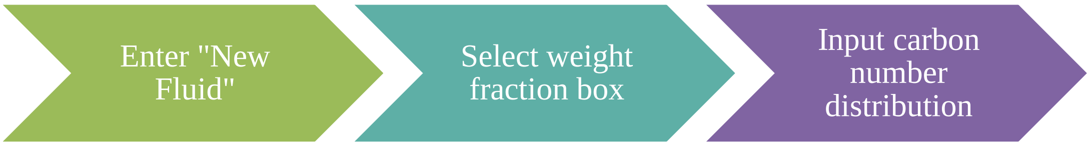
*Note: There might be additional equipment, chemicals or alteration of the procedure during the real experiment.*

## 3.6 RESEARCH PROCEDURE

### 3.6.1 Input Data from Experimental Results into PVTsim and OLGA

The data or results obtained from the experiment done previously play an important role in the simulation of the pipeline. Before run a simulation in OLGA, all the physiochemical properties of crude oil measured during experiment must be created in PVTsim by Calsep International Consultants PVTsim can calculate the properties of oil based on thermodynamic calculation. The carbon number distributions of each fluid need to specify in PVTsim in order to create the fluids. [Appendix B]

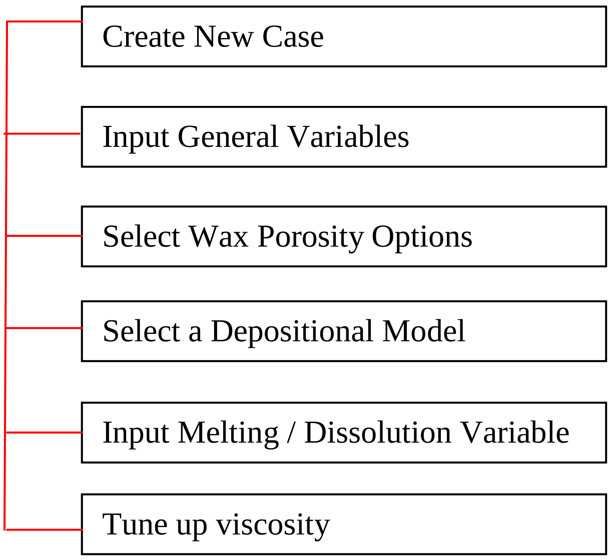
Procedures:

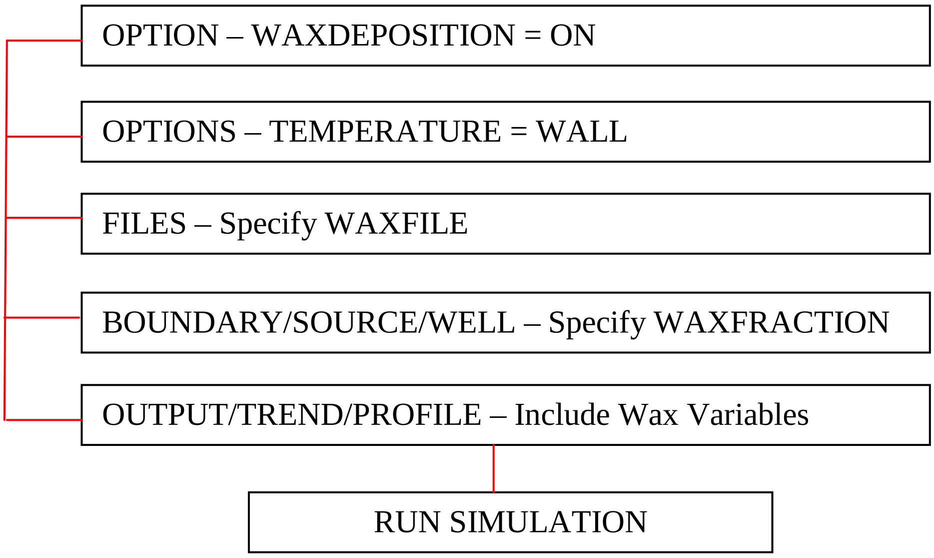



After created the fluids, the rheological data for crude oil that were made and measured analytically could be entered. Lastly, the actual wax appearance temperature (WAT) measured was added to each of the analytically measured fluids.

### 3.6.2 OLGA Wax Modelling

- WAXDEPOSITION Keyword






## 3.7 KEY MILESTONE

***Table 2: Key Milestones for Final Year Project I***

| WEEK | ACTIVITIES |
|---|---|
| 3 | • Completion of preliminary research work |
| 6 | • Submission of Extended Proposal |
| 8 | • Proposal Defence |
| 13 | • Submission of Interim Draft Report |
| 14 | • Submission of Interim Report |

***Table 3: Key Milestones for Final Year Project II***

| WEEK | ACTIVITIES |
|---|---|
| 8 | • Completion of Progress Report |
| 10 | • Pre-SEDEX and Poster Presentation |
| 12 | • SEDEX |
| 13 | • Submission of Final Draft Report<br>• Submission of Technical Paper |
| 15 | • Final Oral Presentation / Viva |
| 16 | • Submission of Project Dissertation (Hard Bound) |

## 3.8 PROJECT TIMELINE

- ***FYP I***

***Table 4: Final Year Project I Timeline***

| NO | DETAIL | WEEK | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| 1 | Selection of Project Topic | | | | | | | | | | | | | | |
| 2 | Awarded a Project Topic | | | | | | | | | | | | | | |
| 3 | Understand the Project Title, Objective and Problem Statement | | | | | | | | | | | | | | |
| 4 | Study the Previous Research Paper | | | | | | | | | | | | | | |
| 5 | Literature Review: Overview and How to do Experimental and Simulation Work | | | | | | | | | | | | | | |
| 6 | Methodology: Wax Deposition | | | | | | | | | | | | | | |
| 7 | Prepare the Extended Proposal | | | | | | | | | | | | | | |
| 8 | Submission of Extended Proposal | | | | | | | | | | | | | | |
| 9 | Preparation of Proposal Defence Presentation | | | | | | | | | | | | | | |
| 10 | Proposal Defence Presentation | | | | | | | | | | | | | | |
| 11 | Laboratory work | | | | | | | | | | | | | | |
| 12 | Prepare Interim Report | | | | | | | | | | | | | | |
| 13 | Submission of Interim Report | | | | | | | | | | | | | | |

- ***FYP II***

***Table 5: Final Year Project II Timeline***

| NO | DETAIL | WEEK | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** |
| **1** | Project Work Continues | | | | | | | | | | | | | | | | |
| **2** | Request for Software Availability | | | | | | | | | | | | | | | | |
| **3** | Fluid data preparation | | | | | | | | | | | | | | | | |
| **4** | Prepare simulation case | | | | | | | | | | | | | | | | |
| **5** | Analysis Data and Result Preparation | | | | | | | | | | | | | | | | |
| **6** | Submission of Progress Report | | | | | | | | | | | | | | | | |
| **7** | Prepare Final Result and Discussion | | | | | | | | | | | | | | | | |
| **8** | Pre-SEDEX and Poster Presentation | | | | | | | | | | | | | | | | |
| **9** | Prepare Final Draft Report | | | | | | | | | | | | | | | | |
| **10** | Submission Final Draft Report | | | | | | | | | | | | | | | | |
| **11** | Submission of Technical Paper | | | | | | | | | | | | | | | | |
| **12** | Viva | | | | | | | | | | | | | | | | |
| **13** | Submission of Project Dissertation (Hard Bound) | | | | | | | | | | | | | | | | |

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 DATA GATHERING AND ANALYSIS

### 4.1.1 Observation Analysis on Pipeline Materials

- **Initial PVC pipe weight**: 158.5762 grams
- **Initial Steel Pipe Weight**: 448.685 grams
- **Chiller temperature**: 10 °C
- **Water bath temperature**: 85 °C
- **Dulang crude oil temperature**: 50 °C

**PCV Pipe**

| Time (minutes) | Temperature (°C) | Weight of Deposition (grams) |
|---|---|---|
| 10 | 33 | 219.0038 |
| 15 | 30 | 328.9138 |
| 20 | 28 | 365.8038 |
| 25 | 25 | 409.7938 |

**Steel Pipe**

| Time (minutes) | Temperature (°C) | Weight of Deposition (grams) |
|---|---|---|
| 10 | 32 | 275.435 |
| 15 | 28.5 | 363.085 |
| 20 | 25 | 405.615 |

**PTFE Plastic Coated Pipe**

| Time (minutes) | Temperature (°C) | Weight of Deposition (grams) |
|---|---|---|
| 10 | 35 | 105.406 |
| 15 | 33 | 197.896 |
| 20 | 32 | 234.964 |
| 25 | 30 | 287.382 |
| 30 | 27 | 375.435 |
| 35 | 24 | 407.328 |

### 4.1.2 Project Deliverable

- **OLGA Modelling**

This study will be conducted using flow assurance simulator, OLGA with version 7.0.0. The respective fluid file will be created using PVTsim, a multifunction PVT simulation program. The simulation model schematic is shown in Figure 3.

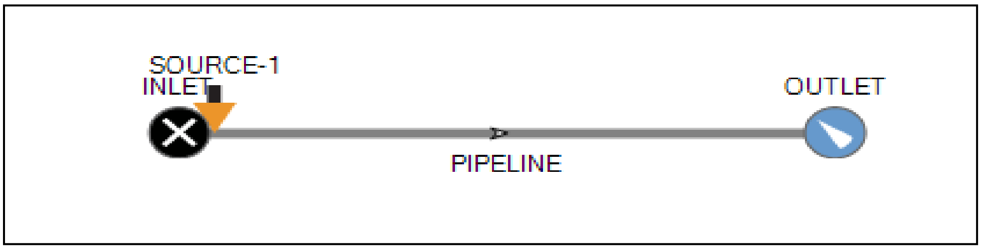



*Figure 3: OLGA Models Schematic*

- **Boundary and Initial Condition**

Heat transfer modelling is particular important for this project as wax is one of the main concern in this project. Heat transfer rate affects the fluid temperature which is directly related to wax formation. In OLGA, the ambient temperature and ambient heat have been set to $6^0$C and 200 W/M$^2$-C respectively.

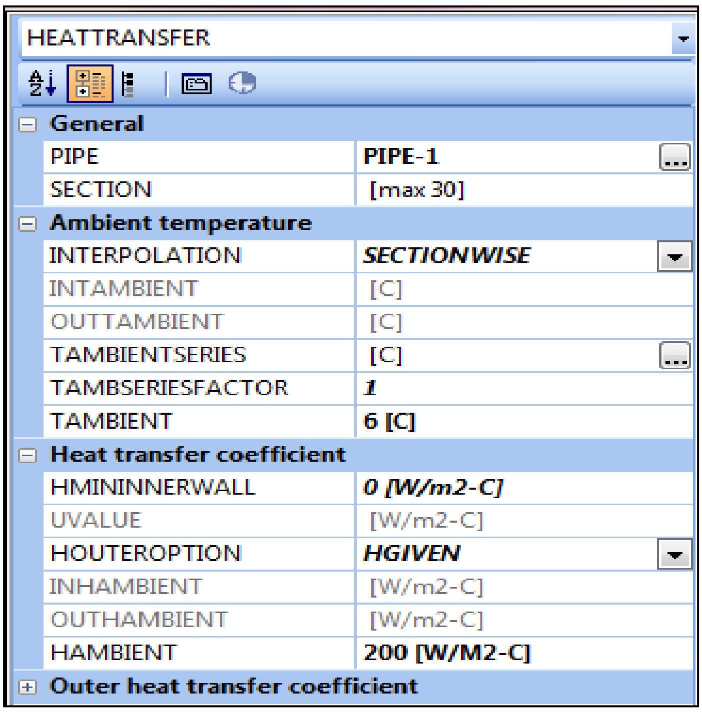



*Figure 4: Properties of Heat Transfer Modelling*

The inlet source is modelled as mass source. It is modelled at the first section of the pipeline system. The temperature is set to $42^0$C.

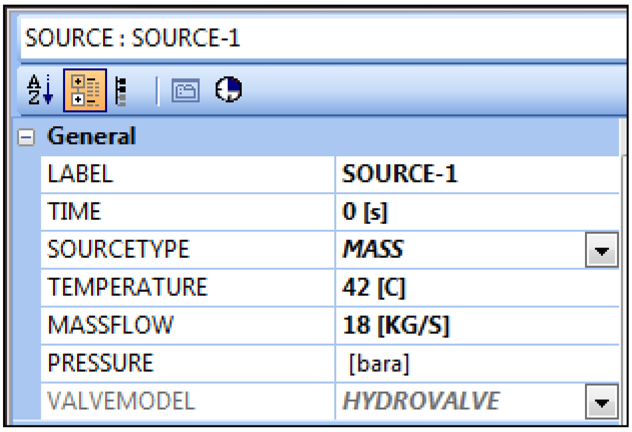



***Figure 5: Boundary Condition of Source***

- **Flow Component**

In OLGA, the pipeline materials will be defined as unique properties using MATERIALS. Then, the pipeline wall is modelled using variable WALL and it will be specified in the pipe section. The wall includes both the pipe and insulation thickness. For this study, pipe length of 3000 m has been used for three different pipe materials which are steel pie, PVC pipe and PTFE plastic coated pipe.

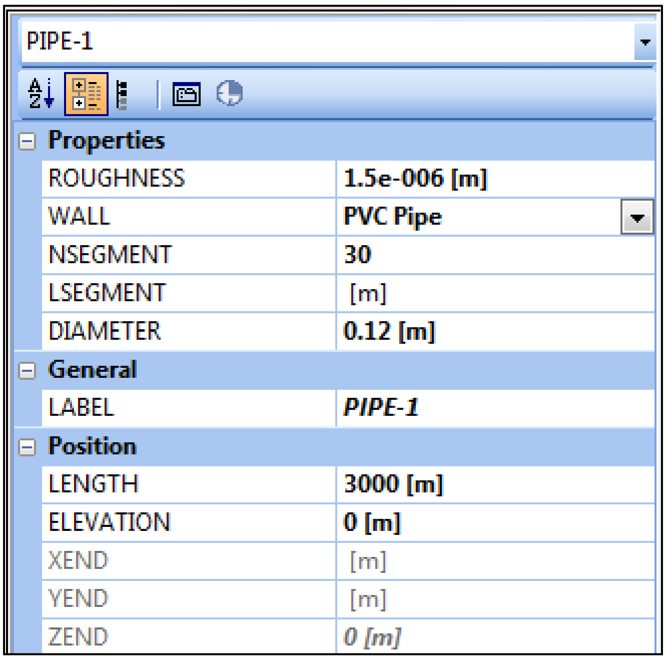



***Figure 6: Properties of Piping***

- **Wax Deposition**

Wax issues will be studied using different OLGA module. To enable study of wax, wax deposition module is activated. Wax Deposition FA model is input in every pipeline. It requires specific wax file which can be generated in PVTsim.

The MATZAIN wax deposition module is used as suggested. The default OLGA properties of wax deposition are used. Some tunings are required in order to produce better prediction of wax deposition such as diffusion coefficient. The tuning of Viscosity Multiplier D, E and F are not required due to insufficient field data.

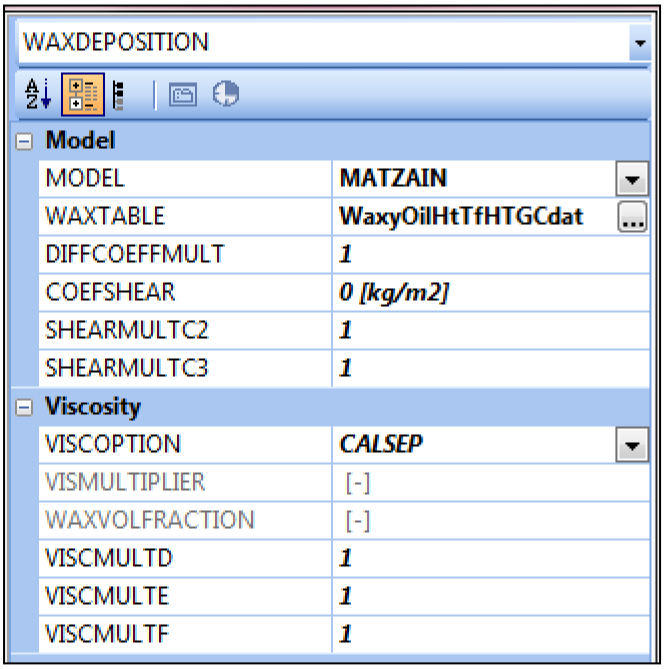



***Figure 7: Wax Deposition FA Model Properties***

- **Variables**

OLGA variables can be divided into trend and profile variables. Trend variables are used to view the change in variable according to the time at specific location or equipment. On the other hand, profile plot can be used to see the variation of variables with respect to the geometry of pipeline. The profile graph at specific operation time can also be plotted.

### 4.1.3 Physical Properties of Pipeline Materials

***Table 6: Properties of Pipeline Materials***

| **Properties** | **Pipeline Material** | | | |
|---|---|---|---|---|
| | **Steel Pipe** | **PVC Pipe** | **PTFE** | **ETFE** |
| Capacity, J/kg-C | 500 | 960 | 1200 | 2000 |
| Conductivity, W/m-k | 52 | 0.19 | 0.25 | 0.238 |
| Density, $kg/m^3$ | 7800 | 1400 | 2200 | 1700 |
| Roughness, m | $4.5x10^{-5}$ | $1.5 x10^{-6}$ | $3.0x10^{-6}$ | $3.6x10^{-6}$ |
| Diameter, m | 0.12 | 0.12 | 0.12 | 0.12 |

## 4.2 EXPERIMENT

Malaysian (Dulang) crude oil has been used in performing experiments to obtain the effect the temperature on rate of paraffin deposition in the static condition. The experiments have been conducted to investigate the effect of temperature on paraffin deposition by lowering temperature of the Dulang crude oil on its cloud point on the static condition.

Temperature of the cold water bath was set at 10$^{o}$C to eliminate subsea condition, while crude oil temperature was increased until 50$^{o}$C which is above its cloud point at constant condition in order to avoid early state of precipitation of the crude oil.


*Figure 8: Measure temperature of the hot water, cold water and crude oil*

The study showed that the paraffin deposit increased with decreasing temperature. As the temperature go down at certain time, the oil will start to form gel and accumulate in the pipe surface.

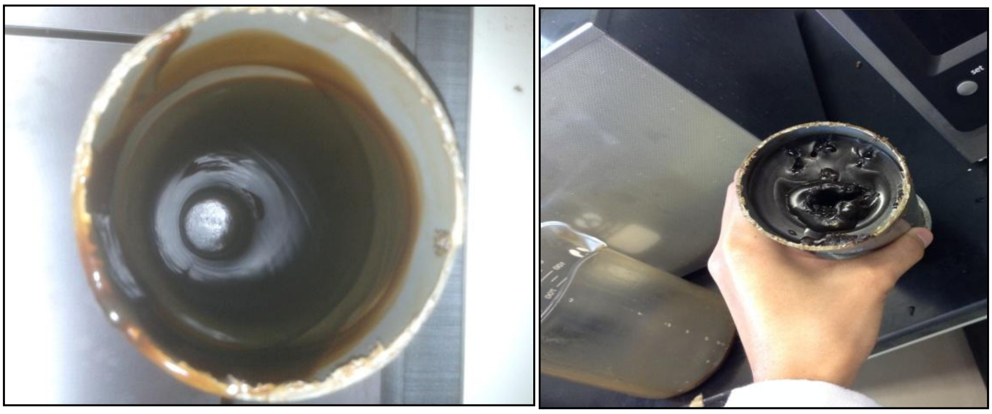


***Figure 9: Crude oil become gel and deposited in the pipe surface***

### 4.2.1 Observation Analysis on PVC Pipe

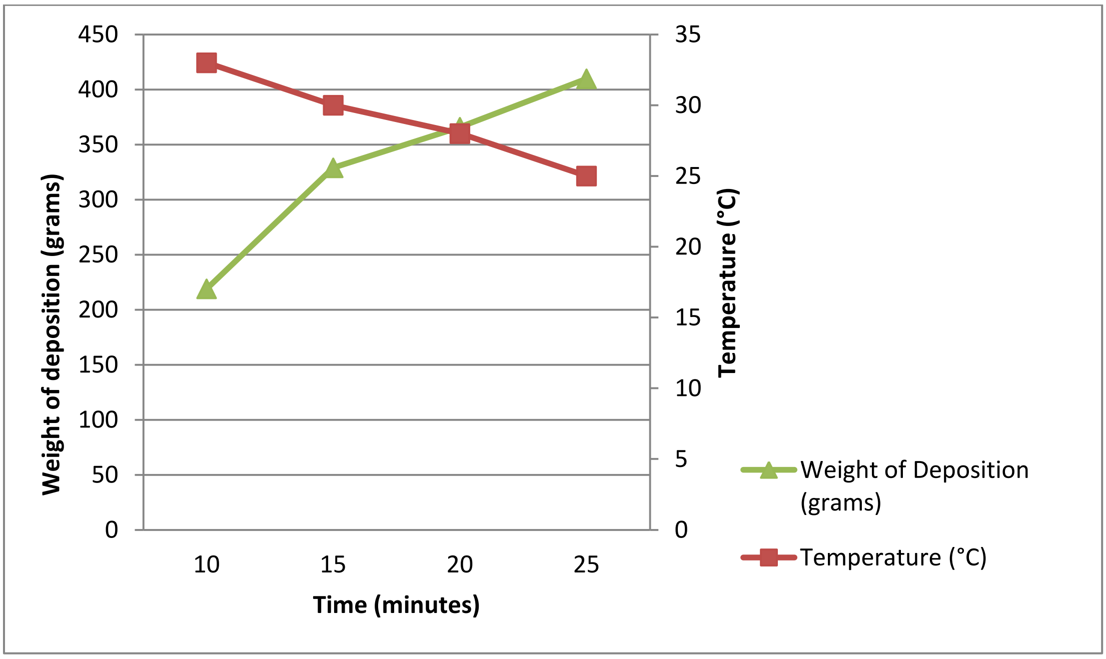



***Figure 10: The effect of Temperature on rate of Paraffin deposition for PVC pipe***

Figure 10 shows the effect of temperature and weight of the wax deposition in case of PVC pipe. From the graph above, after 10 minutes, the wax accumulated on the pipe weighted around 219 gram. However, it took quite a longer time for the deposition to reach its highest point. The highest wax accumulation (409 gram) was recorded after 25 minutes.

### 4.2.2 Observation Analysis on Steel Pipe

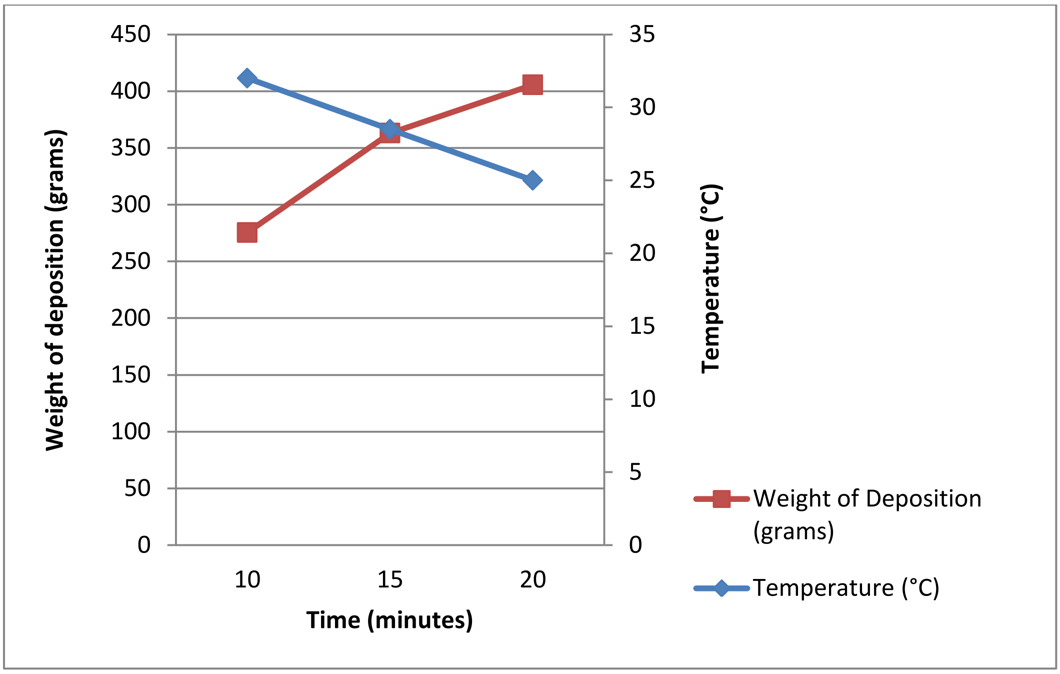



*Figure 11: The effect of temperature on rate of Paraffin deposition for steel pipe*

Figure 11 also illustrates the effect of temperature and weight of paraffin deposition in the case when steel pipe was used. After analyzing the graph above, the steel pipe recorded paraffin deposition around 275 gram after cooling for 10 minutes. The weight of the paraffin deposit was highest on the steel pipe (405 gram) and after 20 minutes the crude oil totally gelled due to its very high thermo conductivity (20 Btu/hr-.ft-deg F, ASTM C 177).

### 4.2.3 Observation analysis on PTFE Plastic Coated Pipe

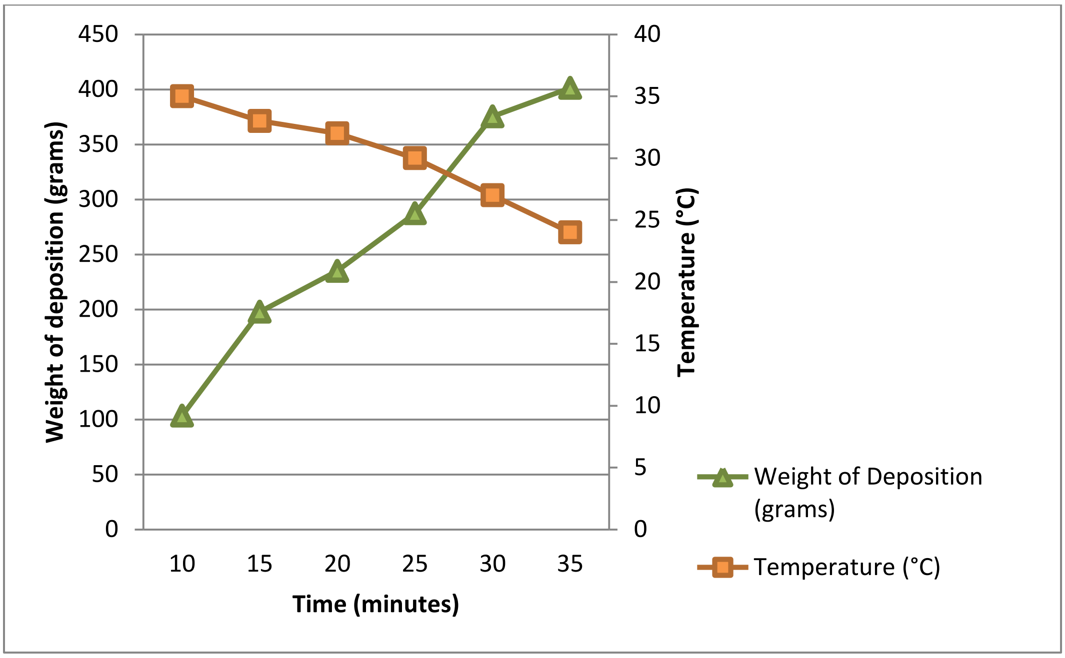



*Figure 12: The effect of Temperature on rate of Paraffin deposition for PTFE plastic coated pipe*

Figure 12 presents the effect of temperature and weight of paraffin deposition on an PTFE plastic coated pipe. From the graph above, it is clearly states that the wax accumulated on the pipe weighted around 105 gram after 10 minutes. It shows that this pipe took the longest time before the paraffin accumulation reached its highest point. The highest wax accumulation was around 407 gram and was recorded after 35 minutes because of its lowest thermal conductivity which is 0.137 Btu/hr-.ft-deg F, ASTM C 177.

## 4.3 ANALYSIS OF BASE CASE STUDY

For analysis on base case study, simulation on four types of materials such as steel pipe, PVC pipe, PTFE and ETFE plastic coating pipes had been carried out.

### 4.3.1 Observation analysis on Fluid Temperature and Wax Appearance Temperature

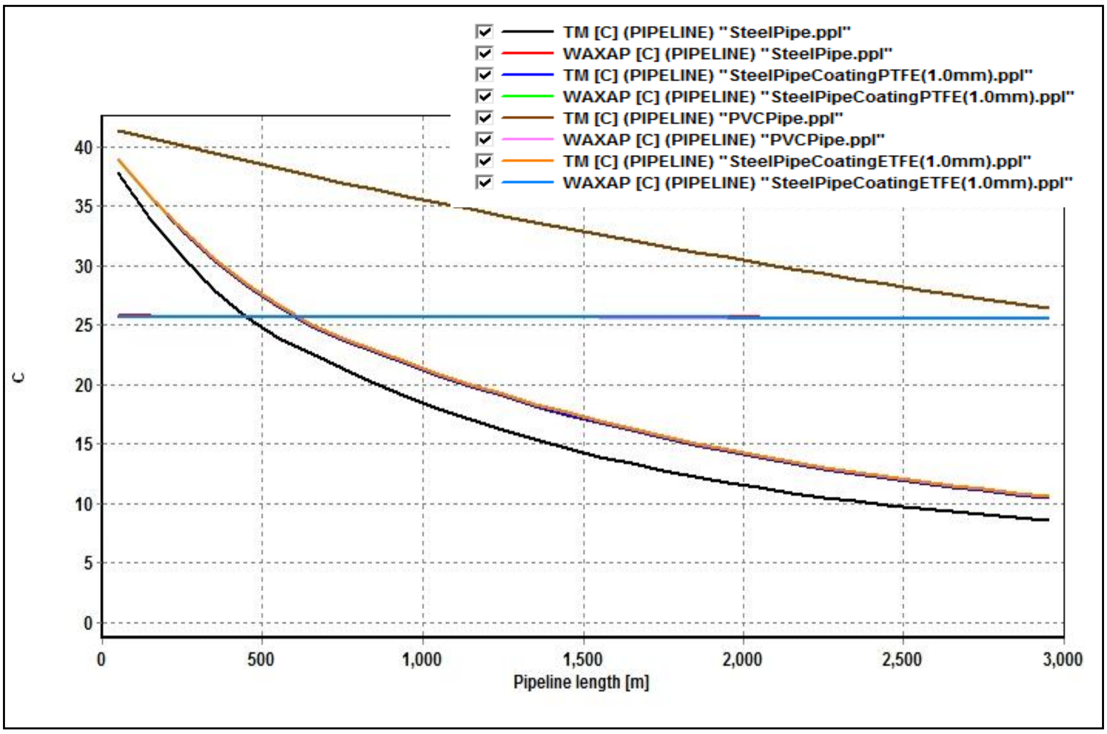



*Figure 13: The effect of Fluid Temperature and Wax Appearance Temperature (WAT)*

Figure 13 show the study of four different pipeline materials which is steel pipe, PVC pipe, PTFE and ETFE plastic coated pipe. From the analysis that has been carried out, the wax appearance temperature (WAT) for the materials are around 25.6 °C. It is clearly shows that all the fluid temperatures drop as the pipeline length increases. The fluid temperature of steel pipe starts to drop below the WAT at pipeline length of 490 m. Once the fluid temperature drops below WAT, wax will start to crystallized, precipitated and adhered on the pipeline surface. However, fluid temperature for PVC pipe do not fall below the WAT, so wax was not formed inside the pipelines.

### 4.3.2 Observation analysis on Wax Thickness

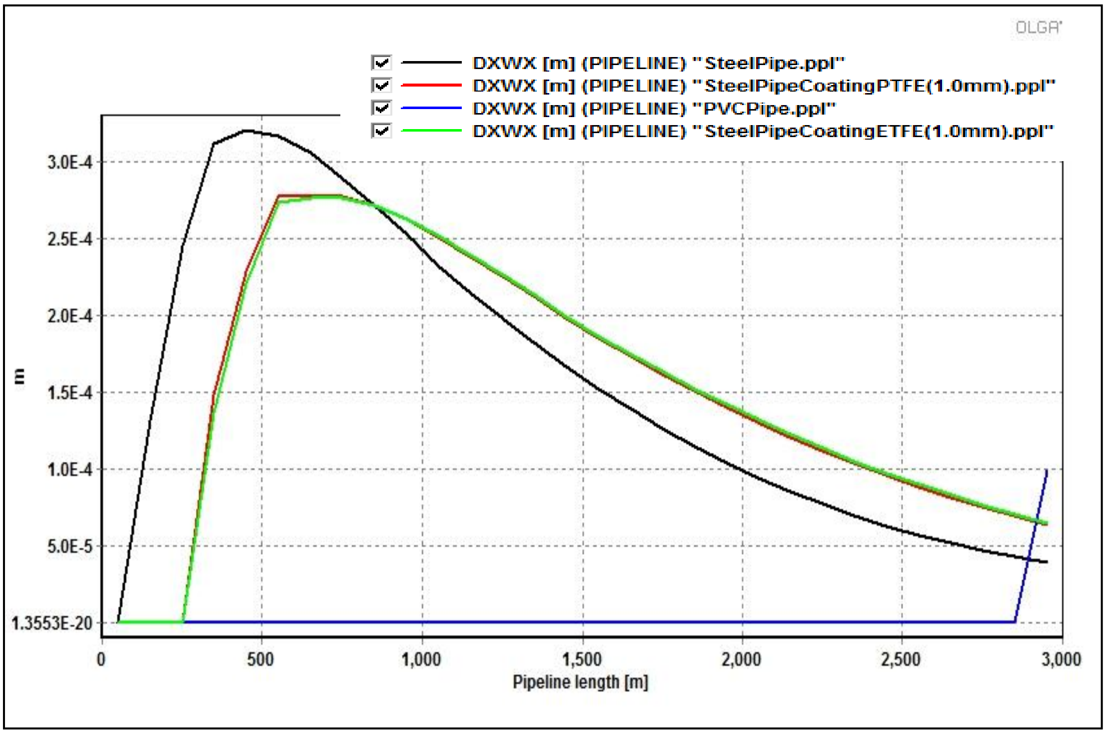



*Figure 14: The effect of Wax Thickness*

In figure 14 above, the wax thickness deposited at pipeline wall can be observed. As the fluid temperature of steel pipe fall below WAT at length of 490 m, wax is formed throughout the time with thickness of 0.00035 m. As the temperature drop is higher, the wax formation thickness also will be higher. However, as the time and length of pipelines increase, the wax thickness reduced. This is because the waxes has become insulation and reduce the temperature gradients. No wax layer deposited at wall PVC pipe can be seen because the fluid temperature is above the WAT. However, wax will be form in pipeline if the length of the pipeline is increases and the fluid temperature drop below the WAT through the time.

### 4.3.3 Observation analysis on Heat Transfer Coefficient

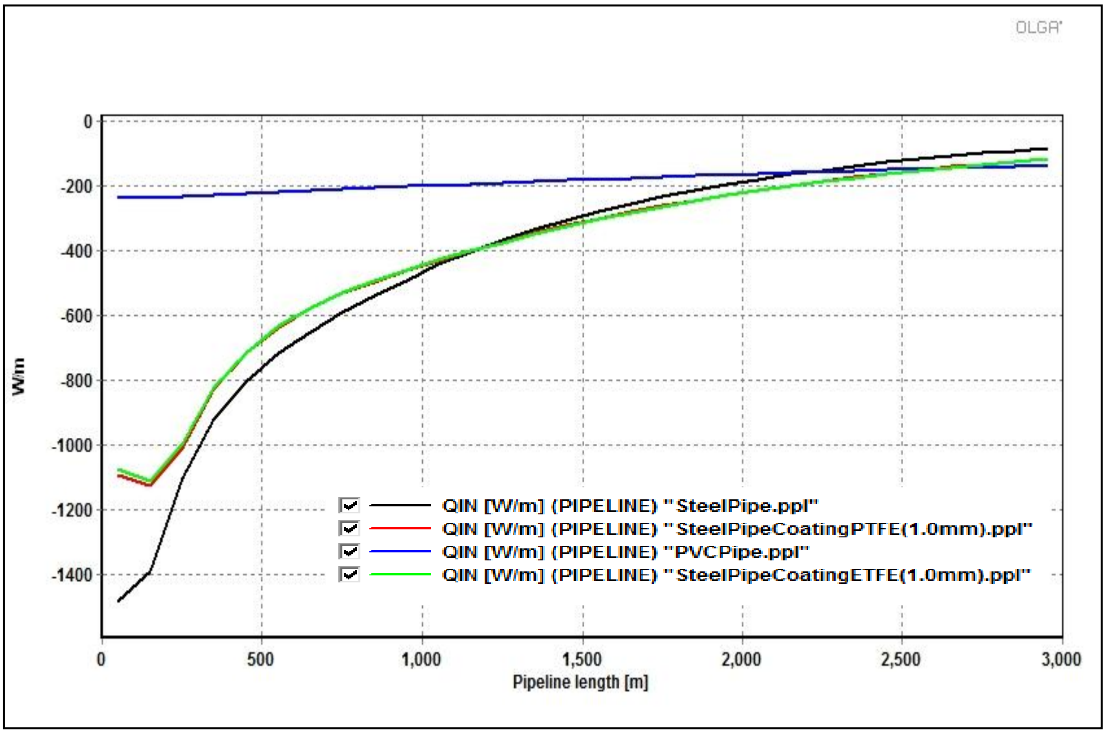



*Figure 15: The effect of Heat Transfer Coefficient*

Based on the figure 15 above, the heat transfer rate affects the fluid temperature which is related to the wax formation. From the graph, as the fluid temperature decreases, the heat transfer from inner pipe to wall increases. This is happened in order to achieve an equilibrium temperature between pipes wall and the oil flow. It is proved by all the four pipeline materials. For steel pipe, the heat transfer change is large compare to PVC pipe, PTFE and ETFE plastic coated pipe due to high fluid temperature change. However, PVC pipe give the smallest value change of heat transfer from inner pipe wall to fluid because it has small temperature drop and no wax formation.

### 4.3.4 Observation analysis on Overall Heat Transfer Coefficient

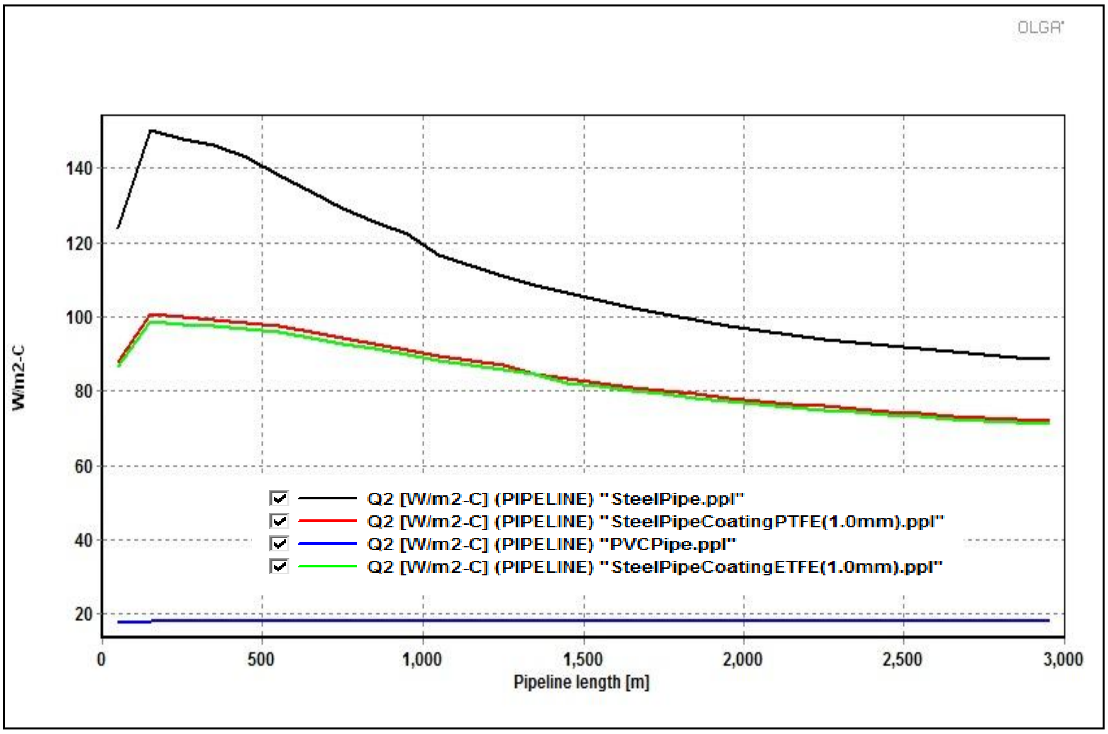



***Figure 16: The effect Overall Heat Transfer Coefficient***

On the other hand, the effect on overall heat transfer coefficient also has been studied. It can be calculated using the overall heat transfer coefficient equation for thick walled pipes. High overall heat transfer coefficient will cause the temperature to drop rapidly towards ambient temperature. Therefore, the overall heat transfer coefficient is the most important factor in the temperature profile development. As in figure 16, steel pipe has high oil content in the wax and thick deposit which result in increasing the overall heat transfer coefficient which give the most high heat transfer. As had been approved by researchers, exposed pipeline have high overall heat transfer coefficient compared to coated pipeline because coating material act to prevent the heat released to the surrounding. [16] Even though PVC pipe gives lowest overall heat transfer coefficient compared to PTFE and ETFE plastic pipe coating but it has it owns disadvantages where PVC pipe cannot stand for a high temperature as it reduces it strength and durability.

## 4.4 SENSITIVITY ANALYSIS

### 4.4.1 Fluid Temperature and Wax Appearance Temperature (WAT)

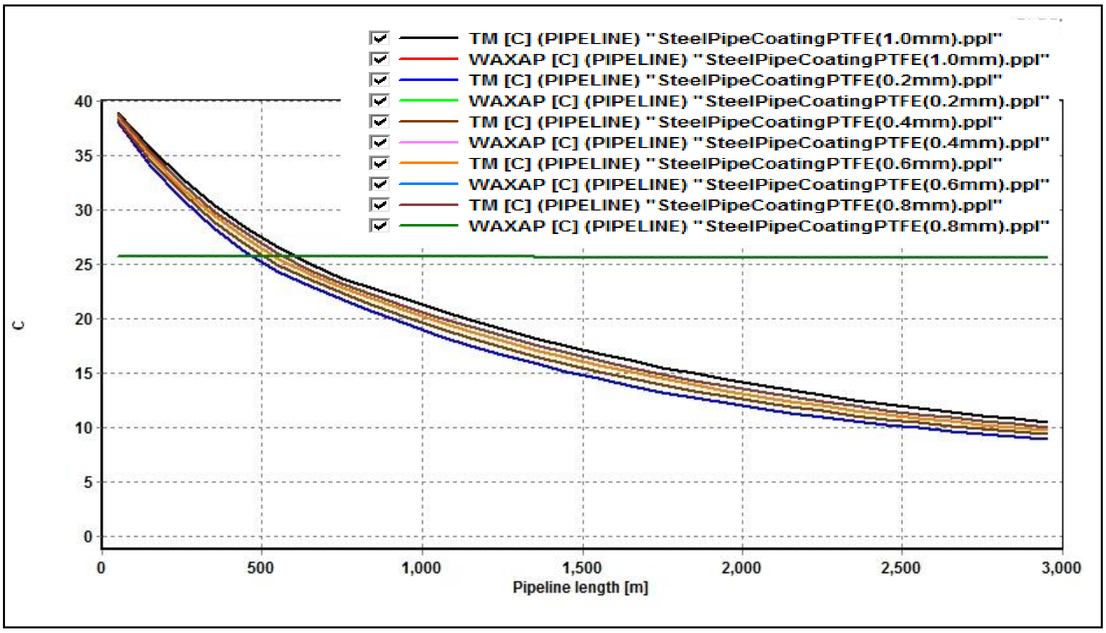



*Figure 17: The Effect of Fluid Temperature on PTFE Pipe*

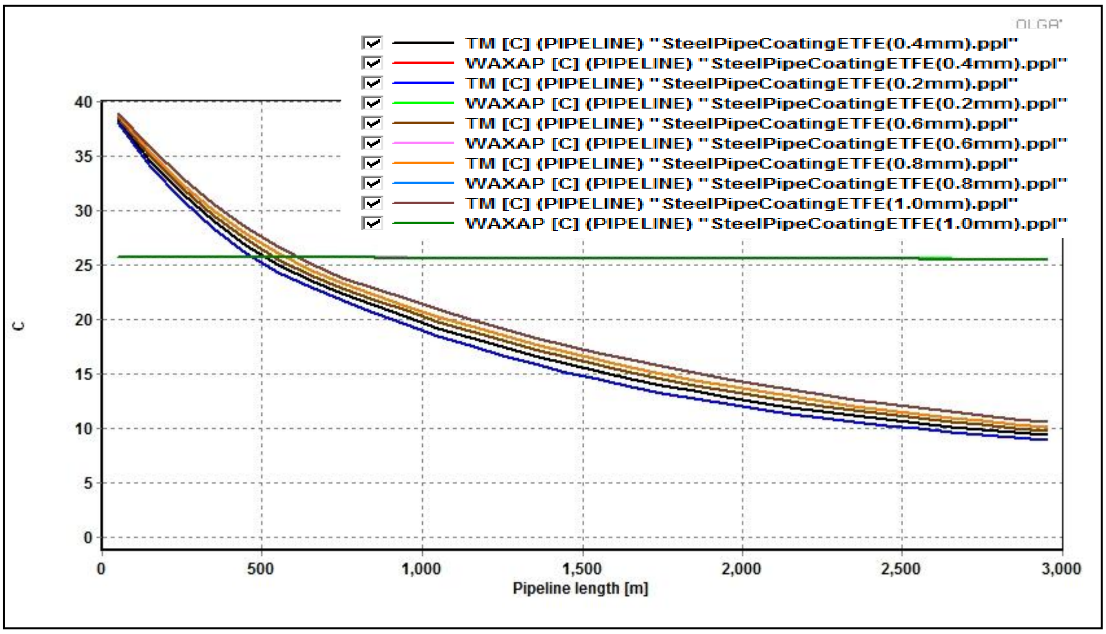



*Figure 18: The Effect of Fluid Temperature on ETFE Pipe*

### 4.4.2 Wax Thickness

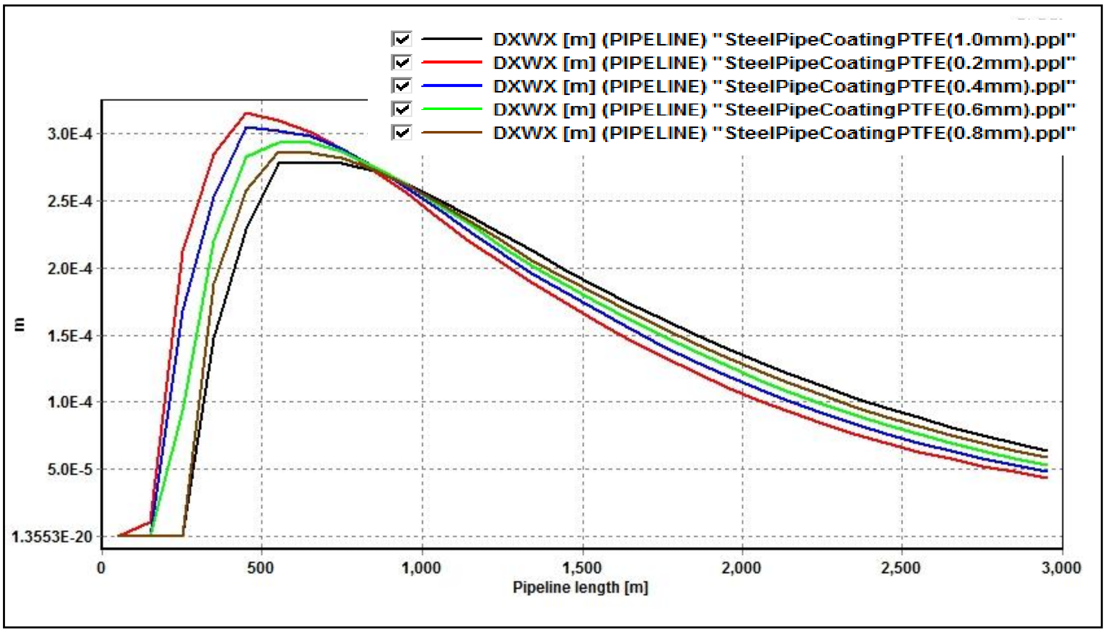



*Figure 19: The Effect of Wax Thickness on PTFE Pipe*

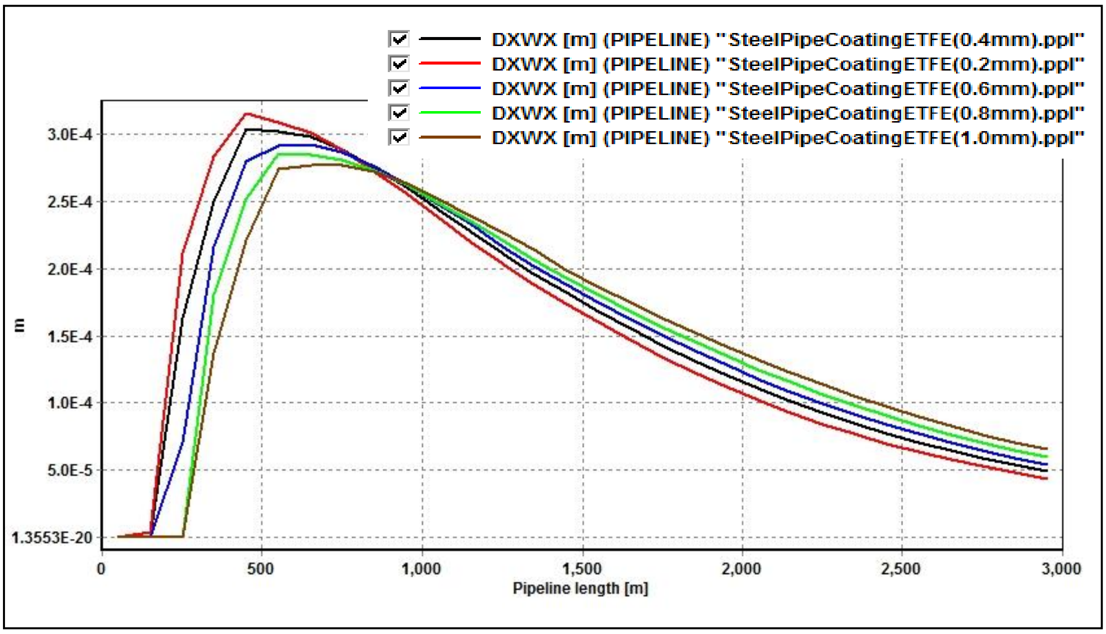



*Figure 20: The Effect of Wax Thickness on ETFE Pipe*

### 4.4.3 Heat Transfer Coefficient

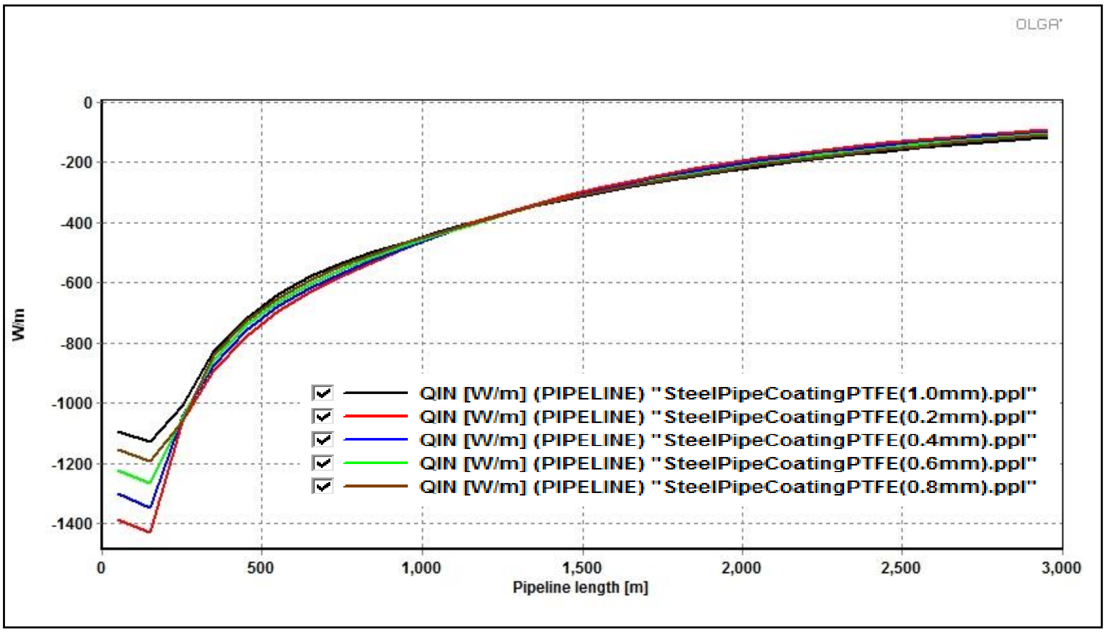



*Figure 21: The Effect of Heat Transfer Coefficient on PTFE Pipe*

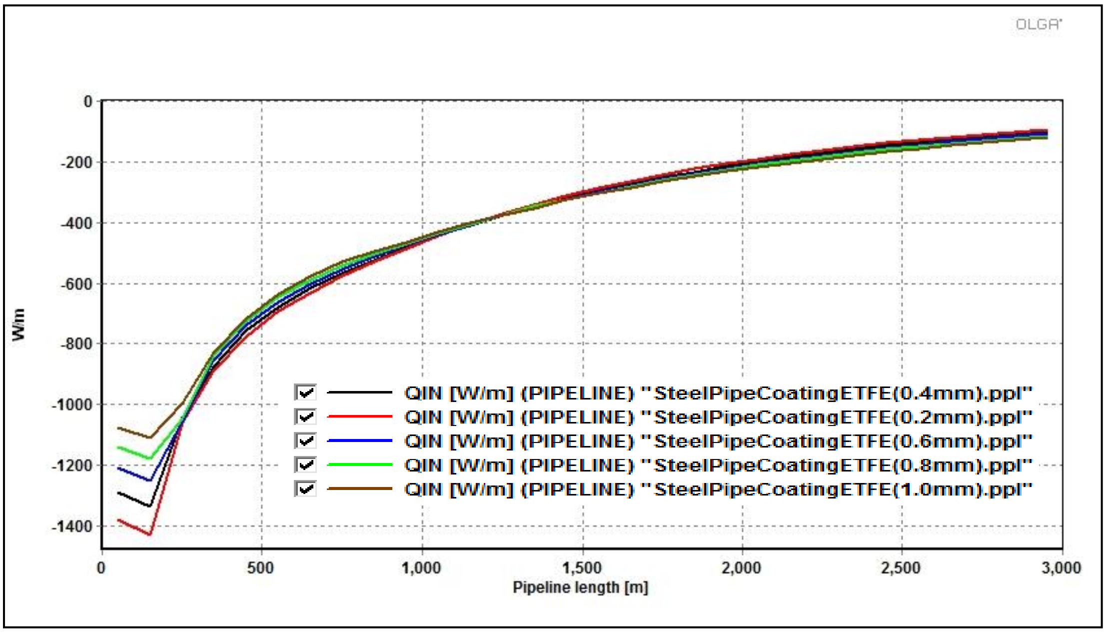



*Figure 22: The Effect of Heat Transfer Coefficient on ETFE Pipe*

### 4.4.4Overall Heat Transfer Coefficient

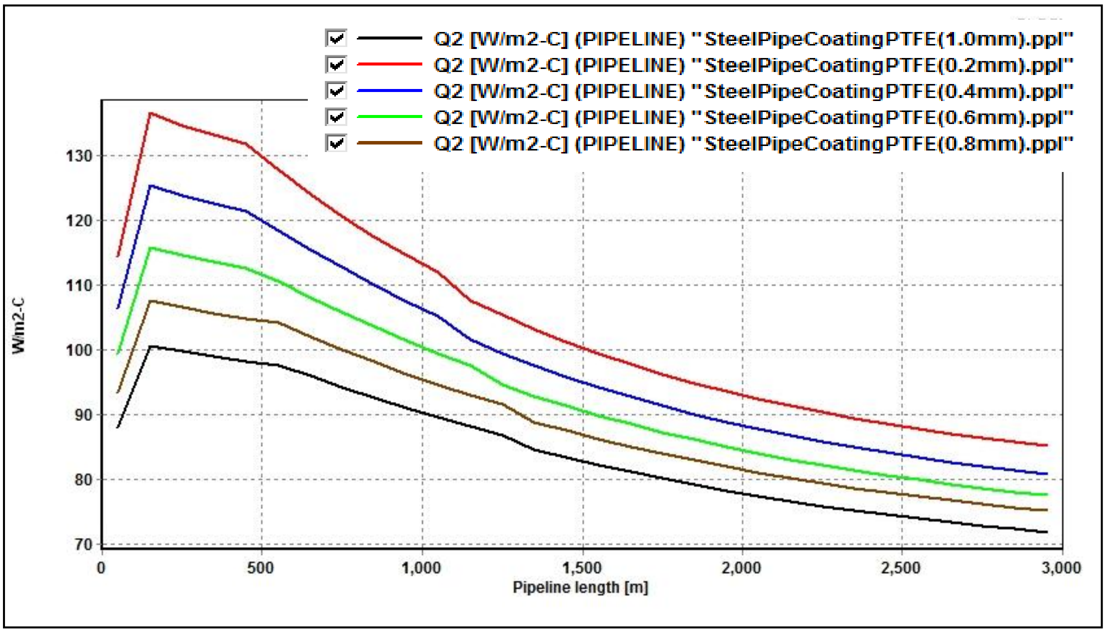



*Figure 23: The Effect of Overall Heat Transfer Coefficient on PTFE Pipe*

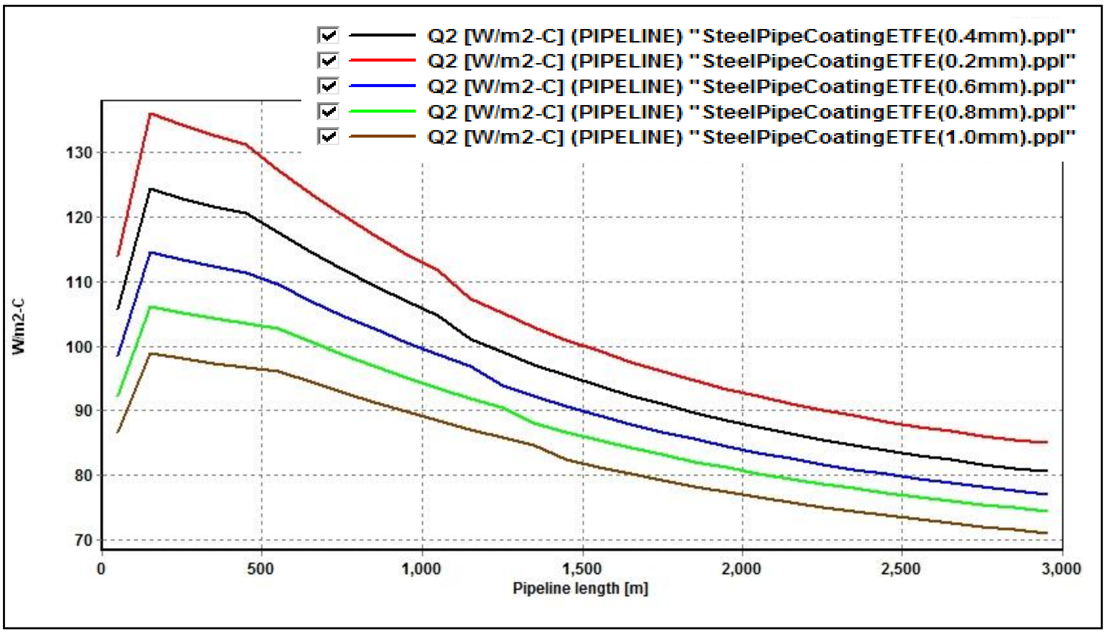



*Figure 24: The Effect of Overall Heat Transfer Coefficient on ETFE Pipe*

Sensitivity analysis at different coating thickness for both PTFE and ETFE plastic coating pipes is tested. The study had been done on 0.2, 0.4, 0.6, 0.8 and 1.0 mm coating thickness.

Based on Figure 17 to 24, we can see the results for both PTFE and ETFE coating pipes at different coating thickness. As the coating thickness increases, it gives the best result to mitigate paraffin deposition in pipeline system. It is clearly showed that the graph trend for both PTFE and ETFE coating pipes result is almost the same.

However, ETFE coating pipe proved as the best solution to control the wax formation. This is because ETFE coating pipe has higher mechanical strength properties than other floropolymers. In addition, overheated PTFE will released fumes that are mildly toxic and can cause dead to humans and animals.

From the results obtained, with coating thickness of 1.0 mm, ETFE coating pipe proved as the best coating thickness as it prolong the time of fluid temperature drop below the wax appearance temperature (WAT). Therefore, wax formation will occur late and the wax thickness will be less. As in Figure 20, lower coating thickness (0.2 mm) will have high wax thickness formed compared to high coating thickness (1.0 mm).

The heat transfer to the surrounding will be lower as it helps to reduce the temperature gradient. Therefore, an equilibrium temperature between inner wall and fluid will be achieved. The overall heat transfer coefficients also lower due to the increasing in coating thickness.

### 4.5 COST ANALYSIS

In order to identify which materials is the best to eliminate the formation of wax, cost analysis for all materials need to take into considerations. This is because it will affect the economic values of the project for a long term.

*Table 7: Cost Analysis for Steel Pipe, PVC Pipe, PTFE & ETFE Pipes*

| Type of Pipe 0.3 m x 1.0 m | Steel Pipe | PVC Pipe | PTFE Coating Pipe | ETFE Coating Pipe |
|---|---|---|---|---|
| **Price , RM** | 226.00 | 88.00 | 831.00 | 838.00 |

From the Table 7 above, the result showed that PVC Pipe gives the lowest price compared to the others pipe materials. However, PVC Pipe is not the best material to overcome this problem because it cannot withstand at high temperature and easily cracked. Therefore, PVC pipe required high maintenance cost in the future.

Next, steel pipes cost is also reasonable to be used to mitigate the paraffin deposition. But steel pipe has its own disadvantages where it is very susceptible to corrosion and should be coated inside and outside. So in this condition, it required extra cost to be implemented.

Cost for both PTFE and ETFE coating pipes are not much different and very expensive. Even though the materials price is high but it is economic and qualitative as it can reduce the maintenance and operating cost of project. For this project, ETFE coating pipe is the best choice as it is the most stable floropolymer and the satisfied the criteria regarding quality as an optimal coating material.

# CHAPTER 5

# CONCLUSION AND RECOMMENDATION

## 5.1 CONCLUSION

In conclusion, all four types of pipes used in this project are showing significant changes in temperature and thickness of the paraffin deposition. The simulation results show that the thickness of paraffin deposition at all temperatures losses to the surrounding was greatest in steel pipe but significant paraffin accumulation was found in PTFE and ETFE plastic coated pipe. The lowest amount of paraffin deposition was observed in the PVC pipe. However, ETFE plastic coated pipe is the best solution to eliminated paraffin deposition due to its advantages.

Besides, both oil content in the paraffin wax and its thickness has a large effect on the overall heat transfer coefficient for exposed pipelines. For coated pipeline, wax deposition has less effect on the overall heat transfer coefficient when it has a low value.

Therefore, the objectives of this project is successfully achieved because it has been proven that the usage of ETFE plastic pipe coatings in a typical crude oil can potentially reduce the amount of paraffin deposition inside the pipelines, hence improving the whole system thoroughly. The use of ETFE plastic pipe coating for solving and preventing paraffin deposition has proved to be an economically and technically feasible method.

## 5.2 FUTURE WORKS AND RECOMMENDATION

As for recommendation for this research, it is recommended to study the effect of velocity, temperature and surface roughness on rate of paraffin deposition in dynamic condition.

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# APPENDICES

A. Physical properties of the Dulang crude oil:

| Properties | Unit | ASTM method | Dulang crude oil |
|---|---|---|---|
| Density | g/m3 | DMA 35N | 0.82 |
| Pour Point | °C | D 97 | 18 |
| Wax Appearance Temperature (Cloud point) | °C | Cross polarized microscopy | 35 |
| Viscosity | cp | Electromagnetic viscometer | 4.012 |
| Carbon Number Distribution | | GCMS | Refer Fig. 1 |

B. Carbon number distribution of Dulang crude oil :

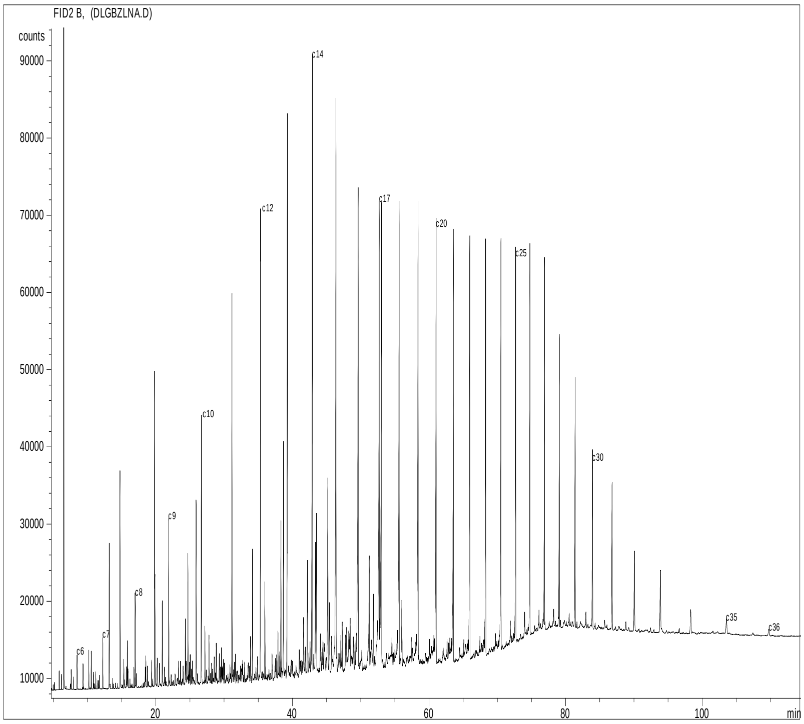


Figure 1: Carbon number distribution of Dulang crude oil