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# Modelling of Hydrates in Subsea Pipeline


By:

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Dissertation in partial fulfilment of

the requirements for the

Bachelor of Engineering (Hons)

(Mechanical Engineering)

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# CERTIFICATION OF APPROVAL

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A project dissertation submitted to the:

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Approved by,

_________________________

(AP Dr. Fakhruldin bin Hashim)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

SEPTEMBER 2012

## CERTIFICATION OF ORIGINALITY

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

..........................................................................

MEOR AHMAD SAIFUL RIDHWAN BIN RAMLI

# ABSTRACT

This thesis describes the modelling and simulation for the hydrates in subsea pipeline. For new developer, a better understanding on how the to calculate the heat transfer throughout pipeline using some formulae and equations is needed to ensure that the system flow will meet all design specifications and reduced the risk with installation and commissioning. Hence, simulating a model of subsea pipeline module provide engineers with the ability to do multiple scenario of pipeline based on changing parameters which are radius of pipeline and material of coating used for pipeline. The methodologies of project involve collection of technical details and date regarding subsea pipeline module, identify formulae and equation needed, method of calculation, and subsea pipeline module design parameters. Result shows that the best option for radius and material coating for subsea pipeline are radius option 5 (0.83 m) and Polibrid material since the surrounding temperature through heat transfer inside of the pipeline is not suitable for the hydrate to be form.

# ACKNOWLEDGEMENT

First and foremost, I thank and praise Allah for His guidance and blessing, definitely without it I would not have been able to complete my final year project lasting for two semesters. I would like to express the deepest appreciation to my supervisor, AP Dr Fakhruldin bin Mohd Hashim, who has support and guidance to complete this project. Without his guidance and persistent help, this dissertation would not been possible. I also would like to express my appreciation to Dr. Azuraien Japper and Dr. V.V.L.N. Rao for their willingness to do evaluation for my proposal defense and poster presentation. Special thanks to my beloved family who have been supporting, understanding and encouraging me in completing this final year project. Last but not least, to all individual that has helped me in any way, but whose name is not mentioned before here, I thank you all.

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# CHAPTER 1

# INTRODUCTION

## 1.1. Background of study

During early era in natural gas business, gas was generated and delivered at relatively low pressure. Thus, hydrate is not the main focus for difficulty and never encounters that situation [1]. Now, oil and gas industry are very cultivated and a lot of company has been organized in this field. In oil and gas industry, the term hydrate is reserved for substances that are usually gaseous at room temperature such as methane, ethane, carbon dioxide, and hydrogen sulphide [1]. A hydrate is a compound containing water and mixture of water and gas molecule that crystallize to form a solid called "ice plug" under certain temperature and pressure [1][3]. Therefore, gas hydrates are ice-like structures that form when water molecules congregate themselves into a 'cage' around a small organic molecule and surrounded by water molecules; hence form crystalline solids [1][4]. When both water and guest molecules are present, hydrates can form at well above 32 °F (0 °C) if the pressure is sufficient. In oil and gas production systems, hydrates form primarily as one of two structure forms, known as Structure-I (or Type-I) or Structure-II (or Type-II) depending primarily on the size and concentration of the guest molecules.

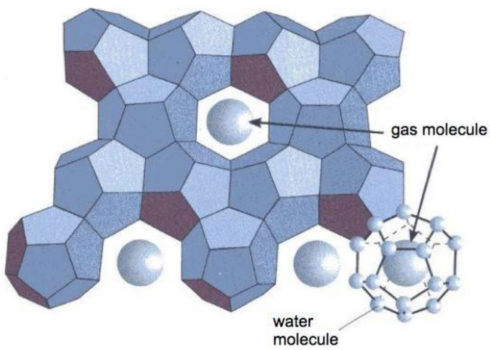



Figure 1: Molecular structure of Hydrate [7].

Typically, the best place for composition of hydrates to be form is in deep-sea environment because of high pressure and low temperature [3][4]. These are the conditions for the formation of hydrate [1]:

1. Right combination of temperature and pressure. Favoured: low temperature, high pressure.
2. A hydrate former must present including methane, ethane and carbon dioxide.
3. A sufficient amount of water.

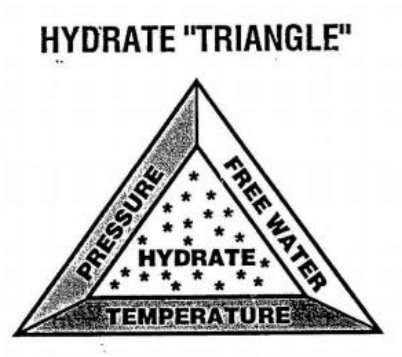



Figure 2: Hydrates "triangle" diagram [4].

Hydrates structure can exist in the form of single or multiple plugs. The formation of multiple hydrates plugs causes pressure to be trapped between the plugs. High differential pressures can be created if multiple hydrates are treated as a single plug [3]. Long deepwater subsea is problematic due to the high pressures and low temperatures of the production fluids in the flow line. Many experiments and chemical methods such as injecting inhibitors and usage of antifreeze protein being used to avoid the conditions that cause hydrate formation, but can be expensive, and ineffective under some conditions. These two prevention method will be explain more in literature review later.

Figure 3: Formation of hydrates in pipeline [6].

Hydrates can obstruct flow assurance in pipelines and interrupt production [2]. At worst, they can cause flow lines to burst. Remediation can be time-consuming, expensive, and dangerous depending on the location and extent of the blockage. Hydrate plugs does not interrupt production only but they also can be a safety risk if not remediated properly. The huge hazard is to dislodge the plug and travel it down the line at high speed due to differential pressure across the plug. This can cause catastrophic failure, resulting in equipment damage, injury, and even loss of life. It is essential to implement a strategy to prevent or manage hydrates for uninterrupted production in a safe and cost-effective manner [4].

## 1.2 Problem Statement

Gas hydrate is easily formed during the transportation of oil and gas when it contains a certain amount of water, resulting in the damage to the oil and gas industry. This will disrupt the production of hydrocarbon and leading to costly maintenance, time-consuming in repairing and potentially dangerous operations. Thus, the prevention of hydrate formation has become an important matter. Nowadays, several methods are being developed in solving this problem such as injecting inhibitor into the pipeline and antifreeze protein. But, the problem for both methods is it's been injected regularly according to the schedule without knowing where and when the formation of hydrate will be form. Experiment at works have been done in finding a solution to this matter by referring to the 3 factors that contribute to hydrate's formation namely free water, presence of hydrate formers and right combination of temperature and pressure. To prevent hydrate formation, one of these conditions needs to be eliminated. Obviously, free water and presence of hydrate formers can't be eliminated because of the environment surrounding pipeline. Thus, addressing temperature inside of the pipeline is the most important criteria in this project by implementing thermodynamics and heat transfers through design. The temperature inside of the pipeline needs to be higher than the temperature required by hydrate to be formed. It will help engineer in conducting proper intervention in designing structure of pipeline. Furthermore, some calculation and assumptions need to be included throughout this project.

## 1.3 Objectives

The objectives of this research are:

1. To simulate the gas flow in subsea pipelines by applying different thickness and materials of coating for controlling the heat transfer throughout the pipeline.

2. To evaluate the heat transfer inside of the pipeline to the surrounding based on the above model.

3. To generate input parameter for the model by using industrial data directly through simulation using ANSYS FLUENT, Computational Fluid Dynamics software.

## 1.4 Scope of Study

The research will involve in the understanding of hydrate formation and heat transfer through the pipeline by using fundamental of heat transfer and thermodynamics. The study of this project focus on Malaysia's deep water restricted to 500m maximum depth and temperature range from $4^{o}C$ to $24^{o}C$. The range for volume flow rate is from 700 to 2100 MMSCF, normal oil production per day.

The scope of study mainly investigates the temperature of the methane hydrate formation and heat transfer by varying the thickness of coating from 0.57m to 0.82m and material of coating which are TyMar, Polibrid and NovoTherm. The study will divided into two stages, the first step involves researching the basic properties of the methane hydrates and determining an ideal formulation of heat transfer using some calculation and also considering important aspects of gas temperature modelling in long subsea pipeline. All data that have been calculated will be used as input parameter in doing a simulation using software called CFD (FLUENT), Computational Fluid Dynamics.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

In this section will contain the physical properties and methods in preventing formation of hydrates in subsea pipeline. For the physical properties of hydrates part, it will explained more about structure and types of hydrates, structure of hydrates and suitable surrounding for the formation of hydrates. Meanwhile, there are several methods for prevention of hydrates which are chemical injection and thermal insulation. For chemical injection method, it can be divided into thermodynamic inhibitors and low-dosage inhibitors.

### 2.1.1 Physical Properties of Gas Hydrates

Clathrate hydrates or gas hydrates are solid structures. Water molecules are linked through hydrogen bonding and create cavities (host lattice) that can enclose a large variety of molecules (guests) [1]. The Clathrate hydrate crystal may exist at temperatures below as well as above the normal freezing point of water [7]. English Chemist, Sir Humphrey Davy stated that "*the ice-like solid formed at temperature greater than the freezing point of water, and the solid was composed of more than just water*" [1][7].

Clathrate hydrates of current interest are composed of water and the following molecules: methane, ethane, propane, isobutene, normal butane, nitrogen, carbon dioxide, and hydrogen sulphide [1]. Clathrate hydrates, commonly called gas hydrates, appear at temperatures close to 273 K and elevated pressures, simply said, it's about ice formation's temperature, $0^{o}$C. [8].

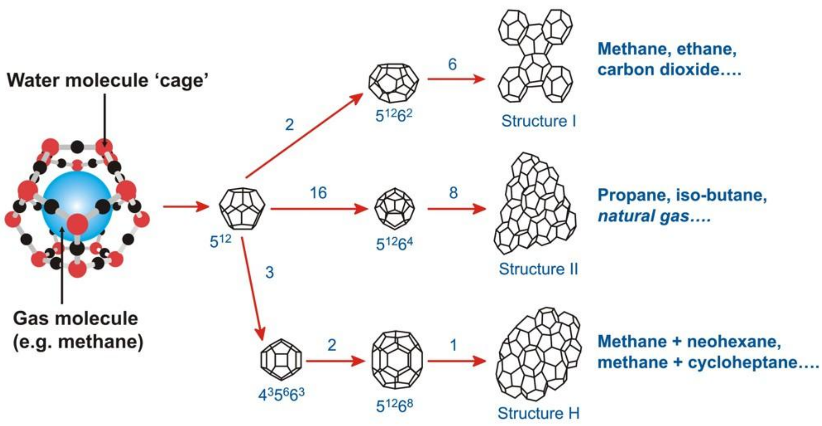



Figure 4: Crystalline Structure of Hydrates

Offshore hydrate-bearing sediments have generally been found in waters deeper than 300 m. Their zone of existence is from the seafloor to a depth of a few hundred meters, depending upon the local thermal gradient [10]. Thereby, 500m depth has been chosen in this project since it is greater than 300m.

Gas hydrates are ice-like solids that form from gas and water under combinations of high pressure and moderately low temperatures.

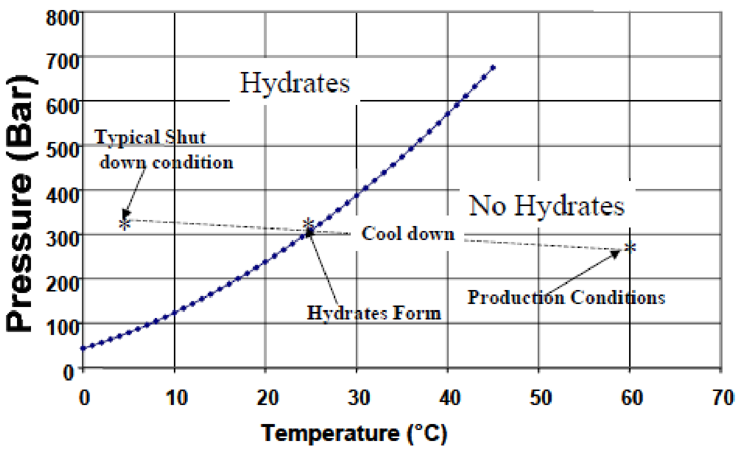



Figure 5: Phase diagram showing the conditions under which hydrates will form [21]

Based on figure above, Alkane hydrates in the form of crystalline methane hydrate can form at temperatures as high as 21 °C (70 °F) at pressures of 300 bars (4,300 psi) [21]. Normally, methane hydrate will be formed in range of 30 °C [1].

### 2.1.2 Methods in preventing formation of hydrates

The risk of forming hydrates is greatest when the pipeline is cold. There are several options to avoid hydrate formation in subsea pipeline. These are chemical injection and thermal insulation. Typically a hydrate inhibitor such as methanol or equivalent is injected to prevent hydrate formation. These chemicals may be injected continuously or during transient events such as start-up or shut down. Hydrate inhibitors are typically injected continuously in subsea pipeline to treat the condensed water. The oil and gas industry are continuously looking for hydrate inhibitors that will allow them to venture out into deeper waters and operate their processes without the risk of hydrates interfering with daily operations. There are two classes of hydrate inhibitors; thermodynamic inhibitors and low-dosage inhibitors [8]. Thermodynamic inhibitors include methanol, mono-ethylene glycol, ethanol and others. A high-concentration in the range of 5 to 50% of these chemicals in the water phase is required to avoid hydrate formation [8]. New and emerging technology includes low dosage inhibitors such as kinetic inhibitors or anti-agglomerants. These chemicals either avoid hydrate crystal nucleation or prevent the agglomeration of crystals so that complete blockages do not form [18]. Thermal insulation also can be used to prevent the heat loss from the subsea pipeline during flowing and shut down events. During an unplanned shut down, insulated subsea pipeline can cool to the seabed temperature within minutes. Operators typically require thermal insulation to achieve 8 to 12 hours of time to react to shut down of flow interruption [22]. This project focuses more on thermal insulation method.

## 2.2 Introduction

In this section contain more detail about modelling subsea pipeline module based on data provided, parameters and also software used in this thesis.

### 2.2.1 Important Aspects in Modelling Subsea Pipeline.

Gassco LTD Company is very active in modelling subsea pipeline. In this project, a lot of parameters need to be considered such as length and diameter of pipeline, flow rate and pipe material. All of these parameters have been taken directly from this company. The pipelines in Gassco's network are typically 200 – 560 miles long, and the gas temperature is only measured at the inlet and outlet. Consequently, the calculated gas temperature along the pipeline depends on the accuracy of the assumed ambient temperature and the estimated heat transfer. This project mainly focuses on heat transfer modelling, and how this affects the estimated gas temperature. The importance of a correct total heat transfer coefficient for different conditions has been studied, and the most important parameters associated with this coefficient have been identified.

These are typical characteristics of the Gassco LTD Company operated pipeline:

**SYSTEM DESCRIPTION**

Typical characteristics of the Gassco operated pipelines:

| | |
|---|---|
| Pressure range: | 700 – 3,000 psi |
| Diameter: | 30 – 45 inches |
| Composition: | 80 – 95 % Methane |
| Length: | 200 – 560 miles |
| Flow rate: | 700 – 2,120 MMSCF/d |
| Roughness: | ~$10^{-4}$ inches, due to internal coating |
| Location: | Sea bed (Mostly partially buried) |
| Sea depth: | 150 – 100 ft |
| Metering: | Pressure, temperature, flow and composition at inlet and outlet |
| Pipe materials: | Steel, Asphalt Enamel and Concrete |
| Total export 2007: | $3 \cdot 10^{6}$ MMSCF |

Figure 6: Characteristic of Gassco operated pipeline [22]

Figure 7: Typical pipeline cross section consisting of a steel pipe coated with asphalt enamel and concrete [22]

These are the thickness and conductivity values for each of wall layer in subsea pipeline used by Gassco:

Table 1: Definition of wall layers for standard pipeline [22].

| Wall layer | Thickness [inches] | Conductivity [Btu/h·ft·°F] |
|---|---|---|
| Steel | 1.07 | 28.9 |
| Corrosion coating (AE) | 0.24 | 0.4 |
| Concrete | 3.94 | 1.16 |

In this project, the inner diameter of the pipeline is set to 40" (1.016m). To determine the outer heat film coefficient, a set of parameters for the surrounding medium has to be defined. This is the properties of surrounding medium:

Table 2: Properties of surrounding medium [22]

| Parameter | Value | Unit |
|---|---|---|
| Sea water | | |
| Density, $\rho_s$ | 63.05 | lb/ft³ |
| Conductivity, $k_s$ | 0.33 | Btu/h·ft·°F |
| Viscosity, $\mu_s$ | 1.05 | cP |
| Sp. heat capacity, $cp_s$ | 1.00 | Btu/lb·°F |
| Sea current, $u_s$ | 0.33 | ft/s |
| Re | $\sim 10^5$ | - |
| Soil | | |
| Ground conductivity, $k_{soil}$ | 1.16 | Btu/h·ft·°F |

According to the above table, sea water and soil become mediums for fully exposed and buried pipeline respectively. This project considered sea water as a medium since the pipeline not buried in soil.

### 2.2.2 Computational Fluid Dynamics Simulation.

CFD stands for Computational Fluid Dynamics. It means predicting physical fluid flows and heat transfer using computational methods. Computers are used to perform the calculations required to simulate the interaction of liquids and gases with surfaces defined by boundary conditions . CFD is used in an extremely wide range of industries. Any industrial process that involves fluid flow and/or heat transfer can benefit from CFD analysis [24]. In this project, the CFD simulation shall use the ANSYS FLUENT software that contains broad physical modelling capabilities needed to model flow, turbulence, heat transfer, and reactions for industrial applications. Case and data files can be read into ANSYS CFD-Post for further analysis with advanced post-processing tools and side-by-side comparison of different cases [25]. Below is an example interface of ANSYS FLUENT Software:

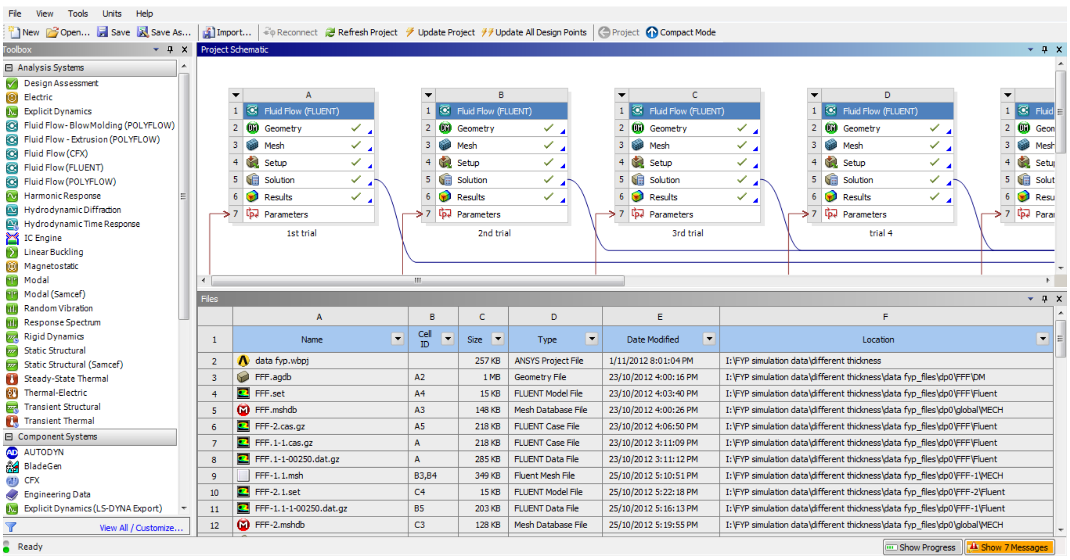



Figure 8: Interface of ANSYS FLUENT Software

## 2.3 Subsea Pipeline Insulation Materials

These are characteristics for a thermal insulation material for subsea pipeline:

1. Low thermal conductivity to minimize the thickness of insulation required. Properties necessary for assessing the performance of an insulation material
2. Density
3. Mechanical properties
4. Processing characteristics.

Thermal conductivity (k), heat capacity (Cp), and density (ρ) are properties that are required to determine the overall heat transfer properties of an insulation system.

Stability under hydrostatic pressure and tensile strength, and tensile elongation, are important mechanical properties to consider in evaluating an insulation material. Tensile strength and elongation are important for resistance to handling damage. All of these are related to mechanical properties of subsea pipeline. This project is focusing more on thermal and physical properties rather than mechanical properties since it is a related to the fundamental of heat transfer and thermodynamics. Below are examples properties of insulation materials used on FMC equipment that being referred while conducting this project:

Table 3: Properties of the insulation materials used in subsea pipeline [22].

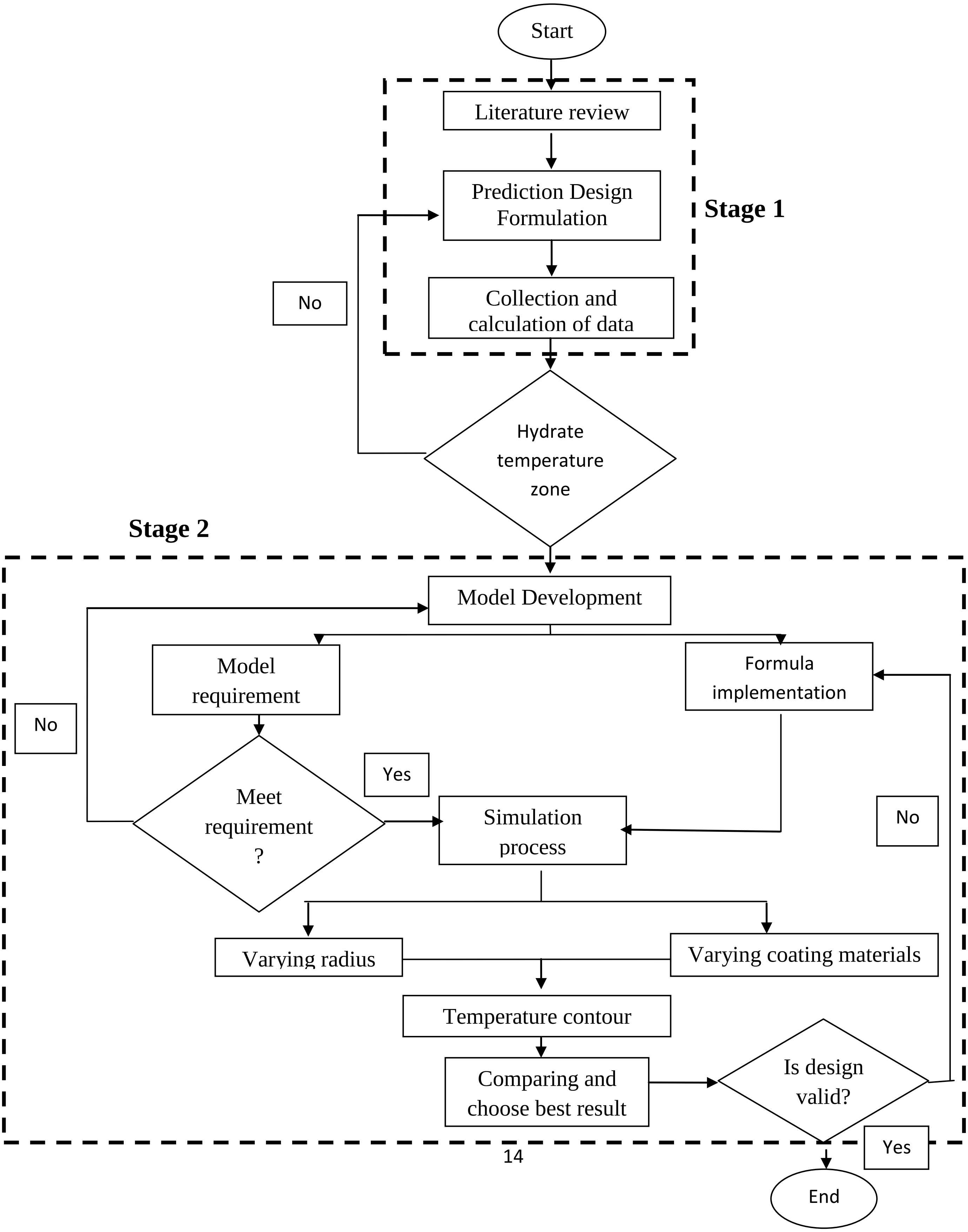
| Material | Thermophysical Properties | Thermal Conductivity after aging* | Tensile Elongation |
|---|---|---|---|
| TyMar 10K | k = 0.13 W/mK (0.07 BTU/hr-ft °F)<br>ρ=593 kg/cu.m (37 lbs/cu. Ft.)<br>$C_p$=1073 J/kg K (0.26 BTU/lb °F) | 0.27 W/m K (0.15 BTU/hr-ft °F) | <1 percent |
| Eccotherm MB 44HT | k = 0.09 W/m K (0.05 BTU/hr-ft-°F)<br>ρ = 705 kg/ cu.m (44 lbs/cu. Ft.)<br>$C_p$ = 1687 J/kg K (0.4 BTU/lb °F) | 0.27 W/m K (0.15 BTU/hr-ft °F) | <1 percent |
| Polibrid 705-E31 | k = 0.13 W/m K (0.07 BTU/hr-ft °F)<br>ρ = 993 kg/ cu. m (62 lbs/cu. Ft.)<br>$C_p$ = 1265 J/kg K (0.3 BTU/lb °F) | 0.29 W/m K (0.16 BTU/hr-ft °F) | 40 to 50 percent |
| NovoTherm | k = 0.22 W/m K (0.12 BTU/hr-ft °F)<br>ρ = 993 kg/cu. m (62 lbs/cu. Ft.)<br>$C_p$ = 2190 J/kg K (0.52 BTU/lb °F) | 0.24 W/m K (0.13 BTU/hr-ft °F) | 20 to 25 percent |
| VikoTherm | k = 0.22 W/m K (0.12 BTU/hr-ft °F)<br>ρ = (62 lbs/cu. Ft.)(insulating layer)<br>$C_p$ = (0.4 BTU/lb °F) (insulating layer) | k = 0.24 W/m K (0.13 BTU/hr-ft °F) | No data |

Data above are the basic insulation materials that is been implemented by FMC Company nowadays. Apart from above data, 3 materials have been randomly chosen throughout this project which are TyMar, Polibrid and NovoTherm to establish the comparison of heat transfer for each of the material coating for subsea pipeline

# CHAPTER 3

## 3.1 Research Methodology Flowchart

The overall project methodology is shown below:



## 3.2 Project Flow

## 3.2.1 Prediction for Design Formulation

Prediction for design formulation has been done by searching related heat transfer and thermodynamics formulae that can be used in this project. The important key elements or parameter in this section is finding or calculate temperature outlet of the pipeline, $T_2$ by using the pipeline data or parameter from Gassco LTD Company data such as length, volume and mass flow rate, diameter and area of pipeline, overall heat transfer value, and inlet temperature, $T_1$ of the subsea pipeline. The value of temperature outlet of the pipeline, $T_2$ must be higher than 30 $^{o}$C to prevent creating suitable environment for the formation of hydrates to be form.

## 3.2.2 Data Collection and Calculation

### Determining Hydrate Temperature Zone.

Some research need to be done in finding hydrate temperature zone and it is already mentioned in literature review, in which the best surrounding temperature for hydrates to be formed is 30 $^{o}$C in range of depth between 300 to 500 m. This means that the outlet temperature needs to be higher than 30 $^{o}$C since hydrates will be formed in that surrounding.

### Parameter Calculation

In this section, author need to familiarize with the formulation and the parameter needed in this project related to the heat transfer and flow assurance. All of the equations stated in this section are referred to reference [1]. Other than that, author also need to know better about conduction and convection of the heat transfer flow since all of these terms are known to be used a lot in this project. First step for this project is defining the $T_1$, inlet temperature of the pipe flow. $T_s$ and $T_2$ which are temperature surface and temperature outlet can be known by using temperature of the fluid bath and temperature outlet that suitable for hindering the hydrate formation. Then, calculate the conduction formulation by using the following Fourier series formula:

$$\frac{1}{r}\frac{\partial}{\partial r}\left(kr\frac{\partial T}{\partial r}\right)+\frac{1}{r^2}\frac{\partial}{\partial \phi}\left(k\frac{\partial T}{\partial \phi}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)+\dot{q}=\rho c_p\frac{\partial T}{\partial t}$$

..... Equation 1

For a steady-state heat transfer, the total heat flow per unit length of cylinder is calculated by following equation:

$$q_r = -2\pi k \frac{T_2 - T_1}{\ln(r_2 / r_1)}$$

…………………………………….. Equation 2

Where, $r_1$, $r_2$ : inner and outer radii of the cylinder medium, ft or m

T1, T2 : temperatures at the corresponding point of $r_1$, $r_2$, $^oC$ or $^oF$

$q_r$ : heat flow rate per unit length of the cylinder, W/m

Since there is a flow inside and outside of the pipeline, author need to consider the convection flow in the design consideration part, internal convection and external convection. Convection depends on the fluid properties, the flow velocity, and the pipe diameter. Before having the total heat flow for convection, author needs to determine the type of flow, laminar or turbulent by referring to the Renault Number by using parameter of the design. For internal convection, these parameters need to be considered:

**Internal convection**

**Turbulent (Re> 10000, Pr from 0.7 to 160)**

$Nu = 0.0255\ Re^{0.8}\ Pr^{0.4}$ ........................................................................ Equation 3

$Re = D_i\ V_f\ \rho_f\ /\ \mu_f$ ........................................................................ Equation 4

$Pr = C_f\ \mu_f\ /\ k_f$ ........................................................................ Equation 5

Where:

n : 0.4 if the fluid s being heated and 0.3 if the fluid is being cooled
hi : internal convection coefficient
Di : pipeline inside diameter
Kf : thermal conductivity of the following liquid
Vf : velocity of the fluid
$\mu_f$ : Viscousity of the fluid
Cf : Specific heat capacity of the fluid
ρf : Density of the fluid

**Laminar (Re< 2100)**

$$Nu_i = 3.66 + \frac{0.0668\left(\frac{D_i}{L_o}\right)Re_i\,Pr_i}{1+0.4\left[\left(\frac{D_i}{L_o}\right)Re_i\,Pr_i\right]^{2/3}}$$

................................................ Equation 5

**For external convection**, these parameters need to be considered:

For pipeline fully exposed to water, the convective heat transfer is given by Nusselt Number equation. The Nusselt number also can be used to calculate the outside heat transfer coefficient.

$$Nu = 0.26 \cdot Re^{0.6} \cdot Pr^{0.3}$$

................................................................. Equation 6

Where

| | |
|---|---|
| Nu | Nusselt number |
| Re | Reynolds number |
| Pr | Prandtl number |

$$h_o = \frac{Nu \cdot k_{sea}}{d_o}$$

........................................................................................... Equation 7

Where

| | |
|---|---|
| Ksea | Thermal conductivity of sea water |
| Do | outer diameter |

Below is the overview layer design of the pipeline,

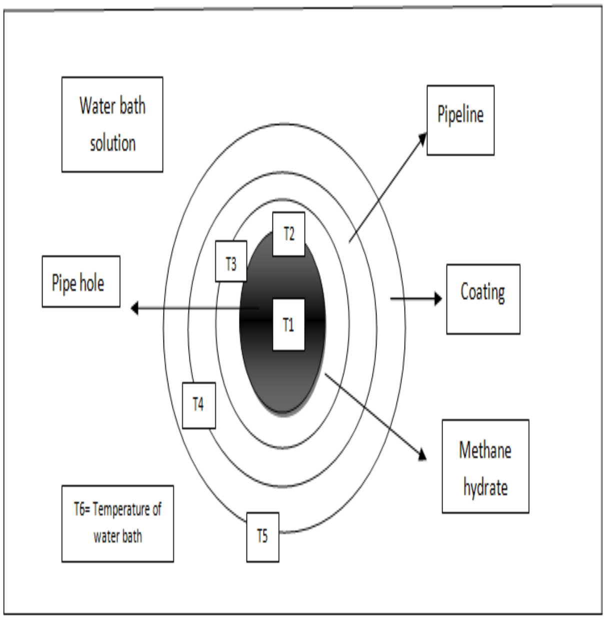



Figure 9: Overview layer design of pipeline.

These multiple resistance may be combined into single heat transfer coefficient as follow:

$$U = \left[ \frac{r_o}{r_i}\frac{1}{h_i} + \sum_{n=2}^{N}\left( \frac{r_o}{k_n}\ln\left( \frac{r_n}{r_{n-1}} \right) \right) + \frac{1}{h_o} \right]^{-1}$$ ......................................... Equation 8

Where

| | |
|---|---|
| U | Overall heat transfer coefficient |
| ri | inner radius of pipe |
| ro | outer radius of pipe |
| rn | Outer radius of wall layer n |
| Kn | Conductivity of wall layer n |
| hi | inside heat transfer coefficient |
| ho | Outside heat transfer coefficient |

The gas temperature profile can be estimated by using this eqution:

$$T_2 = \frac{T_1 - T_{amb} + j/a}{e^{aL}} + T_{amb} - j/a$$ .................................................... Equation 9

Where

| | |
|---|---|
| Tamb | Ambient temperature |
| J | Joule-Thomson coefficient per length |
| L | Length |
| a | =π.d.U/ṁ.Cp |
| D | Diameter |
| U | Total heat transfer coefficient |

The specific heat capacity, pressure drop per length and Joule-Thomson coefficient, is assumed constant but in reality, these values will be varying as a function of pressure and temperature which gain change as a function of distance.

Table 5: Assumed values for some parameter [22]

| Parameter | Typical value | Unit |
|---|---|---|
| $j$ , low flow | 3.0 E-06 | °F/ft |
| $j$ , high flow | 1.8 E-05 | °F/ft |
| $C_p$ | 0.76 | Btu/lb·°F |

### 3.2.3 Model Development.

#### Model Requirement

In developing a pipeline model, research need to be done by implementing parameter of pipeline that is already established in the industry. Gassco Company is one of the well-known pipeline companies. All of the pipeline parameter that needed in this project is being taken from this company data. Data can be seen in literature review.

#### Formula Implementation

All of the formulas that already been mentioned in data calculation part being implemented in calculating the final result of this project, heat transfer and outlet temperature in the pipeline. All data calculation will be stored in Microsoft Excel 2007. Some graph will be plotted in this process to show the result of this project.

### 3.2.4 Design Validation

#### Model Simulation

Simulation process will be done by using ANSYS FLUENT Software. This further explanation about this software already mentioned in literature review. Some of the research need to be done in finding how the simulation process can be done and all of the parameters that have already been calculated will be the input data to find the final result of this project.

## Model Comparison

Graph will be plot in this part and further explanations will be discussed in chapter 4.

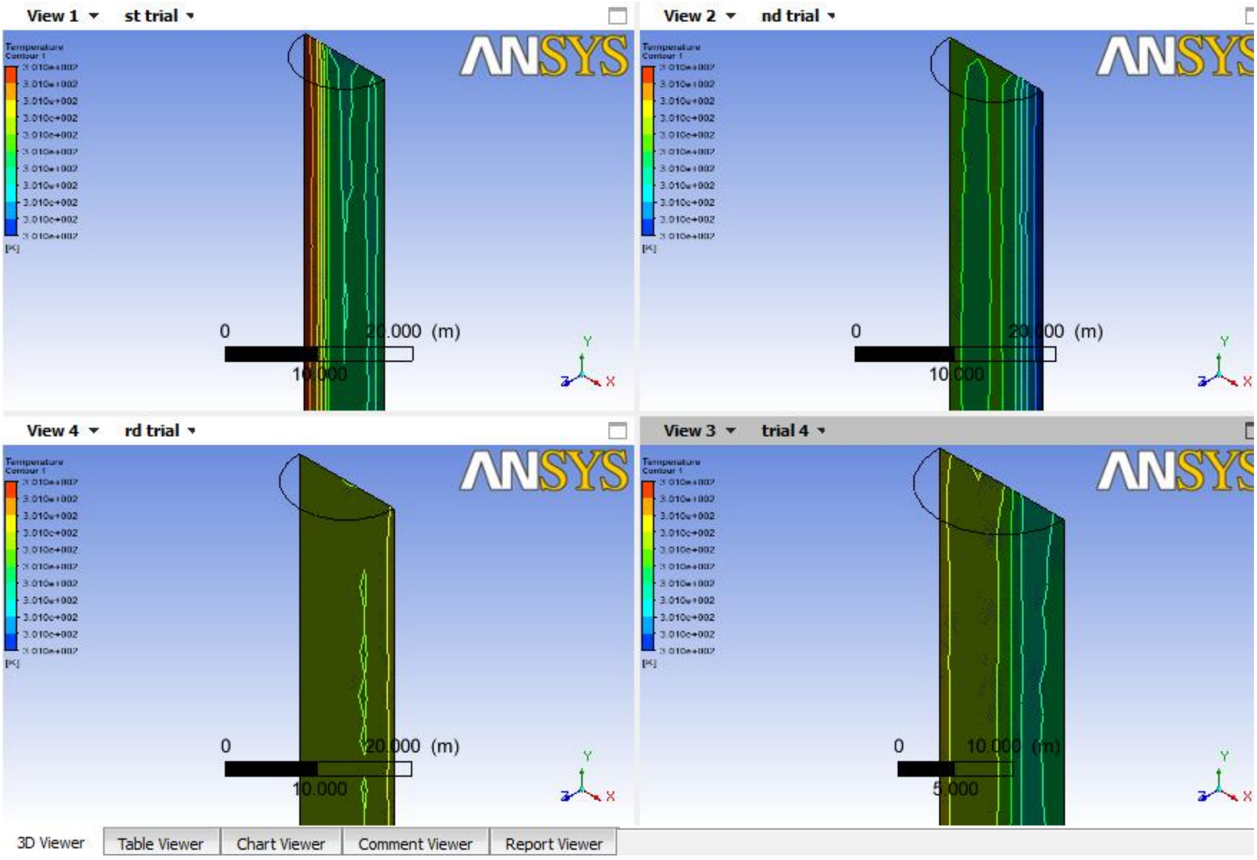



Figure 10: Comparison of temperature contour

# CHAPTER 4

## Result and discussion

### 4.1 Introduction

In this section contain result of the heat transfer and $T_{2,}$ outlet temperature of the subsea pipeline by varying two important parameters, which are radius and material coating of the pipeline based on low flow and high flow of sea water condition. Other than that, this section also have graphs illustrated as a prove of what has been calculated before hence determined the best choice for radius and material coating in preventing creating a suitable surrounding or environment for the formation of hydrates.

### 4.2 Data and result

On table tabulated below is a values of normal volume flow rate in subsea pipeline that been extracted from Gassco LTD Company through that data, velocity can be achieved by using some calculation and to be used in calculating Reynolds Number hence knowing type of flow in the subsea pipeline. In this thesis, type of flow that already been achieved is turbulent flow. Below is a table of calculated parameters that can be achieved by knowing the values of volume flow rate inside of the subsea pipeline.

Table 6: Calculated parameters of subsea pipeline.

| volume flow rate (MMSCF/day) | volume flow rate (m3/s) | Area (m2) | velocity inside of the pipe (m/s) |
|---|---|---|---|
| 700 | 229.45 | 0.8108 | 282.99 |
| 800 | 262.23 | 0.8108 | 323.41 |
| 900 | 295.01 | 0.8108 | 363.84 |
| 1000 | 327.79 | 0.8108 | 404.26 |
| 1100 | 360.57 | 0.8108 | 444.69 |
| 1200 | 393.35 | 0.8108 | 485.12 |
| 1300 | 426.13 | 0.8108 | 525.54 |
| 1400 | 458.91 | 0.8108 | 565.97 |
| 1500 | 491.69 | 0.8108 | 606.40 |
| 1600 | 524.47 | 0.8108 | 646.82 |
| 1700 | 557.25 | 0.8108 | 687.25 |
| 1800 | 590.03 | 0.8108 | 727.68 |
| 1900 | 622.81 | 0.8108 | 768.10 |
| 2000 | 655.59 | 0.8108 | 808.53 |
| 2100 | 688.36 | 0.8108 | 848.96 |

In this project, the range for volume flow rate that being used is from 700 to 2100 MMSCF, which is a normal oil production per day. In fact, the velocity inside of the pipeline can be calculated by knowing the value of the volume flow rate. Velocity of the inside flow is a very important parameter in getting inner heat coefficient, $h_i$ based on Reynolds, Prandtl and Nusselt number. Each of the coating material have different amount of thermal conductivity which are concrete (2.007 W/m.K), asphalt (0.692 W/m.K) and steel (50 W/m.K) respectively. The original thickness of each of the materials are 4.0", 0.3" and 2.0" for concrete, asphalt enamel and steel respectively. Increment of 1 inch is being applied for each type of coating for having a clear result of heat transfer values. After getting all of the data needed, total energy coefficient and amount of heat transfer can be calculated. Figure 10 shows that the amount of heat transfer based on each of the ambient temperature.

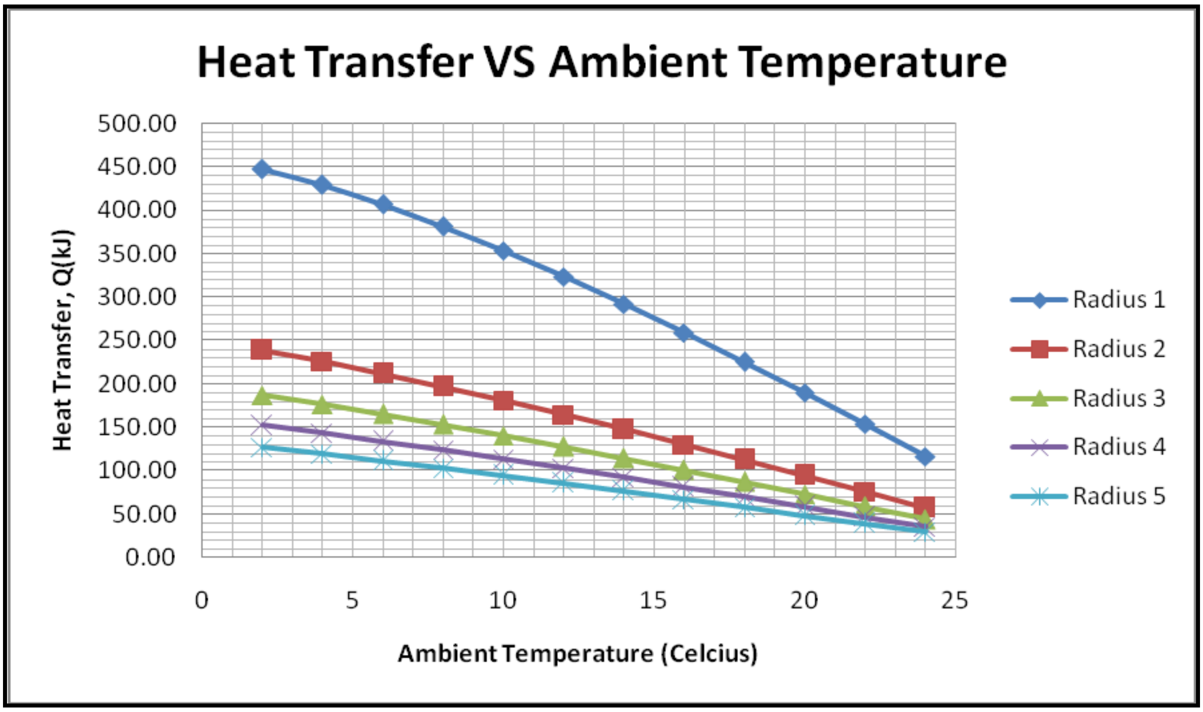


Figure 10: Graph of heat transfer

In the result above, its clearly stated that the amount of heat transfer value is inversely proportional to the ambient temperature of sea water. As radius increases, the amount of heat transfer deacrease as well as overall heat transfer coefficient value. This can be proved by the formulation below:

$$\dot{Q} = U \cdot A \cdot \left(T_{amb} - T_{gas}\right)$$

The amount of overall heat transfer coehfficient decrease as the thickness of the pipeline increases because of the "resistance" value for each of the pipeline coatings which are steel, asphalt and concrete consequently. In this situation, the "resistance" value can be calculated using series configuration since the coating material being placed next to each other. In this situation, the thickness of the pipeline can be ralated with the "resistance" value of the pipeline. The thicker the coating, the higher the "resistance" value that obstruct the heat transfer being transferred to the surrouding.

The outlet temperature, $T_2$ is an important finding in this project. The value of $T_2$ will be compared with the formation temperature of hydrates which is 30 $^oC$. So, in this project, 30 $^oC$ will be the temperature's datum for the surrounding condition of hydrates. The outlet temperature needs to be higher than the datum temperature to achieve the objective of this project. In this project, the flow type of sea water also being considered since in Malaysia's sea water region, some are having high and low flow.

### 4.2.1 Result for different radius of subsea pipeline

### Low flow (for different radius)

Below are the results for both low and high flow for different thickness of coating materials based on the ambient temperature of sea water.

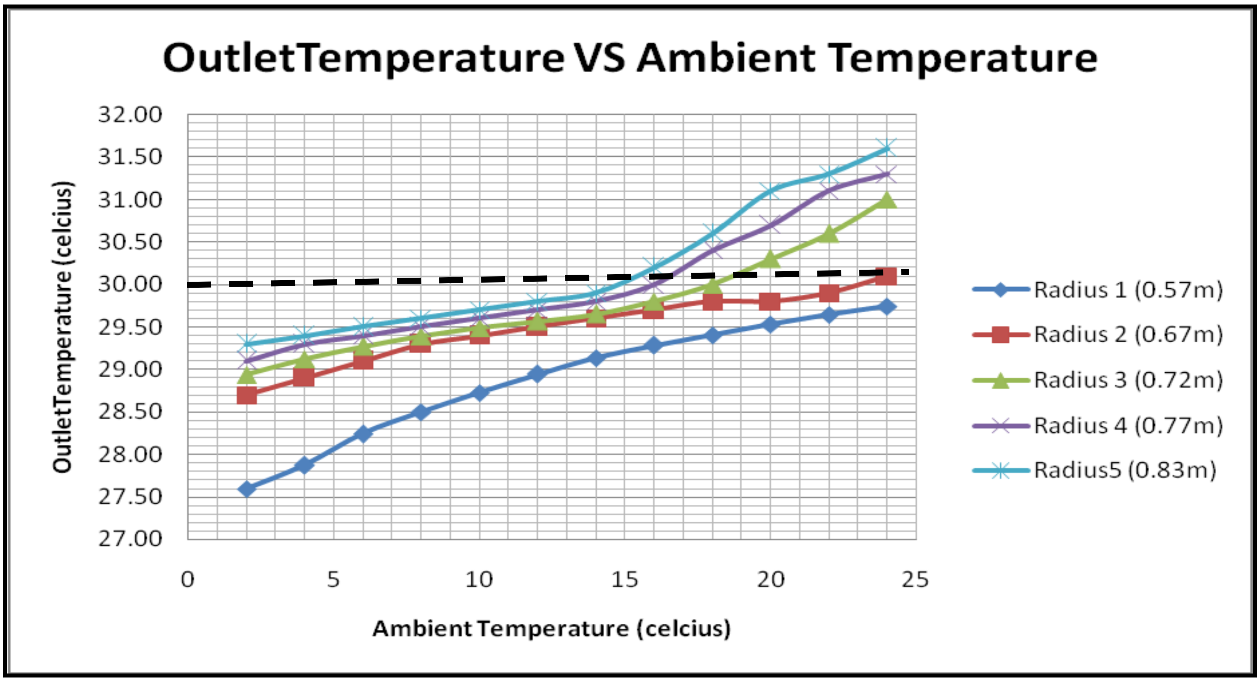



Figure 11: Graph for different radius in low flow of sea water

As shown by the result above, radius 1 (0.57m) and radius 2 (0.67m) having an outlet temperatures below 30 $^{o}$C based on ambient temperature of sea water. This means that the pipeline with the radius 1 and 2 having a high possibility in creating a condition or surrounding for hydrates to be formed. For the others radius stated above, radius 3 (0.72m), radius 4 (0.77m) and radius 5 (0.83m) can be the best option of radius that can be applied on the subsea pipeline since they having a point where exceed formation temperature of hydrates which is 30 $^{o}$C. As mentioned before, this project mainly focuses in Malaysia's sea water region. Thus, the ambient temperature might be having a range from 15 $^{o}$C to 24 $^{o}$C. As stated above, condition number 3, which is radius 3 having a 3 points exceeding 30 $^{o}$C when the ambient temperature are 20, 22 and 24 $^{o}$C. This shows that the option number 3 is not the best radius that should be applied even though it is still in the range, but they only can be applied for ambient temperature within range of 20 to 24 $^{o}$C only. Result for option 4 and 5 are very close with each other but they havinhg a different range which are 14 to 24 $^{o}$C and 16 to 24 $^{o}$C respectively. This means that radius option number 5 is the best radius that can be applied for the subsea pipeline in preventing the formation of hydrates.

## High Flow (for different radius)

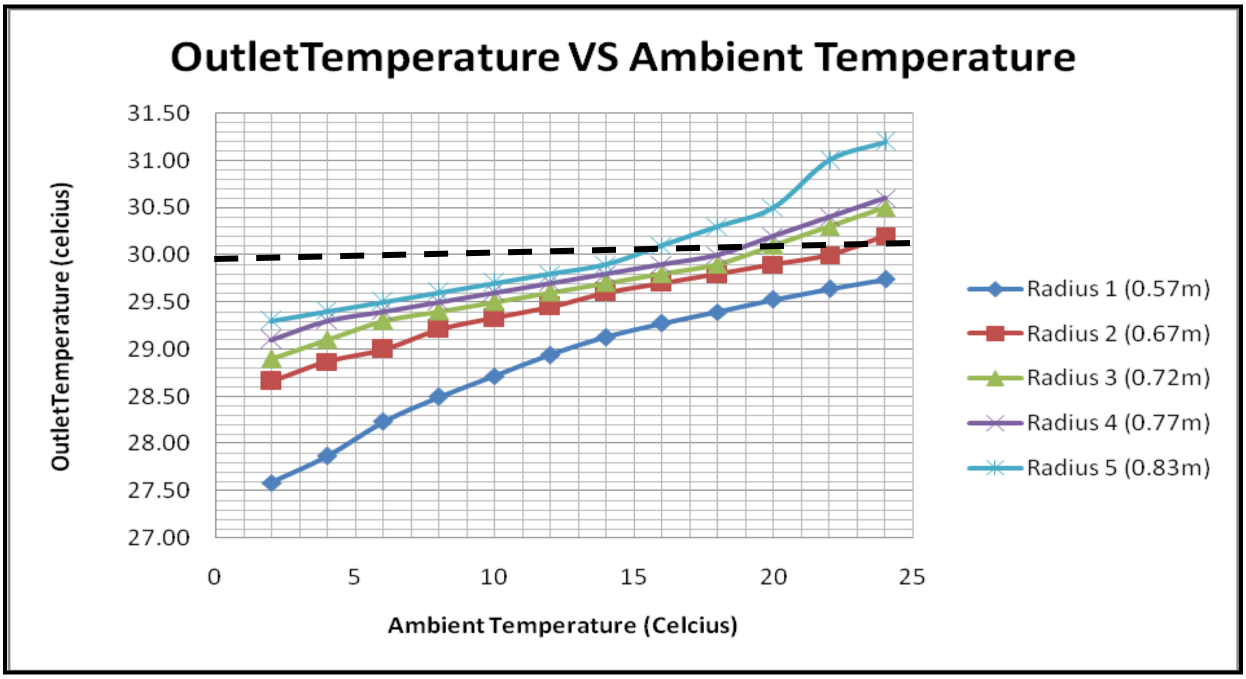



Figure 12: Graph for different radius in high flow of sea water

Basically, the result for high flow is much more similar with low flow but the range has been reduced as can see in the result above. Radius option 5 is still the best radius that can be applied for subsea pipeline since there having a range within 15 to 24 $^{o}$C, same as Malaysia sea water temperature. But, they are having a slight difference with result for radius option 5 in low flow. The result clearly shows that they only have 4 points that exceed datum line which are from 18 toh 24 $^{o}$C of ambient temperature. This shows that radius option 5 is more effective in hindering the formation of hydrate in subsea pipeline in low flow rather than high flow.

### 4.2.2 Result for different coating materials of subsea pipeline

Below are the results for both low and high flow for different coating materials based on the ambient temperature of sea water.

**Low Flow (for different coating material)**

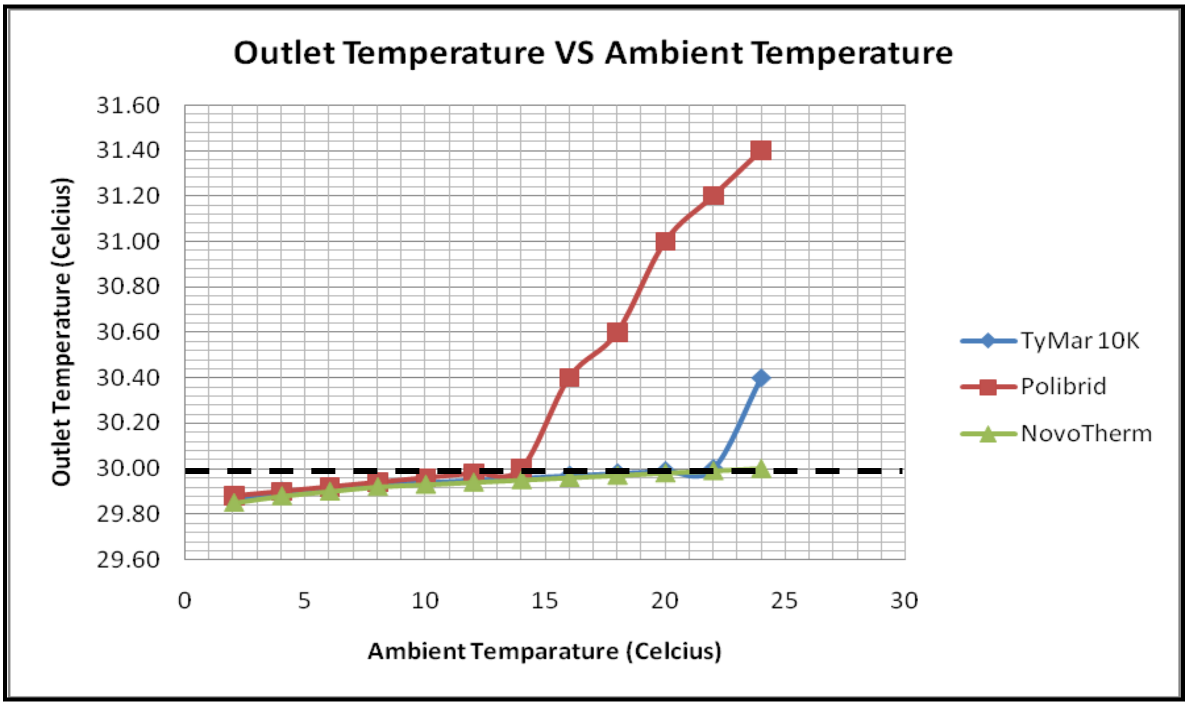



Figure 13: Graph for different coating materials in low flow of sea water

This graph shows that the relationship outlet temperature and ambient temperature for different type of coating materials. This can be explain that Polibrid is the best material that can be choose to be implemented as a pipeline coating material to replace common coating which are steel and asphalt. The graph clearly shows that only Polibrid material having a range of ambient temperature from 15 to 24 $^{o}$C which is higher than 30 $^{o}$C of outlet temperature. When using NovoTherm and TyMar 10K, the heat transfer that happened through these coatings might have higher possibility in creating a condition or surrounding for hydrates to be formed. The obhjective of this project can be achieved by using Polibrid as a coating material of pipeline.

## High Flow (for different coating material)

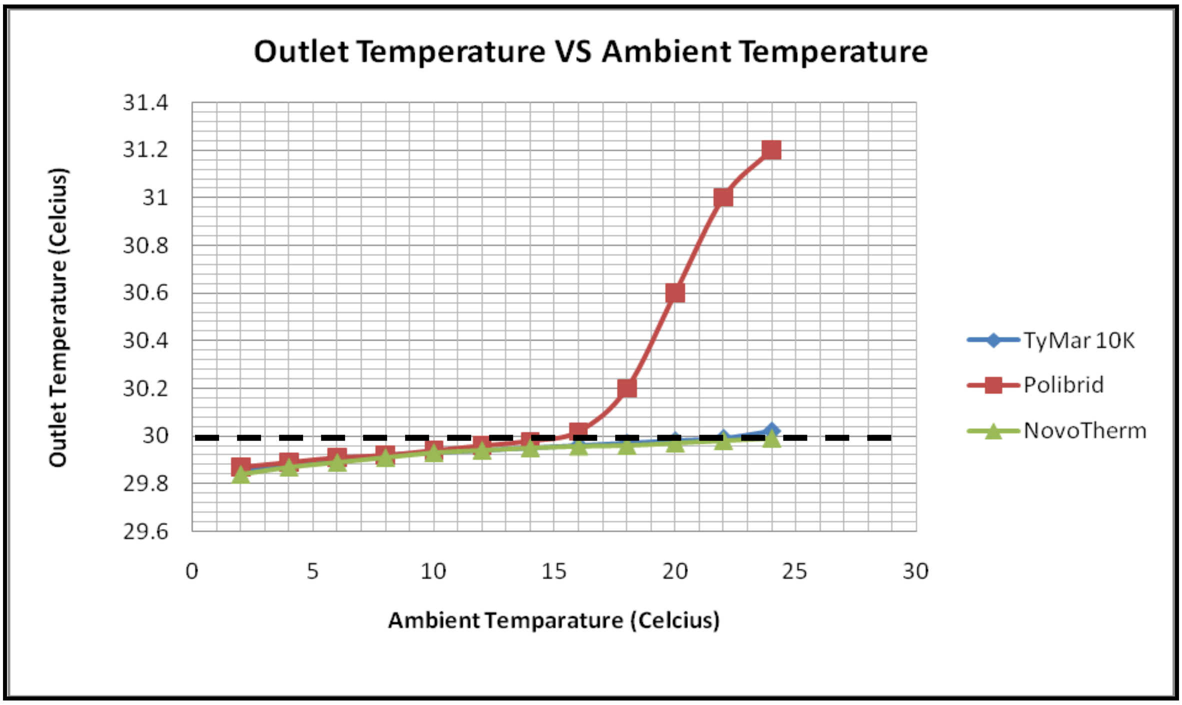



Figure 14: Graph for different coating materials in high flow of sea water

As mentioned before, the result for high flow is much more similar with low flow hbut the range has been reduced as clearly shown in the result above. Polibrid is still the best material of coating that can be applied for subsea pipeline since it having a range of ambient temperature within 15 to 24 $^{o}$C, same as Malaysia sea water temperature. But, they are having a slight difference with result for Polibrid in low flow. The result clearly shows that they only have 4 points that exceed datum line which are from 18 to 24 $^{o}$C of ambient temperature. This can be concluded that implementation of Polibrid as coating material of pipeline is more effective in low flow rather than high flow.

# CHAPTER 5

## 5.1 Conclusion

Based on this thesis, project objectives are successfully achieved. Through this thesis, the gas flow in subsea pipelines were simulated by applying different thickness and coating materials for controlling the heat transfer throughout the pipeline. This has been proved through graphs that have been illustrated in chapter 4. Throughout this project, it can be concluded that the implementation of radius option 5 (0.83m) and Polibrid as a radius and coating material of a pipeline respectively, are the best parameter that can be used since the heat transfer through these parameter hindering from creating a condition or surrounding temperature for hydrates to take place.

Other than that, the heat transfer inside of the pipeline were evaluated based on the gas flow that already been simulated before. The application of controlling the heat transfer by varying the thickness and coating material of pipeline can be modelled by evaluating the temperature flow inside and outside of the pipelines. Hence, the input parameter can be generated through this experiment.

Furthermore, input parameter for the model b using industrial data directly has been generated through simulation using ANSYS FLUENT, Computational Fluid Dynamics Software. This can be proved through some screen shot of temperature contour for different radius and coating materials of subsea pipeline in appendix section.

## 6.2 Recommendation

Recommendations for future works are:

- Using exact thickness of coating materials in ANSYS FLUENT to get better temperature contour.
- Consider a pressure factor in calculation to get better result.

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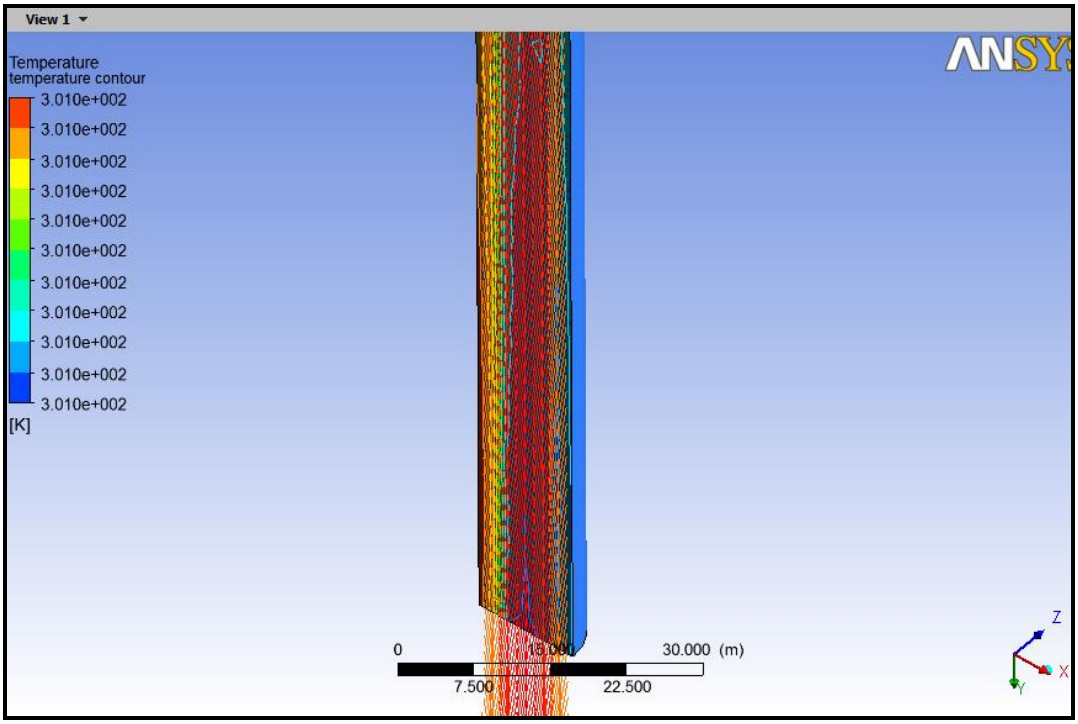
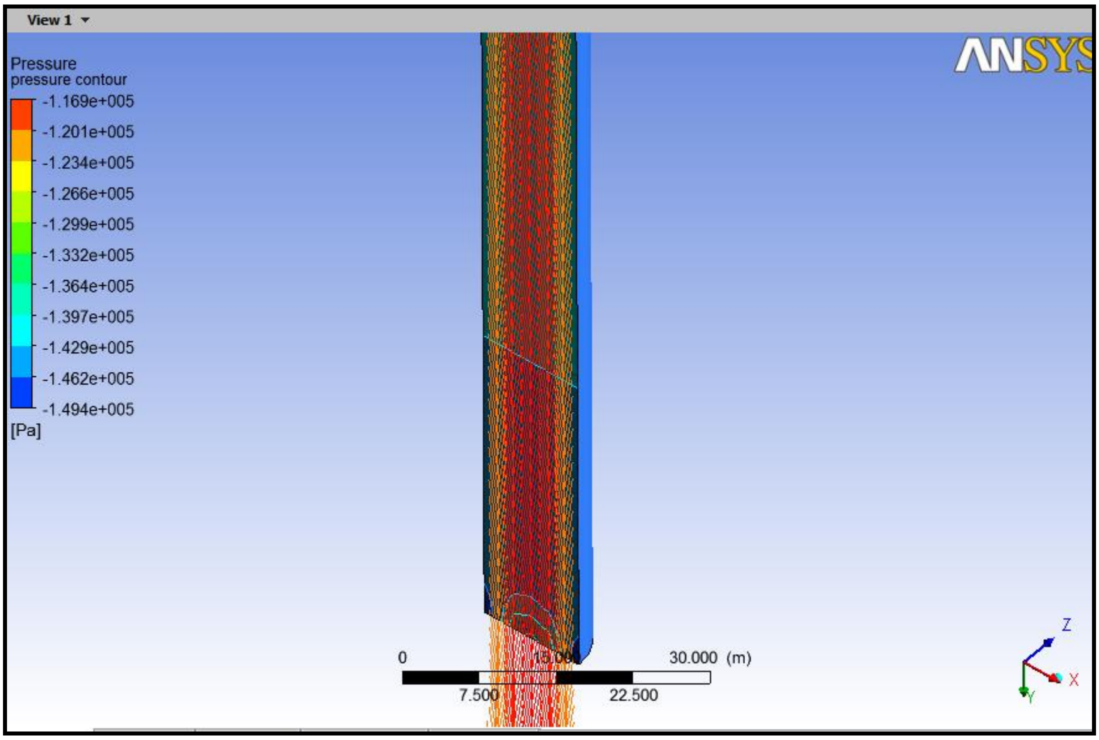
# APPENDIX

Appendix 1: Trial 1 (Radius 0.57m)

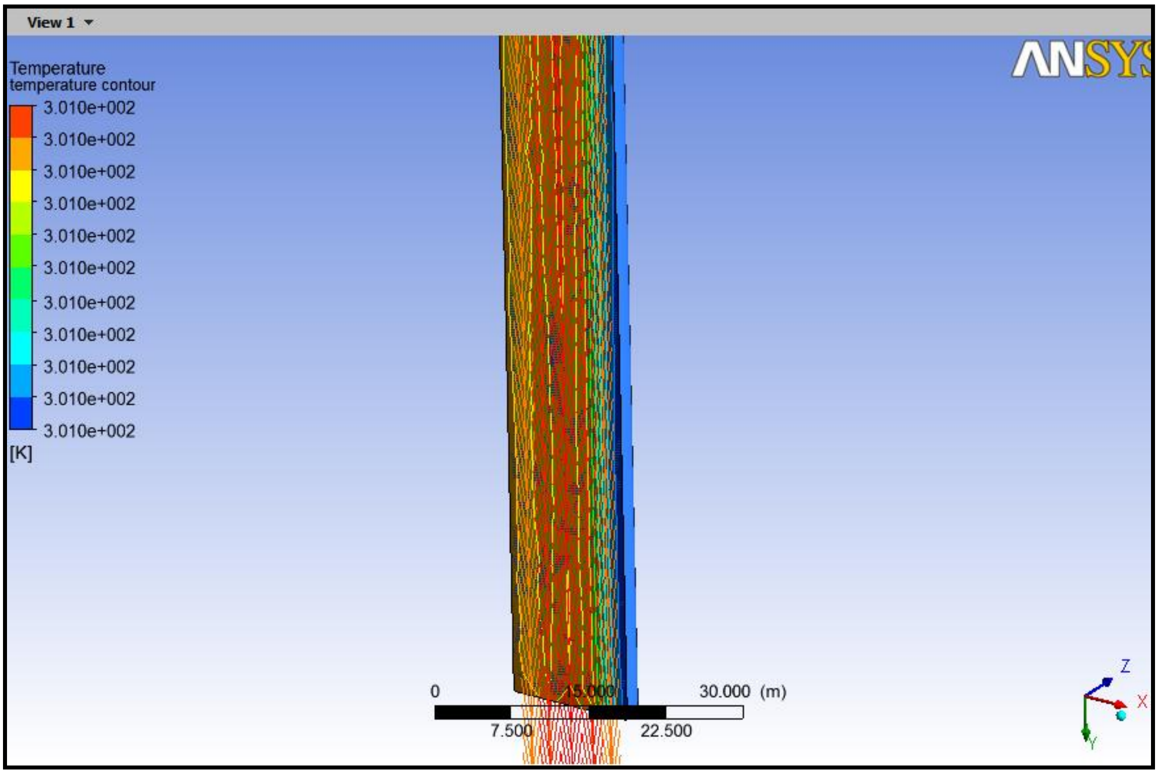



Temperature contour

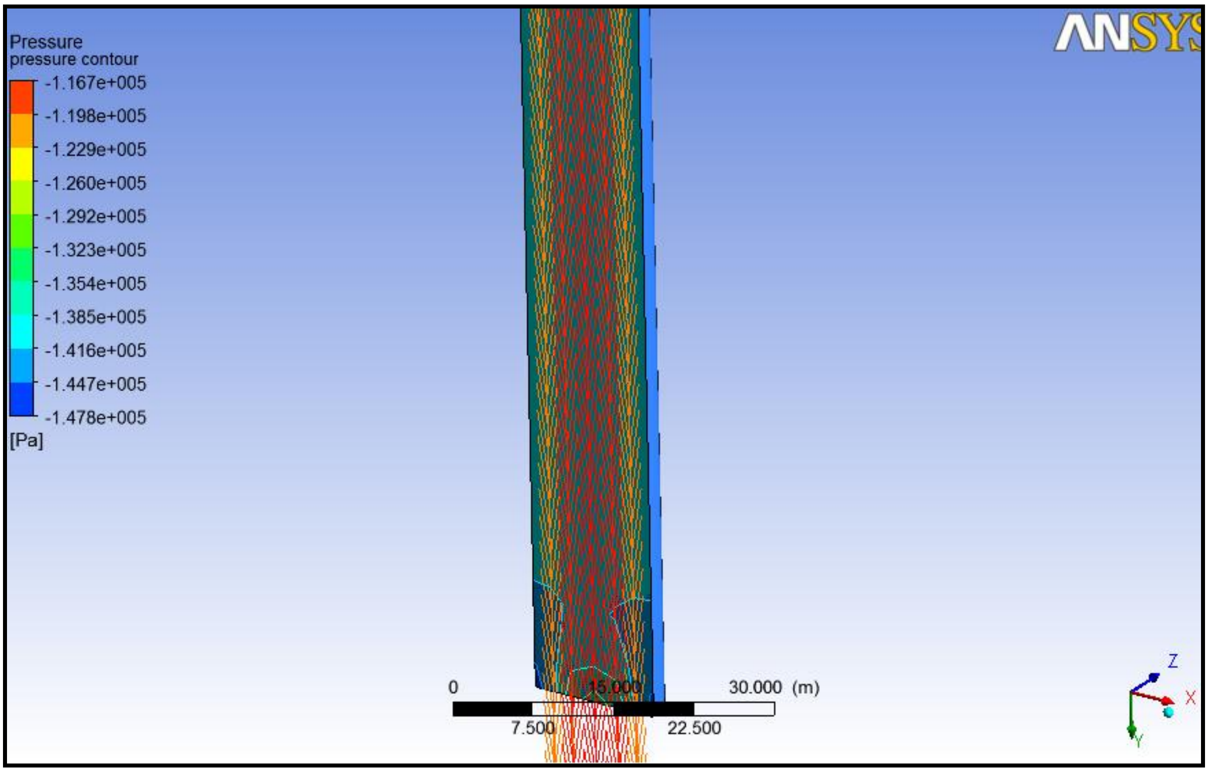



Pressure contour

Appendix 2: Trial 2 (Radius 0.67m)

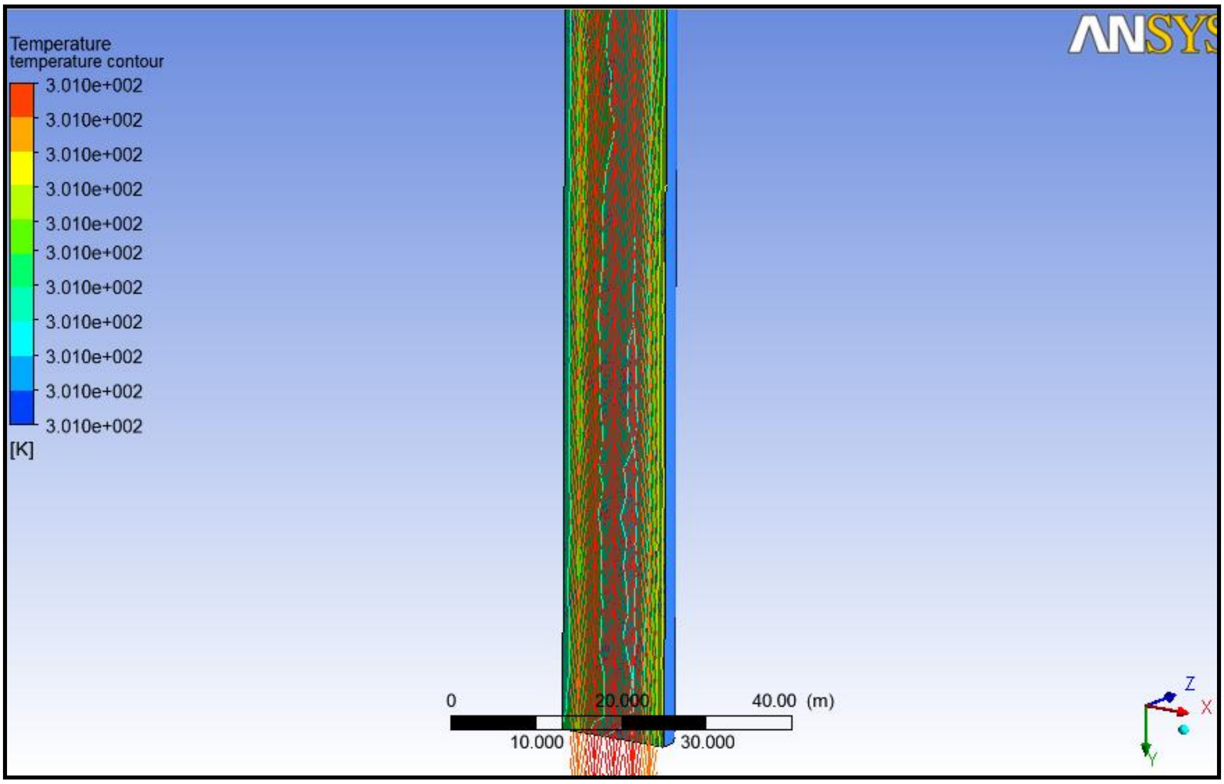



Temperature contour

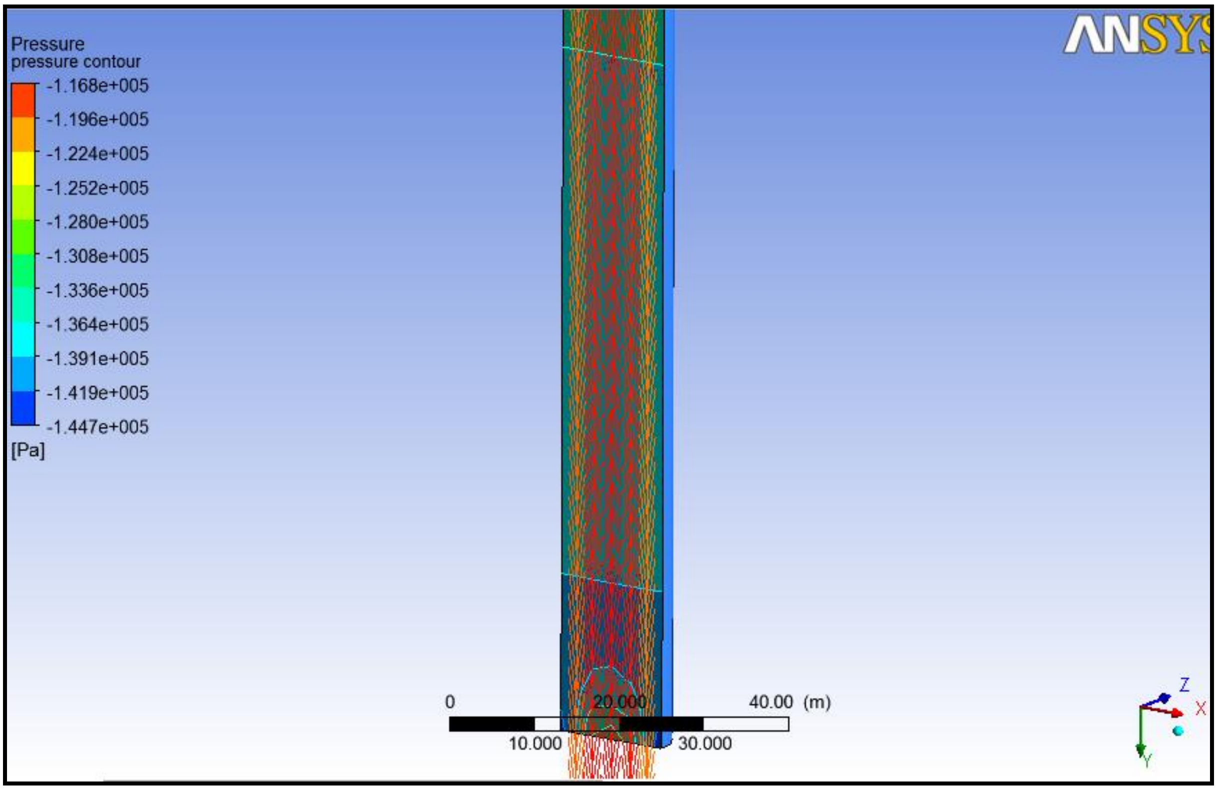



Pressure Contour

Appendix 3: Trial 3 (Radius 0.72m)

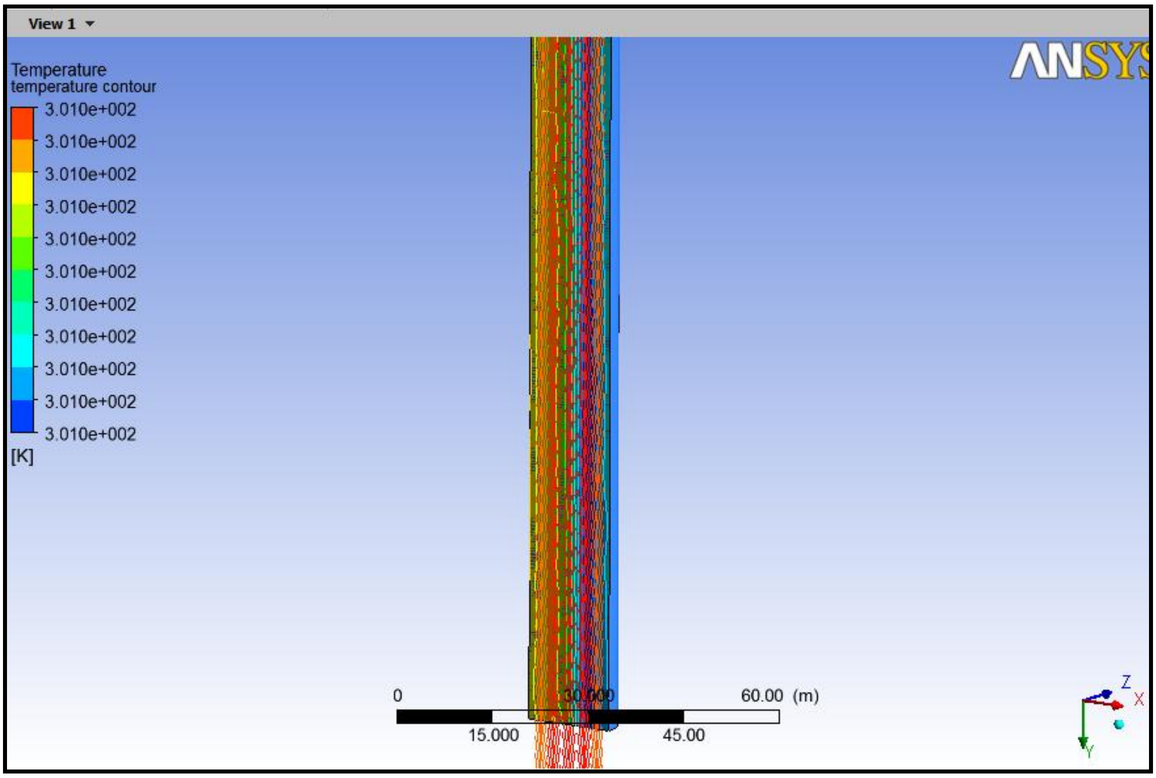



Temperature contour

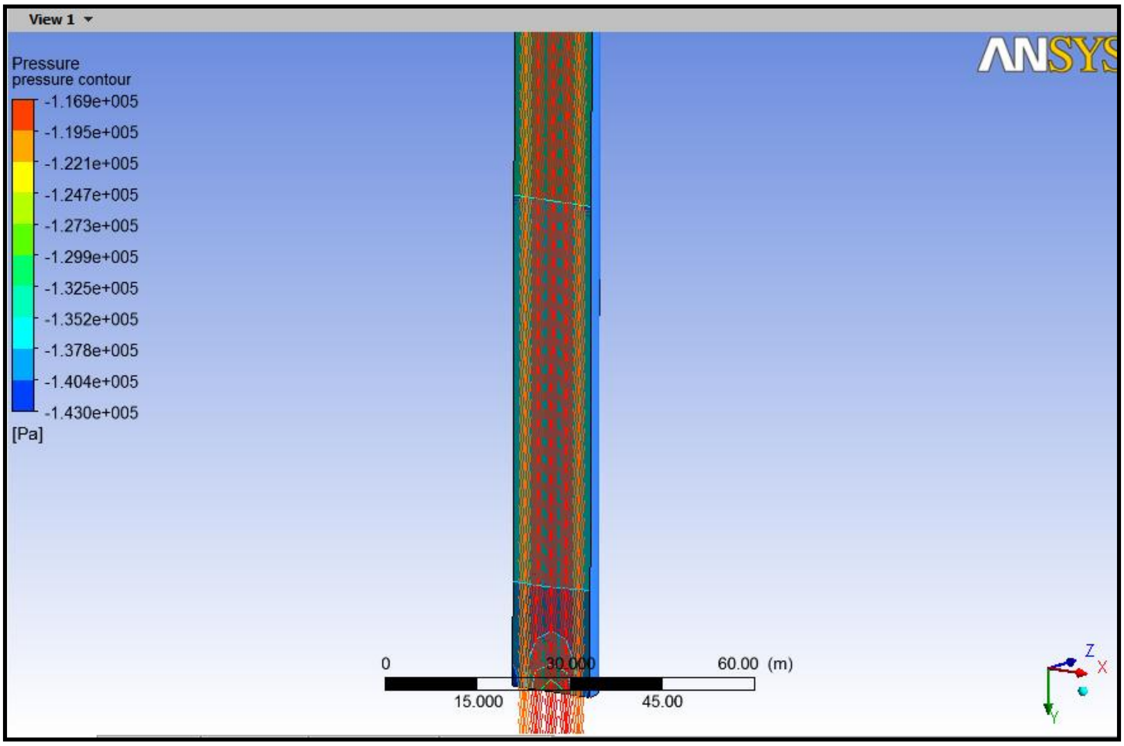



Pressure contour

Appendix 4: Trial 4 (Radius 0.77m)

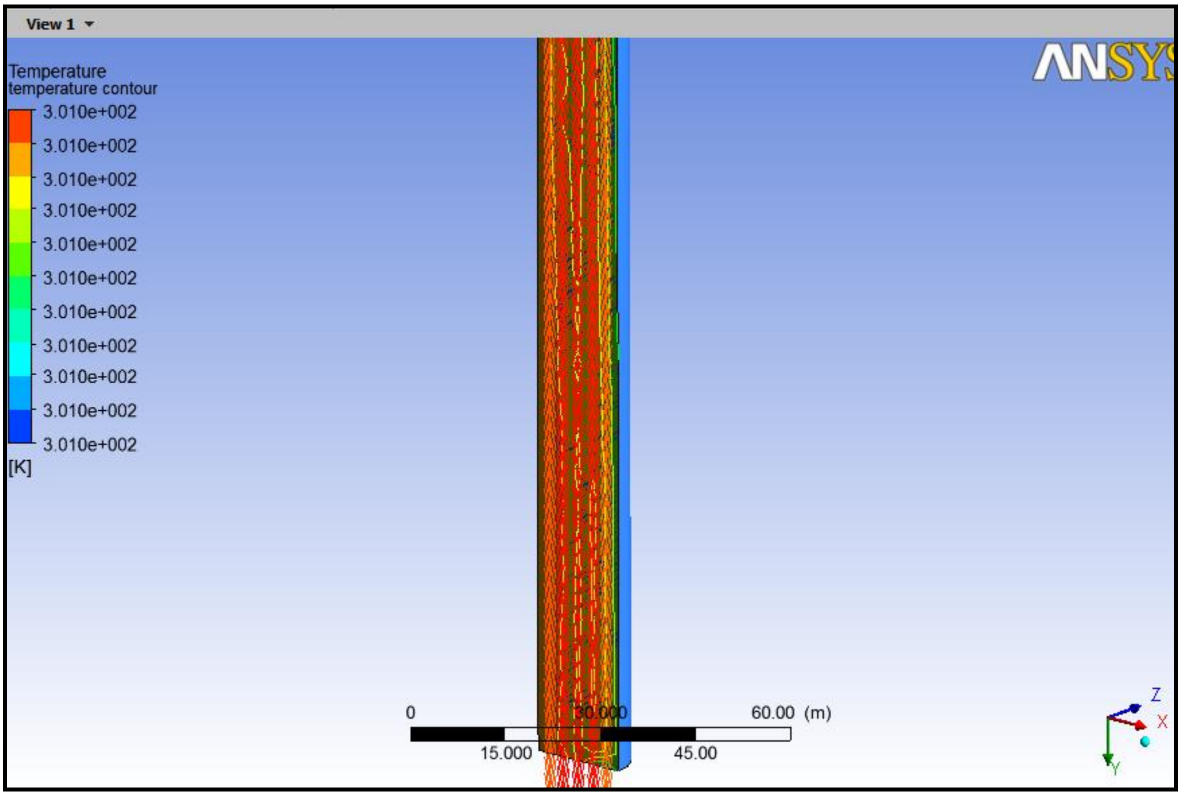



Temperature contour

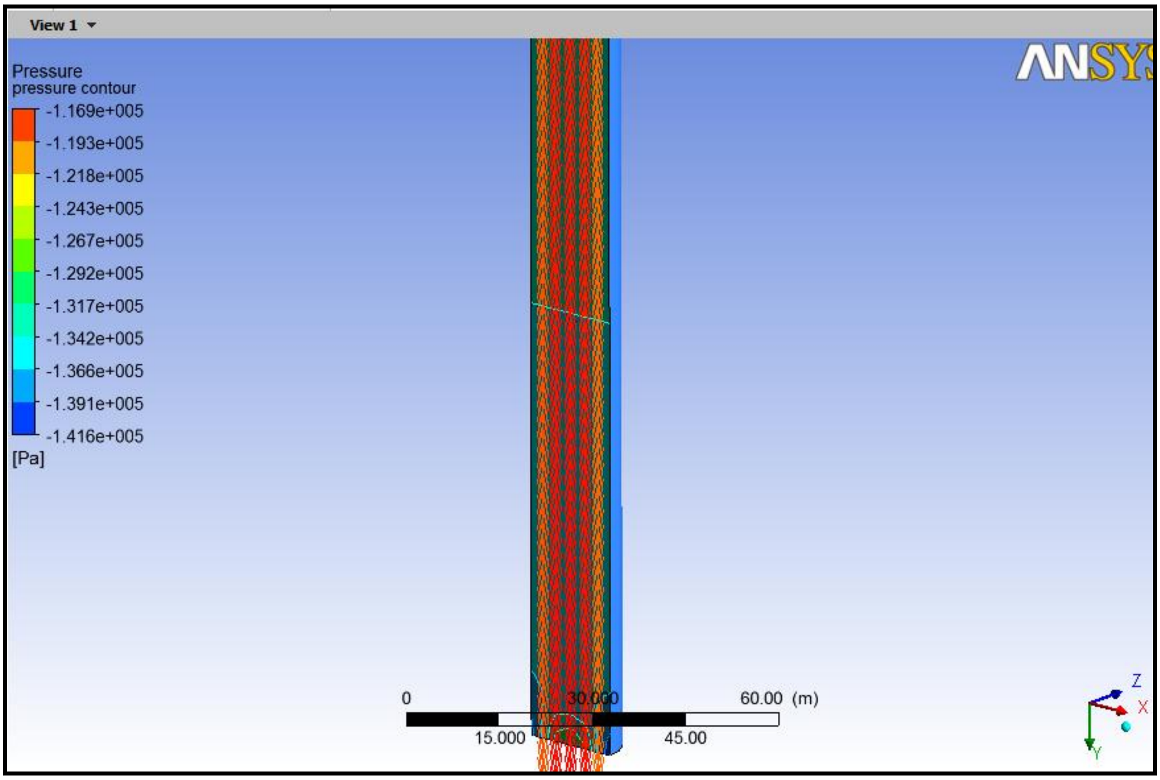



Pressure contour

Appendix 5: Trial 5 (Radius 0.83m)

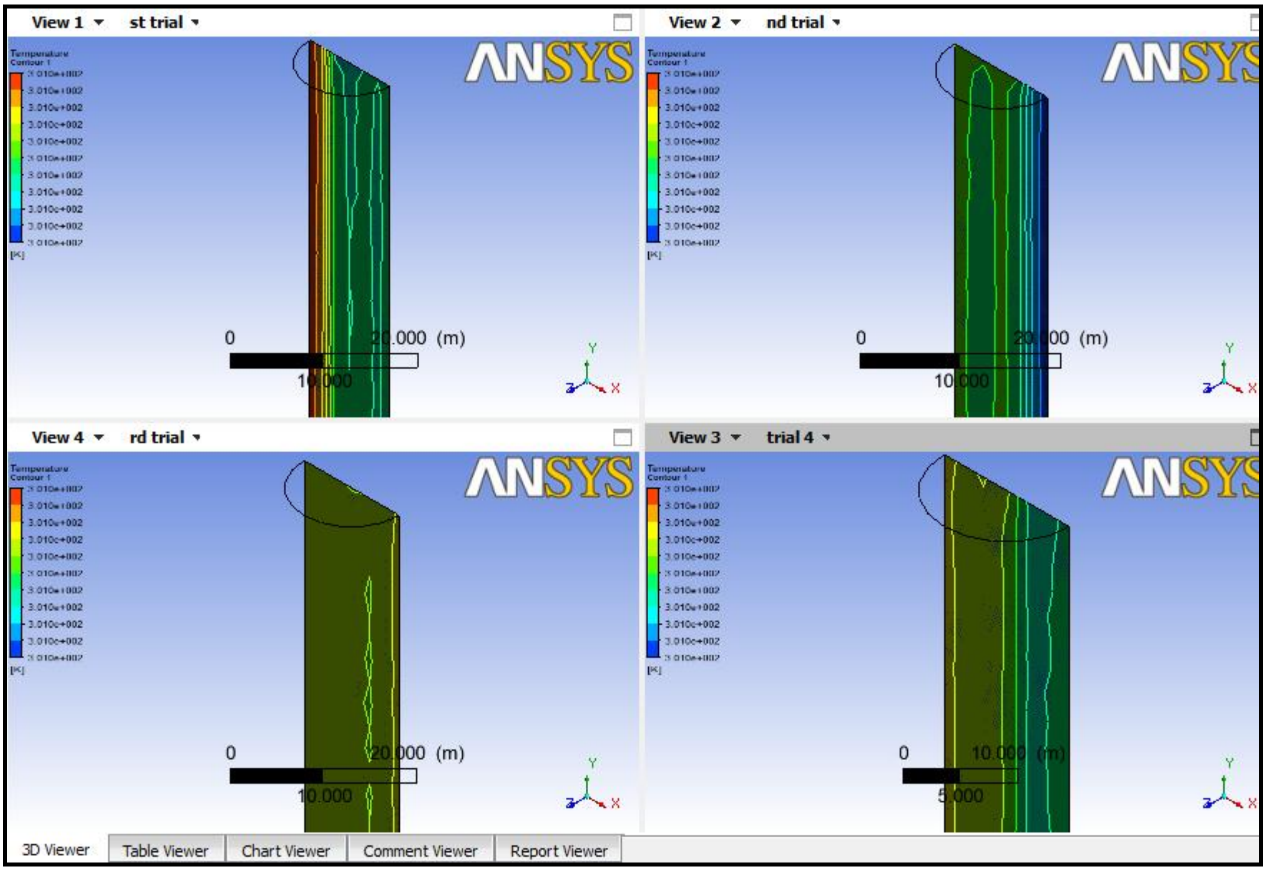


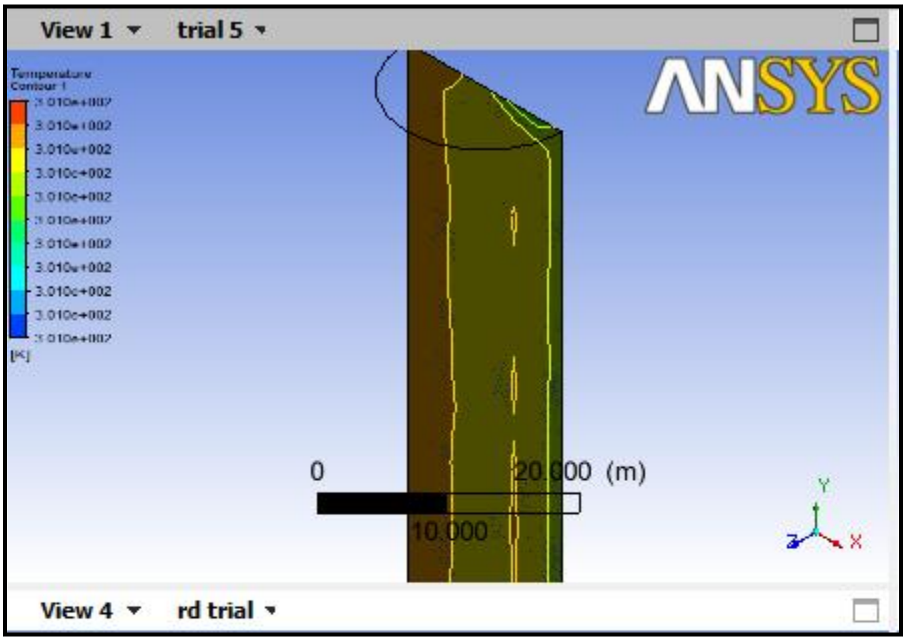

Temperature contour



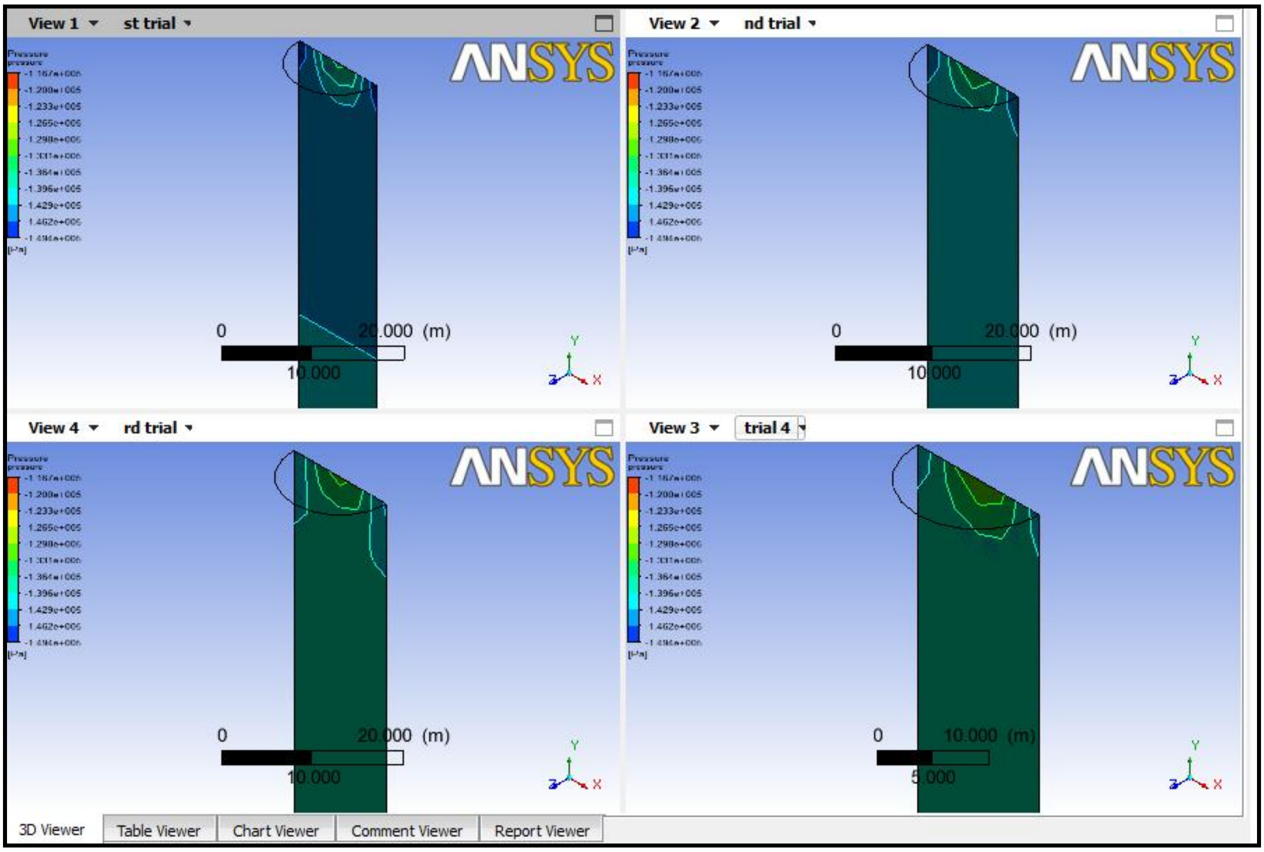

Pressure contour

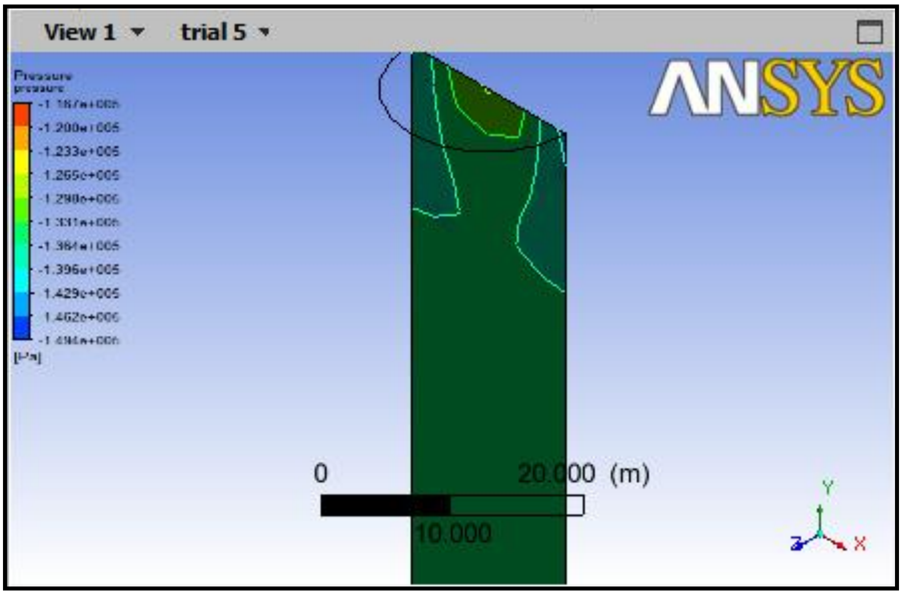
Appendix 6: Comparison of temperature contour



Appendix 7: Comparison of pressure contour



Appendix 8: Research Work Schedule (Gantt Chart)

| Activity | Final Year 1st Semester | | | | | | | | | | | | | | Final Year 2nd Semester | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 |
| 1. Prediction for Design Formulation | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2. Data collection and calculation<br>• Determining hydrate temperature zone<br>• Parameter Calculation | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3. Model Development<br>• Model requirement<br>• Formula implementation | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4. Design validation<br>• Model simulation<br>• Model Comparison | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 5. Submission of Final Report<br>• Report writing<br>• Final presentation | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

**Milestone**

Prediction for Design Formulation

Model Development

Final Report and Presentation

Data Collection and Calculation

Design Validation