Pipeline Thermal Insulation for Malaysia's Deepwater

by

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CERTIFICATION OF APPROVAL

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14968

A project dissertation submitted to the
Mechanical Engineering Programme
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In partial fulfilment of the requirement for the
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(MECHANICAL)

Approved by,

____
(Dr William Pao King Soon)

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 be undertaken or done by unspecified sources or persons.

____
(ALI ABIDIN BIN IDRIS)

ABSTRACT

Thermal insulations are widely used in oil and gas industries to reduce and minimize the heat loss. As the exploration of oil moving into deeper and further region where the temperature is low and pressure is high put new challenges on the insulation systems. There are active and passive insulation and the combination of both which have been used to solve the flow assurance issue of hydrates/wax formation. This paper will systematically categorize the available technology of the thermal insulation based on the criteria of each technology design, heating efficiency, operability and reparability. ANSYS Fluent is used to simulate the best two of active heating technology which are Electrically Trace Heated Pipe-in-Pipe (ETH-PiP) and Integrated Production Bundle (IPB) to find the best thermal insulation option for Malaysia's deepwater condition. The comparison is made by the temperature drop of the production fluid in the pipeline for both thermal insulation technologies without input of heat from external source. Active power requirement by ETH PiP and IPB to maintain the temperature of the production fluid above 65˚C are also the criteria taken to determine the best insulation option in Malaysia's deepwater condition. At the end of this project, ETH PiP is determine to be the better thermal insulation option for Malaysia's deepwater condition.

ACKNOWLEDGEMENT

My completion of Final Year Project will not be a success without many peoples. Hereby, I would like to acknowledge my heartfelt gratitude to those I honor.

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CHAPTER 1

INTRODUCTION

1.1 Background

In deeper water, the hydrostatic pressure can reach 300 bars with ambient temperature as low as 4°C. The extreme conditions pose a challenge to the petroleum industry in terms of the capability of the production facilities in order to exploit oil at greater depth. The loss of energy in the production flow is magnified due to increased water depth and hydrostatic head. The energy loss through Joule Thompson cooling, which is a decrease of temperature due to sharp decrease of gas pressure at constant enthalpy and the second forms is potential energy loss(Denniel, Perrin et al. 2004). At high pressure, low temperature wax will deposits and clog the flowline. Wax will formed when the production fluid temperature is under Wax Appearance Temperature (WAT), thus thermal insulation are used to minimize the heat loss and maintain the temperature of the production fluid above WAT. Thermal insulation technology has reduced the potential of hydrate and wax formation which is often a limiting factor in development of deepwater.

Over the years, new thermal insulation methods have been introduced and existing insulation methods is being perfected by improvising the method according to the needs. As a result, there are many pipeline insulation methods available in the open market. There are two main types of thermal insulation which are passive and active insulation.

1.2 Problem Statement

As Malaysia is starting to venture into deep water, it is still unclear which insulation options are the most suitable for Malaysia's deepwater condition.

1.3 Objectives

This project aims to:

i. Systematically categorize the technology of thermal insulation available in the open market
ii. Determine the best thermal insulation option that is most suitable for Malaysia's deepwater condition.

1.4 Scope of study

The scopes of study are as following:

1) Restricted to deepwater depth of 500 to 1500m, as it is the range defined as deepwater in Malaysia.
2) The product fluid is restricted to oil single phase only because the study is primarily interested in the temperature variable across the pipeline.
3) Restricted to ambient temperature ranging 3-4 °C which is the typical ambient temperature in deepwater.
4) Only considering flowline and riser pipeline.

CHAPTER 2

LITERATURE REVIEW

2.1 Opening Remark

Pipelines are insulated primarily to conserve heat and maintain the temperature of the fluid above a critical temperature due to few reasons. Among them are, to hinder the formation of gas hydrates, wax or asphaltenes, to enhance the product flow properties, to increase the cooldown time after shutting down, and also to accommodate other operational/process equipment requirements. On the contrary, there are insulation which the purpose is to maintain the cold temperature of the gas in order to keep it in a liquid state for example in liquefied gas pipelines, such as LNG (Guo, Song et al.). Insulation can be divided into two kind of insulation namely 1) Active insulation 2) Passive insulation

2.2 Active Insulation

Active heating is defined as the input of heat into a production system from external source. One of the advantage of using the active heating systems is that heat can added to the pipeline to maintain the temperature above the wax appearance temperature (WAT) and hydrate formation temperature without having to depressurizing the pipeline. Active heating may be required to heat the production during turndown, startup and/or shutdown scenarios (Easton and Sathananthan, 2002).

In subsea fields, the relatively hot petroleum (at temperatures as high as 80 °C) is extracted from wells located on the bottom of the ocean, which can be 2000-3000 metres deep. The surrounding seawater at this depth is at a temperature of approximately 4°C, thus causing significant cooling of the petroleum flowing through long pipes in the ocean floor. The temperature of the produced fluids need to be managed such that it is above the critical value (above wax appearance temperature) in order to prevent solid deposition by resorting to few available methods include using Direct Electrical Heating (DEH) or Indirect Electrical Heating (IEH). In the direct electrical heating system, electric current flows through the pipe wall which leads to Joule heating in the fluid. In the indirect electrical heating system, the electrical flows through heating elements (e.g.. one or more electrical cables) on the pipe surface.

2.2.1 Direct Electrical Heating (DEH)

DEH (as shown in Figure 2.1) uses alternating current (A.C) in a metallic conductor such as cable pipes to generate heat or Joules effect. The pipe acts as an active conductor in a single phase circuit. Parallel and close to it is a single core power cable which is the forward conductor.

The heating system is electrically connected to ("earthed") to the surrounding seawater through several sacrificial anodes which is known as "Current Transfer Zone". There should not be any steel structures in these zones (Delebecque, Sibaud et al. 2009).

The electric current that flow through the pipe wall will generates heat due to the electrical resistance of the metal which will then be transferred to the production fluid through thermal conduction, thereby increasing the temperature of the flow above the critical WAT.(Roth, Voight et al. 2012).

Among the types of DEH are Open Loop (Wet Insulated) DEH, End-Fed and Center Fed Pipe in Pipe systems.

Based on the track record, there have been six Open Loop DEH, two PIP Center Fed and one PiP End Fed systems have been successfully installed which are shown in the Table 2.1 below.

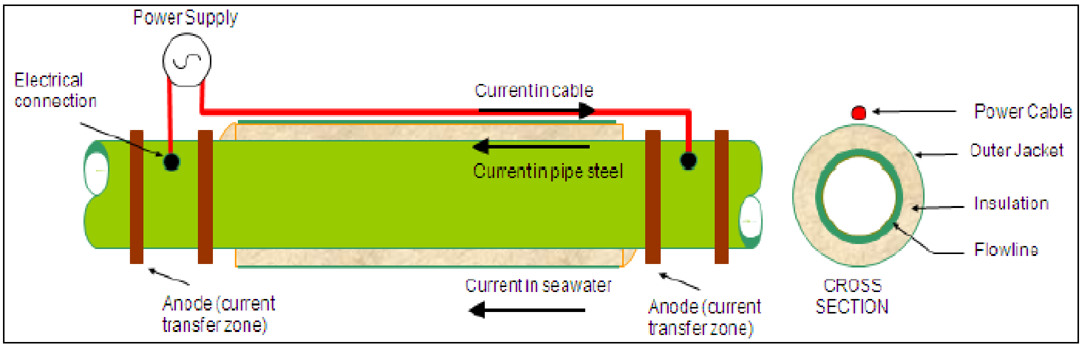


Figure 2.1: Direct Electrical Heating

Table 2.1: Track record of DEH installations

Source: (Roth, Voight et al. 2012)

Open Loop DEH	PIP Center Fed	PIP End Fed
Statoil Asgard (2000)	Shell Habanero (2003)	Shell Serrano and Oregano (2011)
Statoil Huldra (2002)	Shell/BP Na Kika (2004)	
Statoil Kristin (2005)		
Statoil Urd (2005)		
Statoil Tyrihans (2007)		
Olowi (Canadians National Resources) (2011)		

A case study was conducted by INTECSEA (Roth, 2011) with the production fluid have a high WAT of 46°C and the pour point temperature of 21°C. The length of the flowline is 6800m and at the depth of 2100m.

The field development options with and without DEH are considered including the required power requirements and assessing the availability of DEH components, a side-by-side comparison was made of the case study with and without DEH installed and utilized as shown in Figure 1. The fixed parameters in both systems are:

- Pipe-in-pipe flowline with 8-inch inner diameter pipe and insulation to achieve U-value of $11W/m^2K$
- Riser with value of $1W/m^2K$
- Insulated production tubing

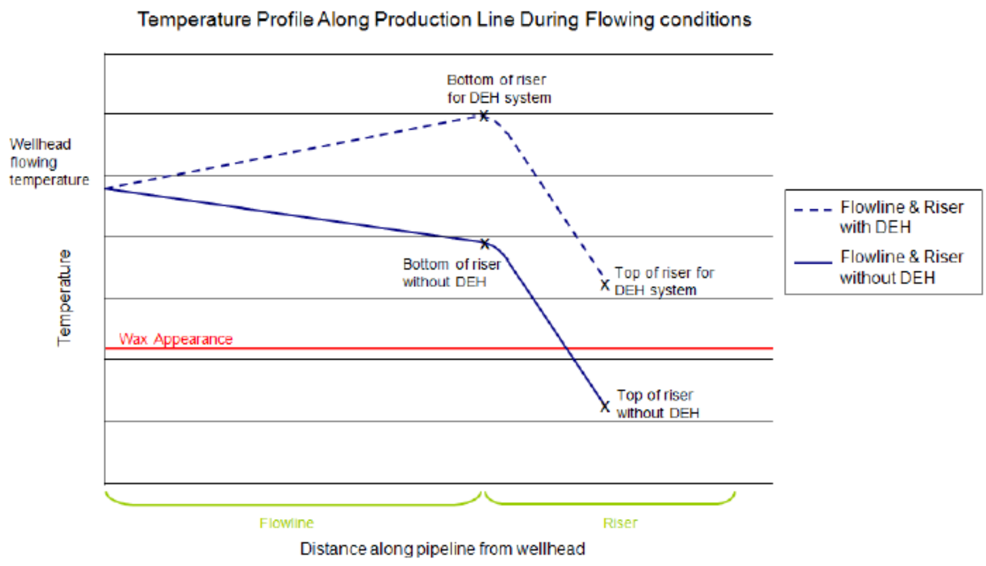


Figure 2.2: Temperature along Flowline and Riser during flowing conditions with and without DEH activated

Source: (Roth, 2011)

The result of the case study as shown in Figure 2.2 indicates that for deepwater without DEH, it need looped lines and periodic pigging of flowline and riser to prevent wax deposition. While for facilities with DEH system, looped flowline and risers are not required. DEH continuous heating at 85 W/m on inner pipe will maintain flowline temperature to ensure top riser temperature > WAT. The topsides power required in this case study is 1.12MW.

Other than that, preservation and restart of a line using active heating allows switching from a conventional loop with dead oil circulation and consequent chemical injection to a single line architecture which brings substantial cost benefits by removing half of the required pipe length and a reduced number of risers (Ansart, Marret et al. 2014). Summary of the advantages and disadvantages of DEH are shown below in Table 2.2.

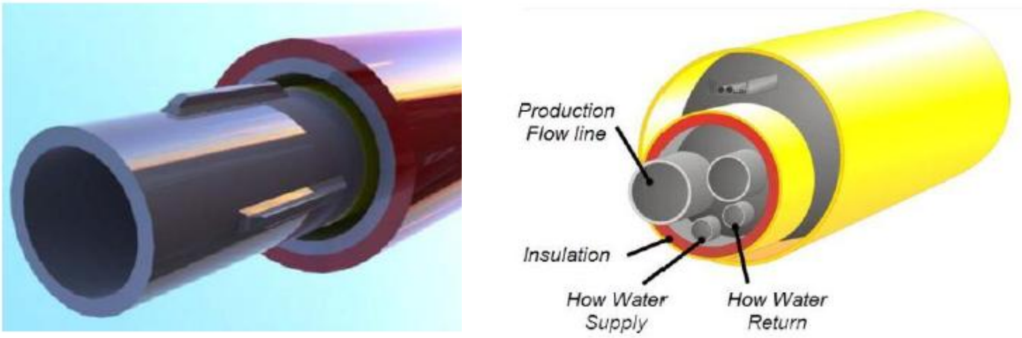
Table 2.2: Advantages and disadvantages of DEH

Source: (Roth, 2011)

Advantages of DEH	Disadvantages of DEH
Improve the flow of heavy oil	Inefficient thermal insulation (U-values of 0.54 to 1.1 $BTU.hr^{-1}.ft^{-2}$(3-6 $W.m^{-2}.K^{-1}$)).
Prevent and remediate hydrates and paraffin	High power requirement (due to inefficient thermal insulation). Needed of 50-100 W/m for hydrate prone crudes and twice that for crudes with waxes
Extend shutdowns without using chemical injections or hot oil circulation (eliminate the infrastructure as well such as displacement pumps, heaters, etc.)	Limited length of the pipeline. The power connections of the system are at the topside of the host, thus distance of the pipeline from the host is limited.
Enable longer tiebacks	Accelerated AC corrosion thus life expectancy of the components will be affected by continuous heating of DEH
Reduce CAPEX and OPEX	Large footprint needed at the topside

2.2.2 Hot Water Circulation (HWC)

Using the principle of heat exchangers, hot water heated pipeline systems have been used since early 90's. The production fluid are warmed by heat exchange with counter current flow which is water or other heating medium such as glycol in either Pipe-in-Pipe (PiP) or bundled system as shown in Figure 2.3 (a) and (b) respectively. The required heating medium thermal energy is normally provided by a heater at the topside host facility.(McDermott and Sathananthan 2014). The circulation of hot fluid (water) will either be in the annular space for PiP or in a dedicated line for Hot Water E



(a) (b)

Figure 2.3: a) Hot Water Circulation PiP b) Hot Water Circulation Bundled Systems

Source: {Ansart, Marret et al, 2014 }

Shown below in Table 2.3 are the advantages and disadvantages of HWC.

Table 2.3: Advantages and disadvantages of HWC

Source: (Ansart, Marret et al. 2014)

Advantages of HWC	Disadvantages of HWC
High performance thermal insulation (U-values 0.6-6 W/m^2K)	High power requirement
Can be used during steady state operations to keep fluid warm enough or during restart a line with pour point issues	Low wet insulation performance for HWC-PiP (U-values 3-6 W/m^2K)
Potential synergies with hot production from other process units on topside	Large footprint required at topside
	No possibility for redundancy of HWC-PiP

As mentioned above, the hot water circulation technology is one of the first active heating technologies developed and installed offshore. Hot Water Bundles have been installed on several projects such as Asgards and Gullfaks for Statoil and on Conoco Brittania. While for hot water PiP, very few have been installed which BP King is among them. (Ansart, Marret et al. 2014).

2.2.3 Integrated Production Bundle (IPB)

IPB (as shown in Figure 2.4) have been developed to provide active flow assurance solutions within flexible pipes for dynamic riser and static flowlines applications. The principle of IPB is assembling elements with various functions around a large central production core. IPB compromises of 3 main parts which are: 1) the core which is a standard flexible pipe structure for transportation of fluid 2) The assembly, which is a bundle of components wrapped around the core such as steel tubes, hoses, cables and fillers. Additional umbilical component functionality can also be provided such as hydraulic hoses and fiber optics. 3) External insulation and protection layers (Denniel, Perrin et al. 2004). Syntactic polypropylene foam is used as the insulation material.

In Table 2.4 are the summary of the advantages and disadvantages of IPB.

Figure 2.4: Integrated Production Bundle (IPB)

Source :{Ansart, Marret et al. 2014}

Table 2.4: Advantages and disadvantages of IPB

Source: (Denniel, Perrin et al. 2004)

Advantages of IPB	Disadvantages of IPB
Can be designed such as that only passive insulation used during flowing conditions while active heating only used during shutdowns,start-ups or during critical conditions	Low thermal performances (U-value = 3-6 W/m^2K). Thus heating efficiency 40-60%.
The congestion of the riser system and subsea equipment can be reduced	Only qualified to maximum water depth of 1500,
High electrical efficiency (90%)	Tracing cable cannot be replaced or repaired subsea
Allows real time monitoring of the temperature	IPB internal diameter is limited to 11-12"
Have redundancy of 23-100%	

Total are using IPB for two of their projects in West Africa: IPB with gas lift tubes only at Pazflor and IPB with both tracing cables and gas lift tubes at Dalia.

IPB have been qualified to deliver a fully heated flexible flowline and rise system in deepwater for the Papa Terra project in Brazil.

2.2.4 Electrical Trace Heated Pipe in Pipe.

Electrically Trace Heated Pipe in Pipe (ETH-PiP) in Figure 2.5 consists of a combination of high thermal performance of reeled subsea Pipe in Pipe with the high efficiency of heat trace cable which will be laid below the insulation layer and directly on the flowline. In order to monitor the production fluid temperature using a DTS system (Distributed Temperature Sensing), optical fibres are incorporated in the system.

The world first ETH-PiP has been installed at Islay development in the North Sea in 2012. Technip have developed "2^{nd} generation" ETH cables for a longer tiebacks and to fulfil a more demanding heat requirements which can deliver up to 1MW each cable (50W/m over 20km or 20W/m over 50km).

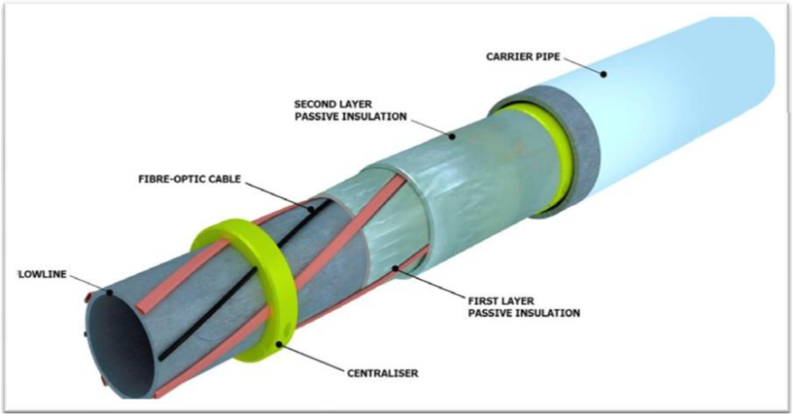


Figure 2.5: ETH PiP

Source: {Ansart, Marret et al. 2014}

Table 2.5: Advantages and disadvantages of ETH-PiP

Source: (Ansart, Marret et al. 2014)

Advantages of ETH-PiP	Disadvantages of ETH-PiP
High thermal performance of the dry insulation in the PiP annulus (U-value= 0.6-2W/m^2K)	Maximum water depth is limited due to high weight of PiP
High heating efficiency: 90-100 %	Tracing cables or splices cannot be repaired once installed subsea
High electrical efficiency of 90%	
Better operability as ETH-PiP have more accurate control and precise adjustment of heating power.	
Fluid temperature can be measured accurately using optical fibers.	
High redundancy: up to 300%	
Can heat up flowline length up to 50km	

2.2 Passive Insulation

Passive insulation uses material of low thermal conductivity properties to minimize the heat loss from the produced fluid to the surroundings. There are two types of passive insulation which are wet and dry insulation.

2.3.1 Wet Insulation

The materials used for wet insulation are typically polyurethane, polypropylene, rubber or glass reinforced plastic. These materials have overall heat transfer coefficient (U-values) of approximately 2W/m^{2}K. (Lee 2002).

2.3.1.1 Polypropylene

In the mid eighties, Norsk Hydro have developed the traditional polypropylene foam for subsea insulation systems (Boye Hansen, Clasen et al. 1999). The technologies have been developed to encompass high temperature material, Syntactic PP and flexible weight coat systems.

Seven layer PP systems of insulation have been developed as shown in Figure 2.6 which have undergone simulated service testing and autoclave verification to established operating parameters for the system in excess of 2000m and a maximum operating temperature in excess of 140°C.

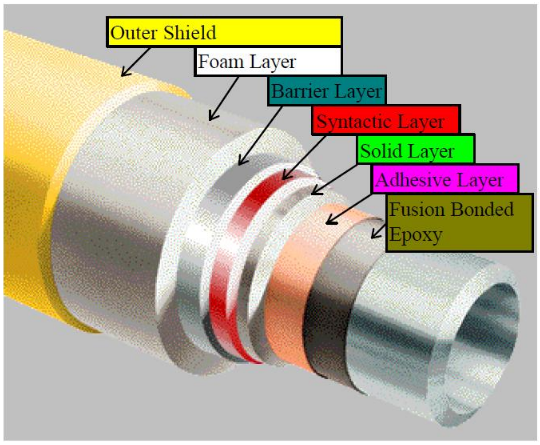


Figure 2.6: Seven Layer PP System

Source: {Hansen, 2000 #6}

Table 2.6: Typical coating design in deepwater

Source: (Hansen 2000)

FBE Coating Layer	**Translucent Adhesive Layer**	**Solid Layer**	**Syntactic Polypropylene Layer**	**Solid Polypropylene Layer**	**Foamed Polypropylene Layer**	**Outer Polypropylene Layer**
300μm	300μm	9.7mm	25.44mm	3mm	33mm	5mm

A typical coating design for deepwater is shown in Table 2.6 and the functions of each layer are shown in Table 2.7 below.

Table 2.7: The PP layer and its function

Source: (Harte, Williams et al. 2004)

Layer	**Functions**
Foam	• Main thermal resistance of the system
Outer Solid PP	• Provides impact resistance • Prevent water ingress to the foam layer
Internal Solid PP	• Thermal barrier to the inner foam layer • Transition between the different foam layer
Inner Fusion Bonded Epoxy	• Corrosion barrier to the steel pipe
Adhesive layer	• Assumed to provide negligible contribution to the thermal and structural capacity of the system.

Functions based on (Harte, Williams et al. 2004).

Thermal conductivity: Fusion bonded Epoxy, 0.3 $W.m^{-1}K^{-1}$, Adhesive PP 0.22 $W.m^{-1}K^{-1}$, PP 0.22 $W.m^{-1}K^{-1}$. The advantages of using Polypropylene as insulation material are because it is simple and low cost but the drawbacks are it have limitied insulation thickness.

2.3.2 Dry Insulation

The dry insulations use polyurethane foam and Rockwool which have a better U-value of approximately 1W/m^{2}K. Using dry insulations, less heat will be lost to the surroundings and the temperature of the produced fluids may be keep above the critical value (wax appearance temperature). Yet, contact with water causes the dry insulation performance to degrade and therefore a Pipe-in-Pipe (PiP) system is developed to avoid water ingress. Thus achieving better insulation (Thant, Sallehud-Din et al. 2011).

2.3.2.1 Polyurethane Foam (PUF)

PUF is an excellent insulation material which is manufactured by mixing polyol and isocyanate together with cyclopentane, a foaming agent. The insulating properties of PUF depend on few aspects such as foam density, temperature and cell gas composition.

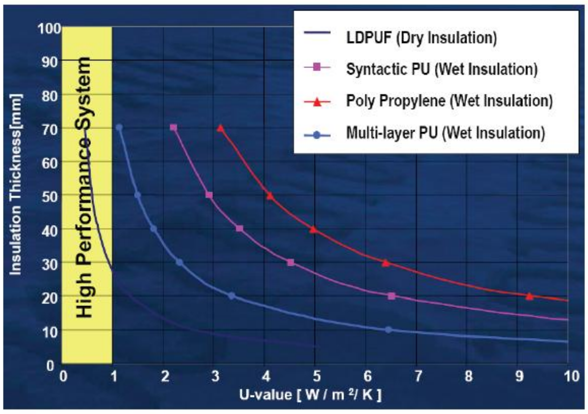


Figure 2.7: Thermal performance of different materials

Source: (Thant, 2011)

The Figure 2.7 shows comparisons the thermal performance of different types of material which are typically used for flowline insulation systems. It can be seen that low density polyurethane foam (LDPUF), which is a type of dry insulation has a heat transfer coefficient value at least half of the U-value of wet insulation material. (Thant, Sallehud-Din et al. 2011).

From a case study, based on the Arrhenius equation for ageing combined with the temperature scenario the minimum PUF density can be derived. With PUF densities in the range from 60 to 150 kg/m^3 the characteristic compressive strength is 0.3 to 1.5 MPa and the axial shear strength is 0.12 to 0.6MPa, considering a lifetime of 30years and maximum operating temperatures of 150 °C. (Palle and Ror 1998).

2.3.2.2 Syntactic foam

Syntactic foam is a composite material which is made up of tiny hollow glass microspheres and it have been used primarily as buoyancy material in an offshore industry for over 30 years but now its use is growing as thermal insulating material for subsea equipment and pipelines.

Table 2.8: Advantages and disadvantages of syntactic foam

Advantages of syntactic foam	Disadvantages of syntactic foam
Low density thus low weight	Degrade when exposed to hot, high pressure water
Low thermal conductivity	Prone to hydrolysis
Durable	Affected by hydrothermal. Will loss properties gradually, breakage and dissolution
High compressive strength	
Cost effective	

Table 2.9 shown track record of syntactic foams insulation applied to deepwater production risers or flow lines.

Table 2.9: Track record of Syntactic foam as insulation

Source: (Watkins and Hershey 2001)

	Shell King Flowlines	BP Amoco King Flowlines	TotalFina/Elf Girasol Riser and Flowlines
Location	Gulf of Mexico	Gulf of Mexico	Offshore Angola
Length (km)	10	50	30
Installation year	1999	2001	2001
Temperatures (°C)	75	55	95
Water depth (m)	1000	1600	1500

2.3 Insulation Comparison Summary

The criteria considered for the active heating technology are divided into 4 categories namely the design of each technology, the heating efficiency, the operability and reliability of the technology.

For design categories, the criteria are weight of the pipe, the U value and the heating component. The lighter the pipe, the easier it is for installation, thus a less weight pipe is desirable. U value known as overall heat transfer coefficients indicates the ability to transfer heat meaning the higher U value, the better or more heats are transferred. Thus, in the pipeline, a lower U value is better for thermal performance.

High heating efficiency is achieved when the heat transferred completely from the heat source to the production fluid. High heating efficiency is good as there is minimal heat loss. While electrical efficiency is the ratio of useful power output to total power input. Low electrical efficiency will increase the required power supply, hence cost more. Active power requirements ratio is compared between ETH PiP requirements for each technology. Higher active power needed means higher cost.

Fluid temperature monitoring criteria under operability categories are important because if the temperature of the production fluid at a point along the line can be known and it is going to drop below WAT, heat can be supply immediately to prevent wax formation. Uniformity of heating can ensure the heat is transferred equally. Continuous heating is crucial during shutdown/startup or during transient state of heating to ensure the production fluid's temperature is above WAT.

High level of redundancy of the heating system is desired which makes the technology more reliable. The heating system reparability is also critical and it takes cost into account as some technology required full replacement even when a section is damaged.

CRITERIA\TECHNOLOGY		HWC	Wet DEH	DEH-PiP	ETH-PiP	IPB
Design	Weight	Heavy Pipe	Light Pipe	Heavy Pipe	Heavy Pipe	Light Pipe
	U Value	HWC Bundles thermal insulation 0.6 to 6 W/m^{2}K	Wet Insulation 3-6 W/m^{2}K	Dry Insulation 0.6 – 2 W/m^{2}K	Dry Insulation 0.6 – 2W/m^{2}K	Wet Insulation 3-6 W/m^{2}K
	Heating Component	Hot Water in PiP annulus or Bundle dedicated tubes	Pipeline itself	Pipeline itself	Small trace heating cable in annulus	Pipeline itself
Heating Efficiency	Heating efficiency	40-60 %	50-70%	95-100%	90-100%	40-60%
	Electrical efficiency	N.A	30-60%	50-70%	90%	90%
	Active power requirements ratio *Compared to ETH-PIP requirements*	**X5** Potential energy saving using the Heat from the production fluid	**X10**	**X2**	**X1**	**X3**
	Comparison power requirements for tie-backs 27km		**8MW**	**4MW**	**1.5MW**	
	Max Single Heated Length	**Limited by pressure drop in water circulation system**	**Longest installed to date: 28km Limited by steel**	**Longest installed to date: 17km Limited by**	**20-50 km due to cables rating limitations**	**Typically 5 to 10km matching typical infield flexible flowline lengths**

		and heating requirements	**electrical properties, stray currents in water & accelerated aging risk of power cables and pipeline corrosion**	**electrical arcing risk between inner and outer pipe**		
Operability	Continuous heating	Yes	Not qualified in deepwater	Not qualified	Yes	Yes
	Precise power adjustment	No	No	No	Fine tuning of Injected power Precise to 1W/m	Fine tuning of Injected power Precise to 1W/m
	Fluid Temperature Monitoring	Only at the inlet and outlet	Only DTS monitoring in the power cable Difficult interpretation of the fluid temperature	Possible if integration optical fibre (on reel lay only)	Fiber Optic measures directly the fluid temperature all along the line	Fiber Optic measures directly the fluid temperature all along the line
	Uniformity of heating	Non uniform heating			Uniform heating	Uniform heating
Reliability	Critical Heating System requirement	PiP Annulus Integrity	Piggyback cable and pipeline itself	PIP itself and insulation	Tracing cables and connector	Tracing cables
	Heating system specific risk	Water corrosion in the annulus PIP Thermal expansion & lateral buckling	Stray Current Corrosion Piggyback cable degradation	Electrical arcing Midline power connector failure	Trace cable failure Power connector failure	Trace cable failure Limited resistance to external impact
	Redundancy of heating system	No	No	No	Very high (up to 300%)	20-100% Limited due to bundle

						geometry
	Heating system reparability	Replacement of PiP damaged section	Replacement of damaged power cable and damaged pipeline section	Full replacement if full failure of pipeline or heating systems	Replacement of Damaged sections: tracing cables only	Replacement of damaged section
	Maturity of Technology(Track Record)	Hot Water Bundles installed at: • Asgard and Gullfalks Hot Water Pipe installed at: • BP King	Installed at: • Statoil Asgard • Statoil Huldra • Statoil Kristin • Statoil Urd • Statoil Tyrihans • Olowi	Installed at: • Shell Serrano and Oregano • Shell/BP Na Kika • Shell Habanero		Installed at: • Pazflor-IPB with gas lift tubes • Dalia-tracing cables and gas lift tubes • Papa Terra-qualified for fully heated flowline and riser system

Table 2.10: Comparison between Active Heating Technologies

From the literature review, the chosen type of insulation is active heating. A further study was conducted and the comparison between the different active heating technologies was tabulated for comparison as shown in Table 13 next page. Based on the critical characteristics and criteria as explained above for each active heating technology, Pugh selection method was done to choose the best two of the active heating technologies as shown in Table 13. From Pugh Selection Matrix, it can be concluded that ETH-PiP and IPB are the two most best of the active heating technology.

Criteria	Baseline	HWC	Wet DEH	DEH-PiP	ETH-PiP	IPB
Weight	0	—	+	—	—	—
Electrical Efficiency	0	0	—	—	+	+
Max single heated length	0	—	—	—	+	—
Active power requirements	0	0	—	0	+	0
Continuous heating	0	+	—	—	+	+
Precise power adjustment	0	—	—	—	+	+
Fluid temperature monitoring	0	—	0	0	+	+
Redundancy of Heating System	0	—	—	—	+	0
Heating System Reparability	0	0	0	—	0	0
Topside Requirement	0	—	—	—	+	+
Maturity	0	0	+	0	—	0
Total		-6	-5	-8	+6	+3

CHAPTER 3

METHODOLOGY

3.1 Research Methodology Chart

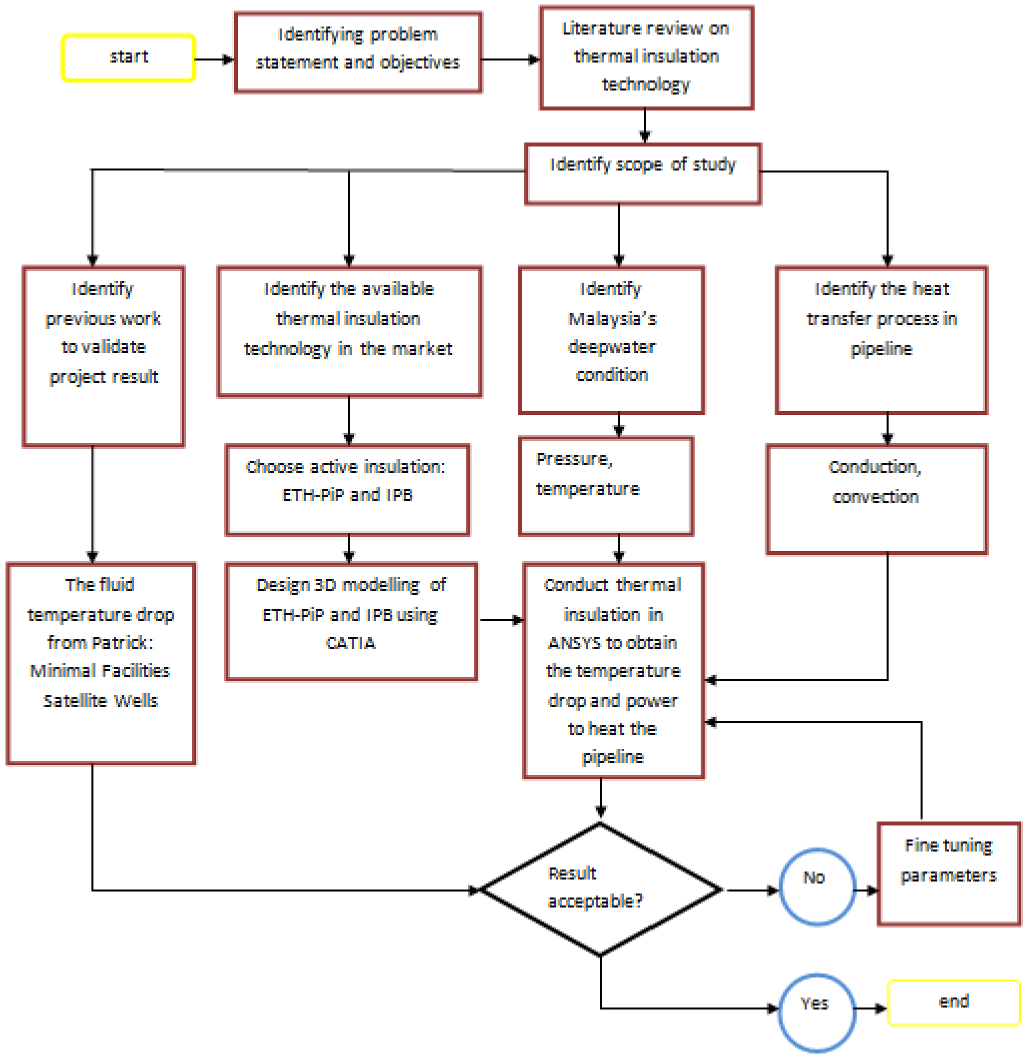


Figure 3.1: Research Flow Chart

3.2 Governing Equation

In solving energy equation in ANSYS Fluent, thermal boundary conditions need to be defined at wall boundaries. There are convective heat transfer in the pipe and the outer pipe where the pipe is immersed in the water. Between the layers of the pipe, the heats are transferred through conduction. The five types of thermal condition available are fixed heat flux, fixed temperature, convective heat transfer, external heat radiation heat transfer, combined external radiation and convection heat transfer.

As heat flux boundary condition are specified at the wall surface, the wall surface temperature adjacent to a fluid cell is calculated as:

$$T_w = \frac{q - q_{rad}}{h_f} + T_f \qquad (1)$$

For the wall zone that has a fluid and solid region on each side, it is called a "two-sided wall" and a shadow zone will be created to distinct between the wall zones and if Coupled option are selected, the boundary thermal conditions are unnecessary as the solver will calculate heat transfer directly from the solution in the adjacent cells.

The fluid side heat transfer computations at the walls are different for laminar and turbulence flow in which FLUENT uses the law-of-the-wall for temperature derived using the analogy between heat and momentum transfer in the case of turbulent flow. In the thermal conduction layer where conduction is important, the linear law is used while logarithmic law is applied at the region where effects of turbulence dominate conduction.

$$T^* \equiv \frac{(T_w - T_p)\rho C_p C_\mu^{\frac{1}{4}} k_p^{\frac{1}{2}}}{\dot{q}} = \begin{cases} Pry^* + \frac{1}{2}\rho Pr \frac{C_\mu^{\frac{1}{4}} k_p^{\frac{1}{2}}}{\dot{q}} U_p^2 & (y^* < y_T^*) \\ Prt\left[\frac{1}{k} ln(Ey^*) + P\right] + \frac{1}{2}\rho \frac{C_\mu^{\frac{1}{4}} k_p^{\frac{1}{2}}}{\dot{q}} \{Pr_t U_p^2 + (Pr - Pr_t) U_c^2\} & (y^* > y_T^*) \end{cases}$$

P is computed by using formula given by (Jayatilleke, 1966):

$$P = 9.24\left[\left(\frac{Pr}{Pr_t}\right)^{\frac{3}{4}} - 1\right]\left[1 + 0.28e^{\frac{-0.007Pr}{Pr_t}}\right]$$

3.3 Gantt Chart

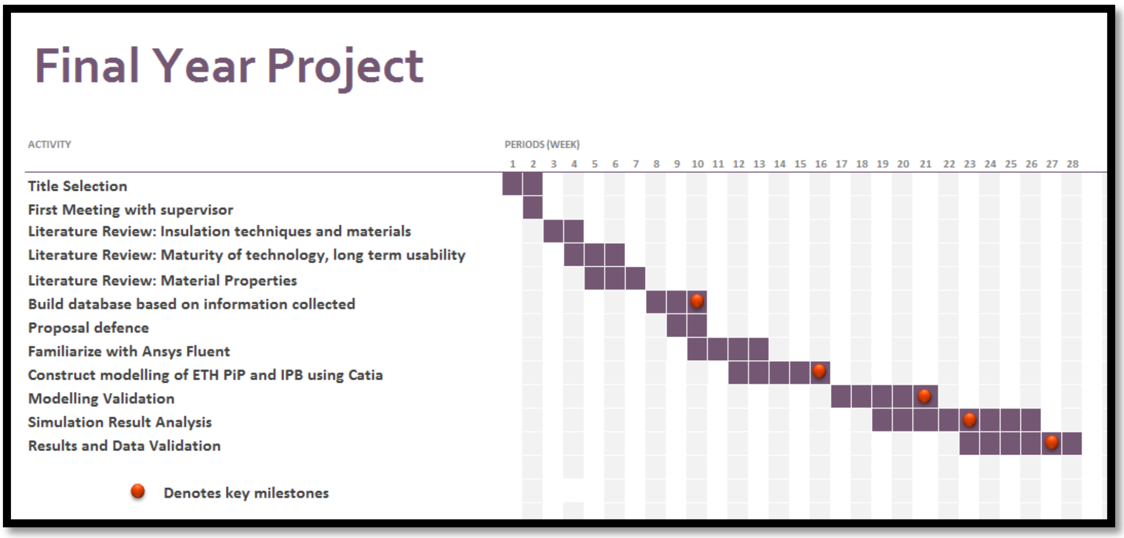


Figure 3.2: Gantt Chart

CHAPTER 4

RESULTS AND DISCUSSION

4.1 ETH-PiP CFD model

During the earlier part of the project, it was decided that the length of the pipeline would be 10km tieback but for the ease of the simulation, the length of the model of the pipeline is chosen to be 1metre. The properties of the production fluid are taken as the properties of the gasoil-liquid from the fluent database. The types of the heat transfer that are considered are the convection inside the pipe, in the annulus and between the surface of the pipe and the surrounding (seawater), the conduction between the solids. Model inputs are tabulated in the Table 4.1 below.

Table 4.1 ETH-PiP CFD Model data

Parameter	Value
Inner Pipe (flowline)	273.1 mm OD x 18.3 mm WT
Outer Pipe (carrier)	406.4 mm)D x 15.9 mm WT
Material	Stainless Steel
Insulation System	Aerogel Insulation 31 mm WT
Tracing cable section	16 mm^2
Tracing cable material	Copper
Number of tracing cables	2
Ambient Temperature	4 °C

There is assumed to be no variation of passive insulation's conductivity with respect to the change of the temperature. Steady state flow and turbulence intensity of 1% were assumed with the flowrate of 150MMscf/d.

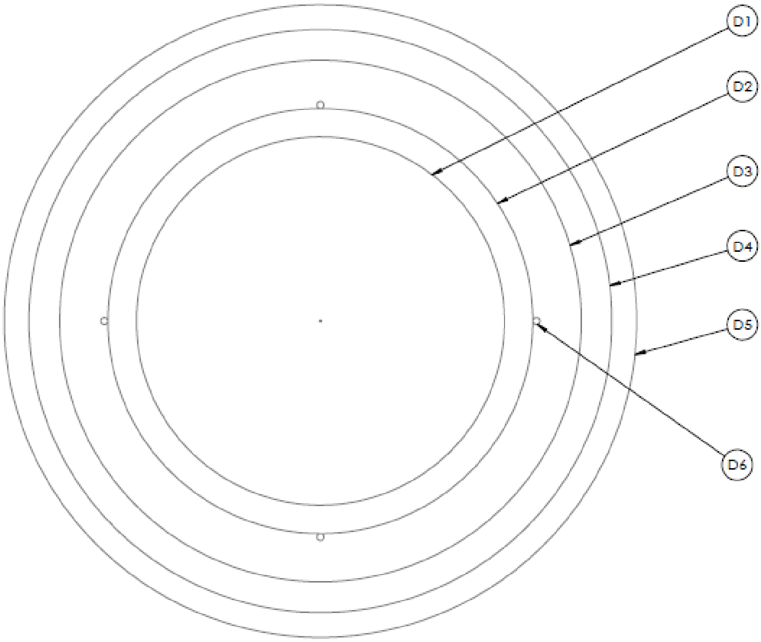


Figure 4.1: Cross section of ETH PiP

Table 4.2: Dimension of ETH PiP

Parameter	Value
D1 (Inner Pipe ID)	236.5 mm
D2 (Inner Pipe OD)	273.1mm
D3 (Insulation)	335.1mm
D4 (Outer Pipe ID)	3744.6mm
D5 (Outer Pipe OD)	406.4mm
D6 (Tracing Cable)	4.5mm

4.1.1 Validation of the ETH-PiP CFD Model

The temperature drop across the pipeline for 10km was compared with the OLGA model of Patrick, James' in Minimal Facilities Satellite Well at steady state behaviour with the difference in values less than 10% as shown in Figure 5.

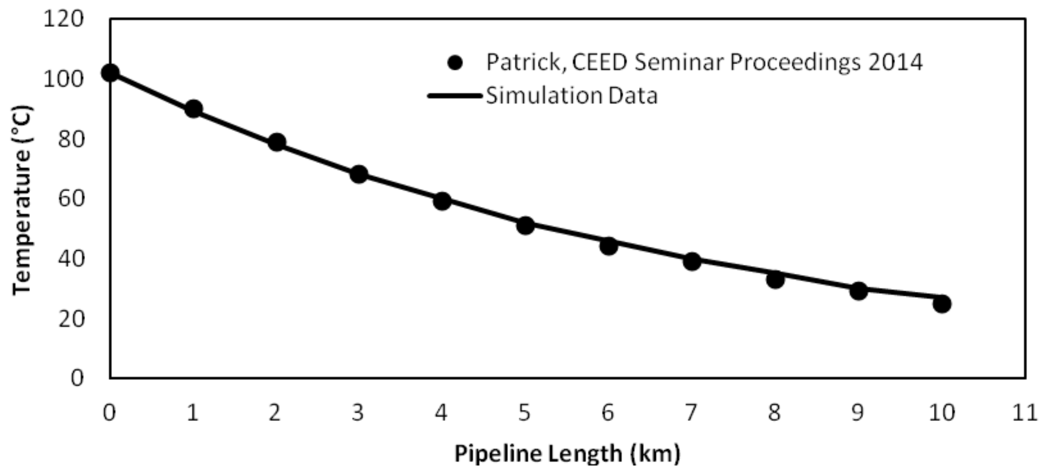


Figure 4.2: Temperature Drop for ETH-PiP Insulated Pipeline

4.2 IPB CFD Model

Table 4.3: IPB CFD Model Data

Parameter	Value
Flexible Pipe	236.5 mm ID
Material	Thermoplastics/Steel
Insulation System	Syntactic propylene foam
Tracing Cable section	$16mm^2$
Tracing Cable Material	Copper
Number of Tracing Cable	16
Ambient Temperature	4°C

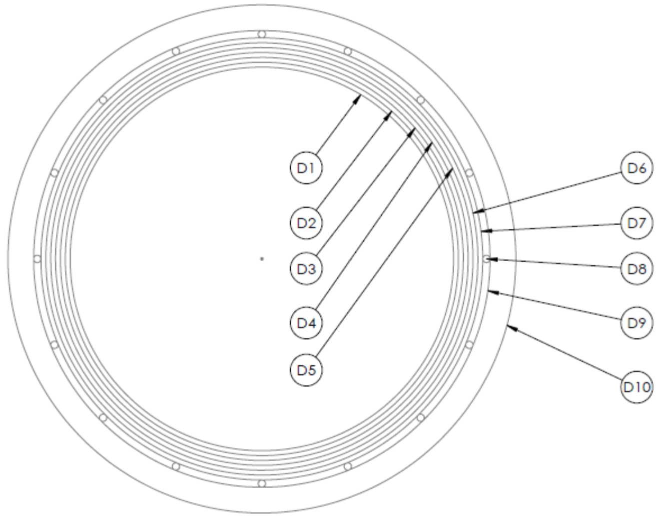


Figure 4.3: Cross Section of IPB

Table 4.4: IPB Model Dimension

Parameter	Value
D1	236.5mm
D2	242.4mm
D3	248.5mm
D4	254.5mm
D5	260.5mm
D6	266.5mm
D7	272.5mm
D8	4.5mm
D9	281.5mm
D10	313.3mm

4.2.1 Validation of IPB Model

Overall Heat Transfer Coefficient or U-Value is a measure of heat loss in an element and can be a parameter to measure how well an element transfer heat. According to (Ansart, 2014) the U-Value for IPB are between the ranges of 3-6 W/m^2K. Using the equation below, the U-Value for IPB CFD model was calculated.

$$HTC = \frac{(Total\ Surface\ Heat\ Flux - Radiation\ Heat\ Flux)}{(Wall\ Temperature(Outer\ Surface) - Static\ Temperature)}$$

$$OHTC = \frac{(2243.3164) - (1837.351 + 691.15161)}{(323.18185 - 375.14981)} = 5.5W/m^2K$$

4.3 Comparison between ETH PiP and IPB

The temperature drop across 10km ETH PiP and IPB pipeline are shown below in graph. It can be seen from the graph that the production fluid temperature drop more in IPB compared to ETH PiP. It can be concluded that IPB transfer heat better and has a poor passive insulation compared to ETH PiP. The static temperature contour of ETH PiP and IPB are shown in Figure 4.5 and 4.6 respectively.

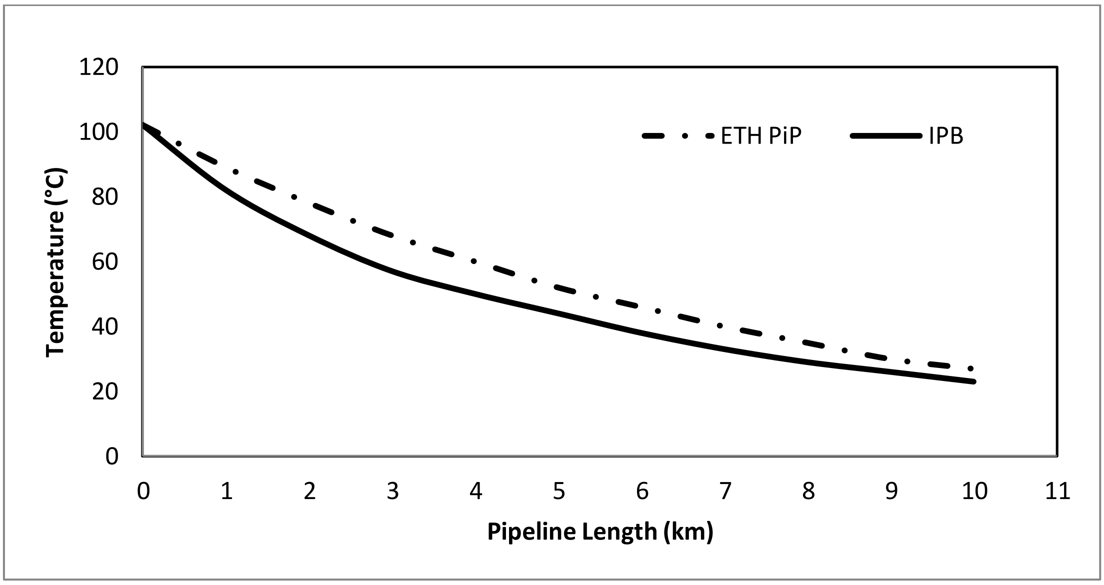


Figure 4.4: Temperature for ETH PiP and IPB

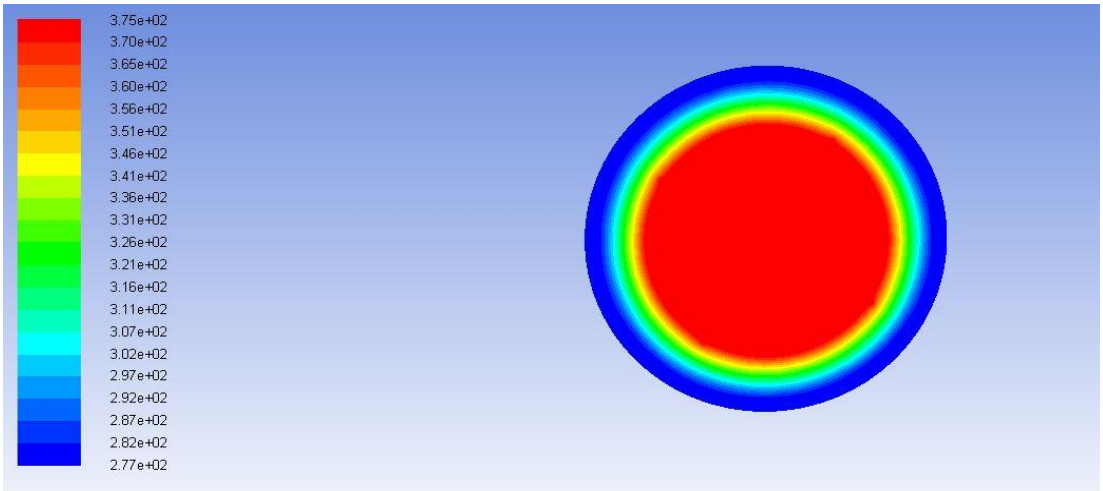


Figure 4.5: Contour of Static Temperature of ETH PiP

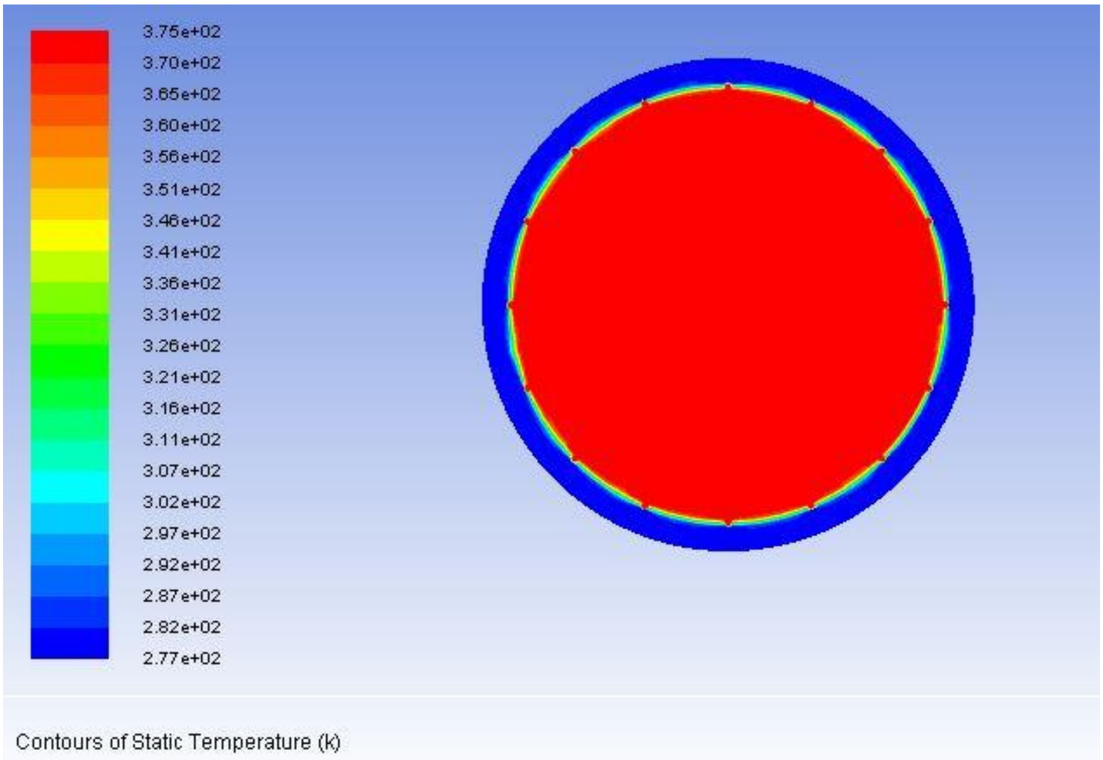


Figure 4.6: Contours of Static Temperature of IPB

The simulation for heating is also done to determine the power needed to maintain the temperature of the pipeline above 65°C which is the average WAT in Malaysia's deepwater. For IPB, the power required is 240W/m on 16 cables (15W/m per cable). For ETH PiP, the power required is 60W/m on 4 cables (15W/m per cable). The overall active power required is lower for ETH PiP compared to IPB which are 0.6 MW and 2.4 MW respectively.

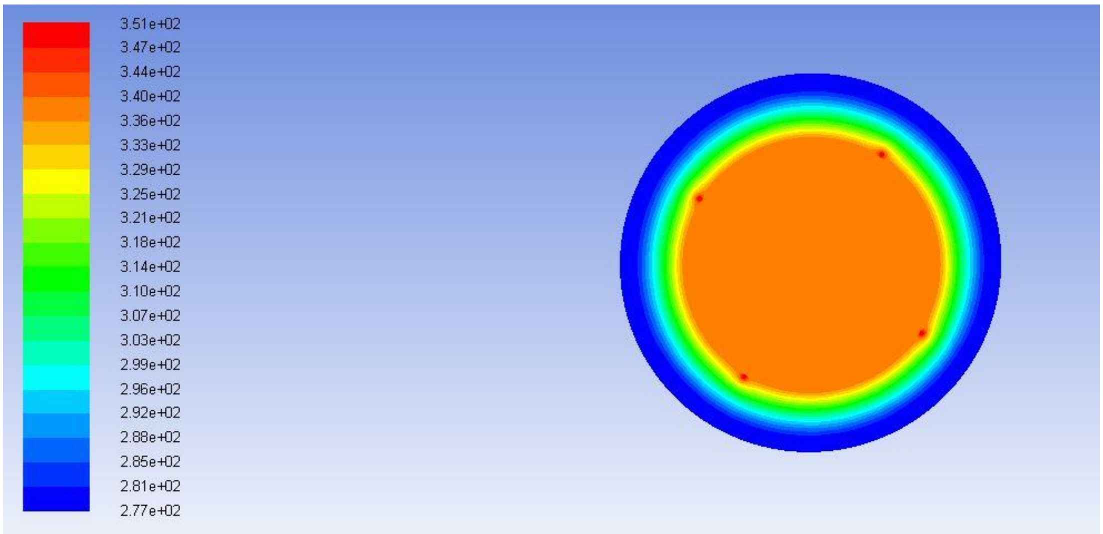


Figure 4.7: Static Temperature Contour of ETH PiP Heating

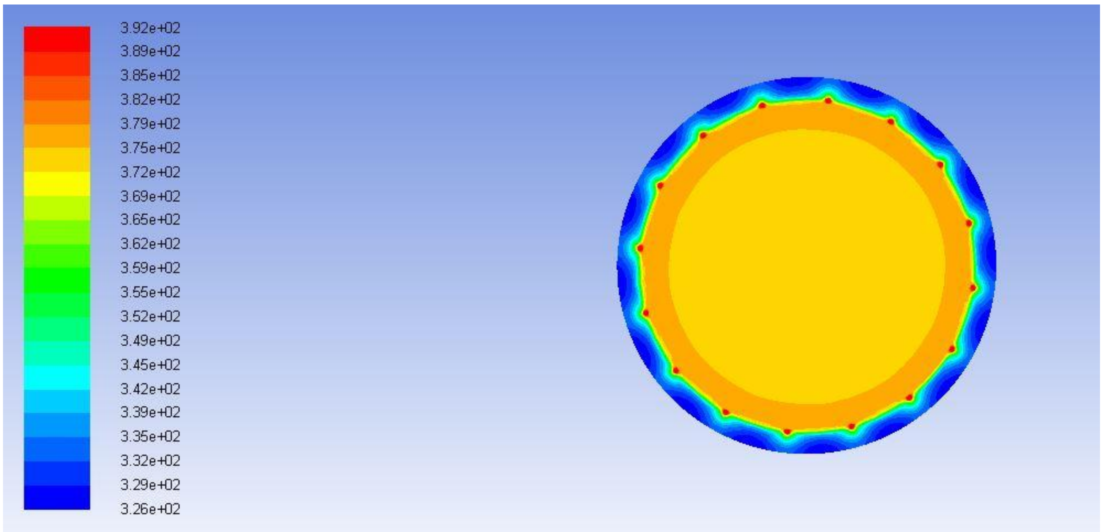


Figure 4.8: Static Temperature Contour of IPB Heating

CHAPTER 5

CONCLUSION AND RECOMMENDATION

The available pipeline insulation methods in the market have been identified and listed.

There are two types of insulation which are active and passive insulation. For active insulation, there are direct electrical heating system, hot water circulation and integrated production bundle. For passive insulation, there are dry and wet insulation.

From the literature review, it can be concluded that active insulation is a better thermal insulation option compared to passive insulation as it can actively control the amount of heat input into the production systems and hence, it is capable to control the temperature of the production fluid and ensuring it is above critical value (hydrate formation temperature and wax appearance temperature). From the Pugh Selection Matrix, ETH PiP and IPB is the most two best active heating technology. Using ANSYS FLUENT for simulation of ETH PiP and IPB, it is found out that ETH PiP is a better active heating technology as it has less temperature drop during steady state and also less power required to maintain the temperature of the pipeline above 65˚C compared to IPB.

For recommendation of future work, an economic analysis should be done to determine the best active heating in Malaysia's deepwater technically and economically.

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