Wax Deposition Prediction inside Pipeline

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Abstract. Crude oil has long been one of the major energy sources in the world. Heavy oil is predicted as the future of the petroleum industry, research and development are increased massively in line with the discovery of the heavy oil reserves around the world. Heavy oil has asphaltenes and paraffin fractions very high, with the high content of paraffin is one of the problems that occur in the operation of heavy oil production is found to have deposition on the wall of pipes. This paper will be discussed about the simulation of the formation of wax deposits on the wall of the pipe, the known starting point of deposition at pipe wall will be additional information to perform the design of the method or what to do to mitigate in order to avoid these deposition problems.

Literature study became an option as a supporting for of paper writing, a case study chosen as the base for this research. The selected case is placed in West Java, Indonesia, which has a fairly high paraffin content. Dynamic multiphase flow Software is used to help with predictive modelling, from the simulation process can get the results of wax deposition along pipeline, the maximum thickness of wax deposit, and a temperature. From the results obtained, it can be used as an additional information for equipment selection consideration.

After analyzing the sensitivity of the simulation results, the equipment and materials can be selected effective, efficient, and also economical to use in this case. After analyzing the result, it can be concluded to select steel-based pipe material using insulation to reduced excessive heat release, and then the temperature reduction can be minimized.

Keyword: Wax, Deposition, Pipeline, Flow Assurance, Temperature.

1. Introduction

The world's need for energy is growing, these needs are directly proportional to the development of the industry. The energy can be obtained from various sources, until now petroleum is still the main source of energy producers used around the world. But in the oil and gas industry itself to face many challenges to producing oil.

Growing global energy demand is making energy companies also innovate and develop energy sources that have not been explored before. In cold underwater conditions, the production of energy sources in the form of fluids will experience obstacles in the form of freezing and deposition of fluids in the underwater piping system that has a cold temperature. The accumulation of these deposits is due in part to the composition of the oil itself which has a high content of paraffin and asphaltenes. This once expensive energy source is fast becoming a more reliable alternative option. However, because this type of oil is newly produced so that the technology for its production operations is not maximal and there are still various problems, one of the problems is related to the oil properties that are high viscosity at low temperatures that make it difficult to move the oil from one place to another through the pipeline.

When oil with a high amount of paraffin content is flowed through the pipeline system due to the decrease in temperature caused by the release and transfer of heat from the system in this case the pipe goes into the environment, paraffin crystals begin to appear and if accumulated, a collection of crystal particles that have this mass will be exposed by gravitational forces to be deposited at the bottom column of the pipe, which may cause a total blockage of the pipe (Mohyaldinn, 2019).

2. Methodology

This dynamic multiphase flow software has capabilities and some limitations when compared to other software. The software can dynamically model fluid flow streams whose results can be seen changing over time. In dynamic multiphase flow software can also divide the pipe into several segmentations, from segmentation can be inserted different inputs such as pipe roughness, pipe diameter, pipe material, pipe elevation, and temperature.

The simulation process found several limitations of this software, one of which is unable to simulate the initial condition of pipes already filled by fluids and or other materials. In addition, the software cannot perform the initial pressure input, instead of initial pressure input the input is a mass flow that will be calculated by the software.

2.1. RRR Correlation

This correlation can be used to predict wax deposition inside tubing in wells or at pipeline. In this correlation the most mechanism that affect wax deposition are molecular diffusion and shear dispersion. Wax volumes formed by molecular diffusion method can be calculated with formula 2.2 and volumes formed by shear dispersion method are calculated with formula 2.3. To calculate the addition of wax volume of both methods can be used formula 2.1. Sediment formation occurs in all parts of the pipe circumference.

$$\dot{\delta} = \frac{Vol_{wax}^{diff} + Vol_{wax}^{shear}}{(1-\phi_{wax})2\pi r_s L} \quad (2.1)$$

$$Vol_{wax}^{diff} = \sum_{i=1}^{N_{wax}} \frac{D_{wo,i}(C_{wb,i} - C_{ws,i}) S_{wet} M_{wax,i}}{\delta_{lam} \rho_{wax,i}} 2\pi r_s L \quad (2.2)$$

$$Vol_{wax}^{shear} = \frac{k^* C_{ws} \dot{\gamma} A}{\rho_{wax}} \quad (2.3)$$

$$C_{ws} = C_{ws,Ts} + \frac{dC_w}{dT}\bigg|_{WAT} (T_s - WDT) \quad (2.4)$$

$$WDT = WAT + \Delta T_{dissolution} \quad (2.5)$$

With:

δ	= Total addition of deposition thickness
Vol_{wax}^{diff}	= Volume of wax deposits caused by molecular diffusion
N_{wax}	= Wax component numbers
$D_{wo,i}$	= Coefficient diffusion Hayduk-Minhas (m^2/s)
$C_{wb,i}$ & $C_{ws,i}$	= Molar concentration of wax components dissolved in oil (mol/m^3)
S_{wet}	= Wetted fraction of the circumference
$M_{wax,i}$	= Molar weight of wax component i (kg/mol)
δ_{lam}	= Thickness of the laminar sub-layer (m)
$\rho_{wax,i}$	= Density of wax component (kg/m^3)
r_s	= Current inner pipe radius (m)
L	= Length of the pipe section (m)
k^*	= Shear deposition rate constant (kg/m^2)
C_{ws}	= volume fraction of precipitated wax
$\dot{\gamma}$	= Shear rate at the wall (s^{-1})
A	= Surface area available for deposition (m^2)
ρ_{wax}	= Average wax density (kg/m^3)
$C_{ws,Ts}$	= Wax concentration at the deposit surface temperature
T_s	= Pipe surface temperature (°C)
WDT	= *Wax Dissolution Temperature* (°C)

2.2. Matzain Correlation

Correlations that consider the shear stripping, molecular diffusion, and shear dispersion are made based on derivatives of Fick law as the mechanism that affects wax deposition. The effect of shear stripping can be calculated with formula 2.12. Wax concentration is calculated by considering its temperature changes, from the result both can be calculated the increase in the thickness of wax deposits by the time.

$$\frac{d\delta}{dt} = \frac{\Pi_1}{1+\Pi_2} D_{wo} \left[\frac{dC_w}{dT}\frac{dT}{dr}\right] \quad (2.6)$$

$$\Pi_1 = \frac{C_1}{1-C_L/100} \quad (2.7)$$

$$\Pi_2 = 1 + C_2 N_{SR}{}^{C_3} \quad (2.8)$$

$$C_L = 100\left(1 - \frac{N_{Re}{}^{0.15}}{8}\right) \quad (2.9)$$

$$N_{SR} = \frac{\rho_{oil} v_{oil} \delta}{\mu_{oil}} \quad (2.10)$$

$$N_{RE} = \frac{\rho_{oil} v_{oil} 2 r_s}{\mu_{oil}} \quad (2.11)$$

$$\frac{dT}{dr} = \frac{(T_b - T_{ws})}{K_{oil}} h_h \quad (2.12)$$

With:

δ = Thickness of wax layer deposited on the wall(m)

D_{wo} = Diffusion coefficient calculated with the Wilke and Chang correlation (-)

C_w = Concentration of wax in solution (%)

r = Pipe radial distance (m)

T = Fluid temperature (°C)

C_1 = 15

N_{Re} = Effective inside radius of the pipeline

N_{SR} = Flow Regime

C_2 = 0.055

C_3 = 1.4

K_{oil} = Thermal conductivity of the oil

h_h = Inner wall heat transfer coefficient

T_b = Fluid bulk temperature

T_{ws} = Surface Deposit temperature

2.3. Input Data

Table 1. Input Data for Simulation

No	Parameter	Value	Unit
1	Oil Density	870	kg/m^3
2	Cloud Point / WAT	40	°C
3	Initial Temperature	58	°C
4	Ambient Temperature	21	°C
5	Mass Flow	13	Kg/s
6	Pipe Material	Steel	
7	Length Pipe	15000	m
8	Pipe Size	6	inch
9	Pipe Thickness	7	mm
10	Pipe Elevation	0	°
11	Pipe Roughness	0.00015	ft
12	Coating	No	
13	Simulation Time	12	Hour

2.4. Limitations and Assumptions

The limitations of this research are:

- No specific data of pipe elevation.
- No specific data of ambient temperature along pipeline.
- No soil conductivity data.

From the limitations as above, assumptions are made to simplify the simulation but still not ignore the important things that will affect the simulation results. Some of the assumptions used are:

- 0° elevation along pipeline.
- Ambient temperature from 0 to 15 km of pipe same.
- No ambient temperature change during simulation.
- No temperature intervention.

- Pipe laying above ground.

3. Result and Discussion

3.1. Wax Deposition Cause

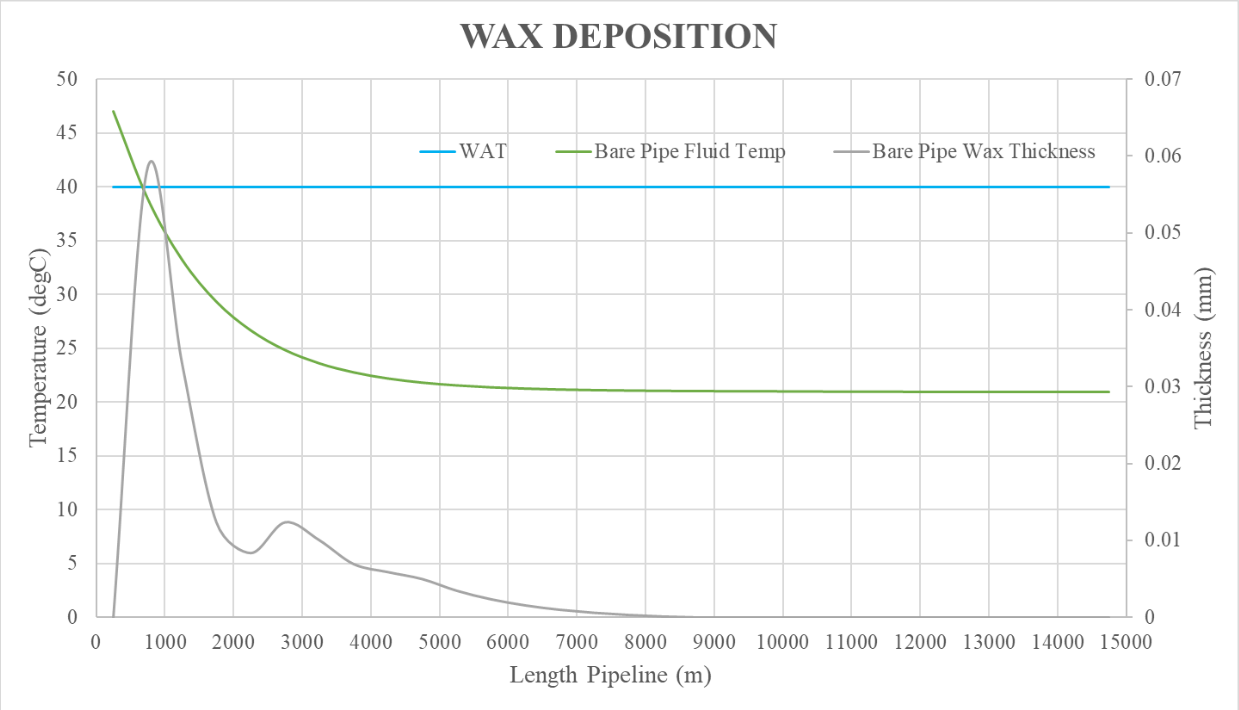

Figure 1. Wax Deposition Base Case

In Figure 1. there are 3 (three) lines, each of which represents a result parameter. The gray color is the graph of the thickness of the sediment in the pipe, the blue color is the Wax Appearance Temperature (WAT) graph, and the green line is the temperature of the fluid in the pipe. It can be seen on the graph that when the temperature of the fluid in the pipe has passed WAT at 40°C at about 500 m from the starting point, wax precipitation begins to form. The deposit thickens over time and will thin out from the start to the length of the pipe.

There are several peaks of wax deposits, each of which has a different length and thickness. At the peak of the first deposit is higher and is formed very quickly because of the fluid from the well that still hot exposed by lower pipe temperature so the fluid temperature drops rapidly due to the adjustment of the fluid temperature to the ambient conditions. Because of this, there is an immediate formation of quite thick deposits of about kilometers 0 to 2 in the pipe.

The operation of transporting oil with a high paraffin content through the pipe tends to form deposits in the pipe. Some of the causes of deposition in the pipe wall are:

- Gravitational Force.

Naturally, everything on earth and has mass will be move in the direction of a straight line towards the earth's core. This also happens with fluid in the pipe that tends to fill the bottom pipe column first, in this case it's precipitation.

- Temperature Drop.

The decrease in temperature can lead to the appearance of paraffin crystals in the oil which if the temperature of this oil drops to below wax appearance temperature (WAT) will appear paraffin crystals that will be able to accumulate into a solid phase of paraffin and by the gravitation, it will settle at the bottom of the pipe.

- Pressure and Flow Rate.

The amount of mass divided by the time if in the case of transferring waxy oil through the pipe will be very affecting. With a large flow rate, the wax will be less precipitated in the pipe, this happens because the mass transferred at one unit of time is high enough that no time for wax crystal particles to settle. Before the particle settles it will be pushed by other particles that have high speed because of the high flow rate. But this parameter also depends on the diameter of the pipe.

- Pipe Fittings.

The pipeline must be used fittings as a technique to adjust the direction and place passed by the pipe. The pipe fitting used has various shapes and sizes to suit the needs, which is commonly used is an elbow pipe or L-shaped pipe that can be used to make a pipe direction. Deposition can happen at low energy point, wax can be deposited because there is no force applied to that substance than it will be settled.

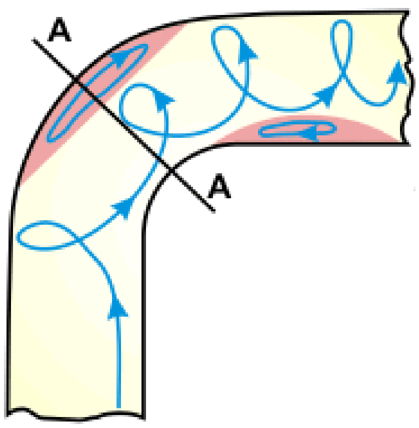

Figure 2. Energy Distribution at Elbow Pipe (Idel'chik, 1986)

- Pipe Connection Techniques.

The connection or joint of the pipe that decrease the flow diameter will be choking the flow. For example, the welding technique connection, if there is a welding material that gets into the inside of the pipe, that point will become a fluid flow resistance and can be the starting point of wax deposition. To avoid this, a pipe connecting technique must be selected that does not change the diameter in the pipe.

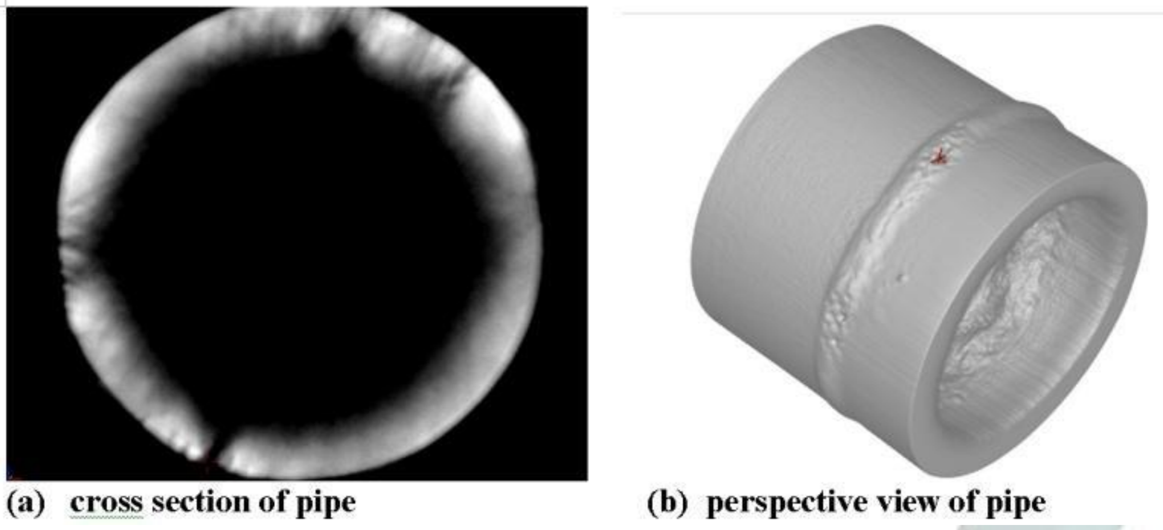

Figure 3. Pipe Welding Connection Technique (Vengrinovich, 2013)

- Pipe Roughness.

Pipe roughness is the value of the smoothness of the inner surface of the pipe. Pipes that have a high roughness value will have a higher flow resistance. With the magnitude of the resistance, it will have an impact on the force (pressure) that must be created to counter this resistance. The roughness of the pipe will increase if there is corrosion on the pipe and also due to various other factors. In pipes with high roughness value, it will be easier to form deposits on the pipe walls because of the large resistance.

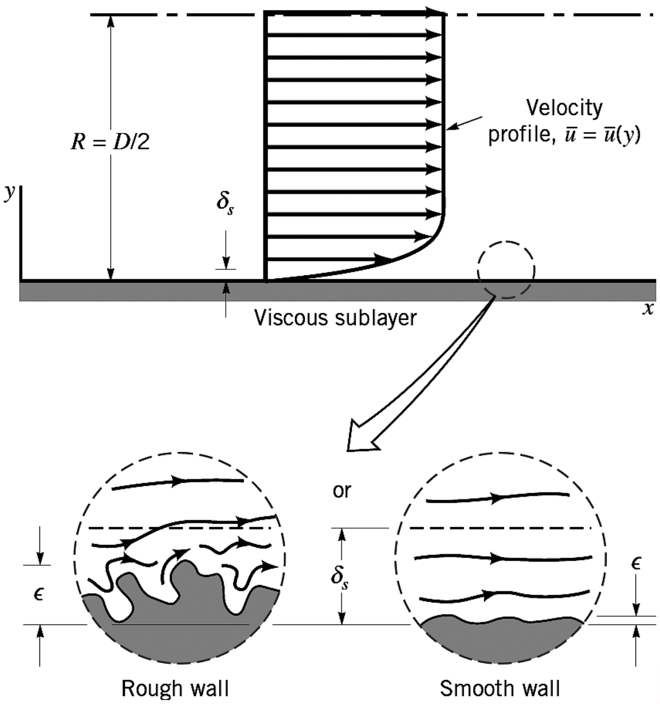

Figure 4. Effect Pipe Roughness to Fluid Flow

- Pipe Diameter.
  The size of the pipe diameter is related to the surface area of the pipe. If it is assumed that the amount of volume flowed is the same, a pipe with a smaller diameter will have a greater friction force which will result in greater difficulty/resistance for the fluid to flow. An example of a change in pipe diameter is the use of a pipe reducer or pipe increaser that will affect the wax deposition process.

The deposition inside the pipe has implications for problems in the production operations of fluid transfer through the pipe. One of the causes of this impact is the reduced area of fluid flowing in the pipe due to sedimentation. Some of the consequences of this phenomenon are: (Bern, 1980)

- Equipment damage.
  Damage to the equipment occurs when the design capacity of the tool that has been made is different from the actual operating conditions. The overload or underload to accommodate problems in a fast way will adversely affect the long-term condition of the equipment.
- Downtime
  Downtime occurs for example if during production operations, equipment damage occurs due to sedimentation in the pipe so that cleaning must be done at that time and if the temporary storage tank is full, other alternatives must be done to transfer the oil, if not well must be temporarily shut-in and maybe can damage the well.
- Addition of Equipment and Materials Needed
  Additional tools and materials need to be done to prevent downtime due to various kinds of problems that can occur. For example, adding a tool in the form of a chemical injection pump if you

are going to use PPD (Pour Point Depressants). The use of tools must also be tested so that the use of tools can be optimal in field conditions.

- Increased Energy Demand

The increased energy demand is the result of flow resistance in the pipe. It takes a greater force to move the fluids if there is additional flow resistance, in this case, pressure. Large flow pressures will require more power in the pump drive engine which is related to fuel consumption.

- Increased Manpower Needs

The need for expert operators will increase if problems occur, for example, to add experts in pigging equipment to clean the inside of the pipe.

- Operation Time

Because wax deposits are very sensitive to temperature, it is recommended that the operation be carried out only during the day because the ambient temperature during the day will be higher than at night. In addition, operations are also cannot be done in heavy rain conditions because the temperature in the pipes will drop due to exposure to rain.

The bad thing that can happen is when the storage tank is full at night or in rainy conditions, the operators have to wait during the day and the rain stops in order to carry out the fluid transfer operation, in other words, have to look for other fluid transfer options or temporarily shut down the well to accommodate the full storage tank.

- Increased Production Costs.

The increase in production costs is an implication of the problems that occur, to deal with the problem you have to add equipment, materials, and energy to solve it, which means you have to buy goods and pay for repair services if there is damage.

3.2. Wax Deposition Prevention and Handling

The process of transferring waxy oil from one place to another using pipe media often faces various problems both from the oil and the pipe itself. Previously researcher found ways and techniques to deal with such problems, and previous studies have also found methods to prevent these deposition problems from occurring. Precipitation can be overcome in a variety of ways, from various ways that exist, can be classified into several methods, namely: (Al-Yaari, 2011)

- Cold Flow

This is done by cooling the oil first before flowing through the pipe. Fluids cooled and transported through pipeline as usual, it will be stable without further solid deposition.

- Chemical.

The chemicals used can be divided into two kinds, the first to dissolve the already formed wax deposits, these chemicals are a solution of a mixture of various chemicals that can dissolve waxes attached to the walls of the equipment. The second to prevent the formation of wax crystals, for example, paraffin dispersants, wax crystal modifiers, surfactant deposit inhibitors, polymer additives.

- Using Different Pipe Material and Pipe Coating.

The use of plastic pipes or plastic-coated pipes has been done to reduce wax deposits. At its original purpose, this plastic pipe is intended to avoid corrosion, good results also show that wax deposits in this pipe are less than steel pipes. This plastic pipe has on problems working pressure limit and working temperature that cannot be too high, too high temperature will deform the pipe.

- Pipe Heater.

  This method aims to minimize temperature drop, hold the temperature at a certain point, and even to add heat to rise to a certain temperature. This method can be done by heating the equipment using induction or by using hot water flowed. This heater should be placed before the accumulation of wax particles is deposited in the pipe. Too high heat applied can be dangerous to pipe, it can make pipe deformed.

- Mechanical.

  This method is used when the wax deposition is already formed and hardened on the tubing or flowline. Using a mechanical tool in the form of a scrapper called pigging. This tool is run using high pressure or using wireline if at the well tubing.

- Microbial.

  Microbials have been studied to prevent or at least reduce the formation of sediment in pipes. This microbial will eat the paraffin particles that are in the oil. But it should be checked so that microbial colonies do not grow too large to cause other new problems.

- Combination.

  Some cases of complex deposition problems require a combination of methods to control the precipitation that occurs and to maintain the rate of production. The selection of combinations used is usually based on previous experience, the combination is also adjusted to the operating conditions and economic value of the project.

3.2.1. Wax Deposition Prevention Using Insulated Pipe.

In this study, further simulation is done with dynamic multiphase flow software to model the method of preventing waxy oil deposition along the pipe. Modeling is done to try to find out how the insulation method and the use of different pipe materials affect the rate of increasing the thickness of the sediment in the pipe.

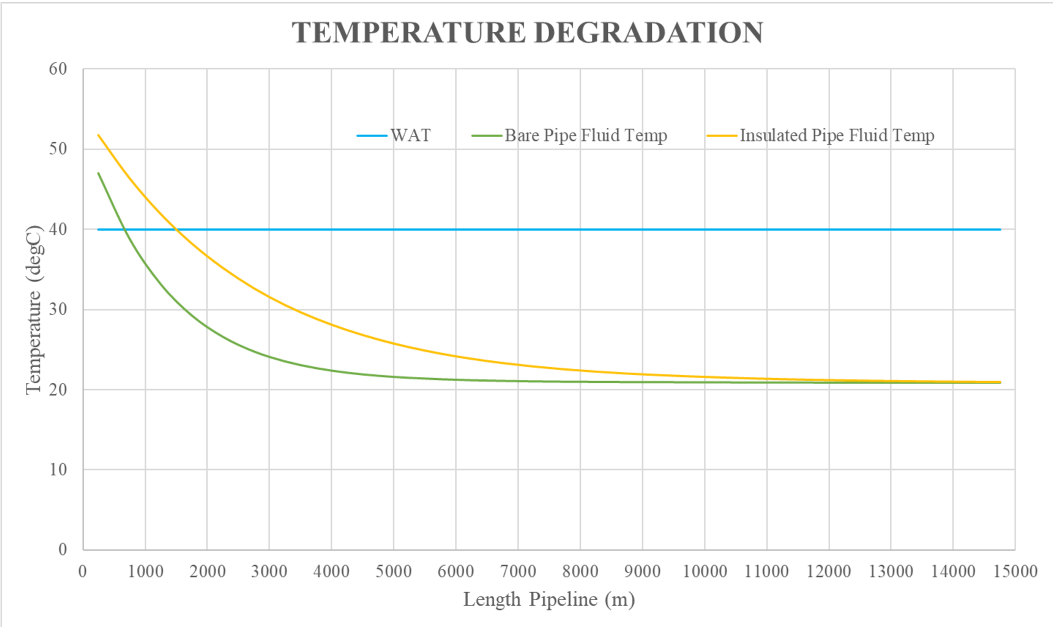

Figure 5. Temperature Degradation Insulated Pipe

The temperature drop in pipes with insulation is slower than those without insulation, at kilometers 0 to 4 there is a very fast drop in temperature from the initial 58°C to about the same as the ambient temperature and then the temperature drop rate can be said to be 0 to 15 kilometers of pipes, whereas the temperature drop in pipes using 5mm PP material as a wrapper, the temperature can be held up to 8 kilometers, is the same as the ambient temperature, which means that with the addition of this insulation material the temperature drop slows down.

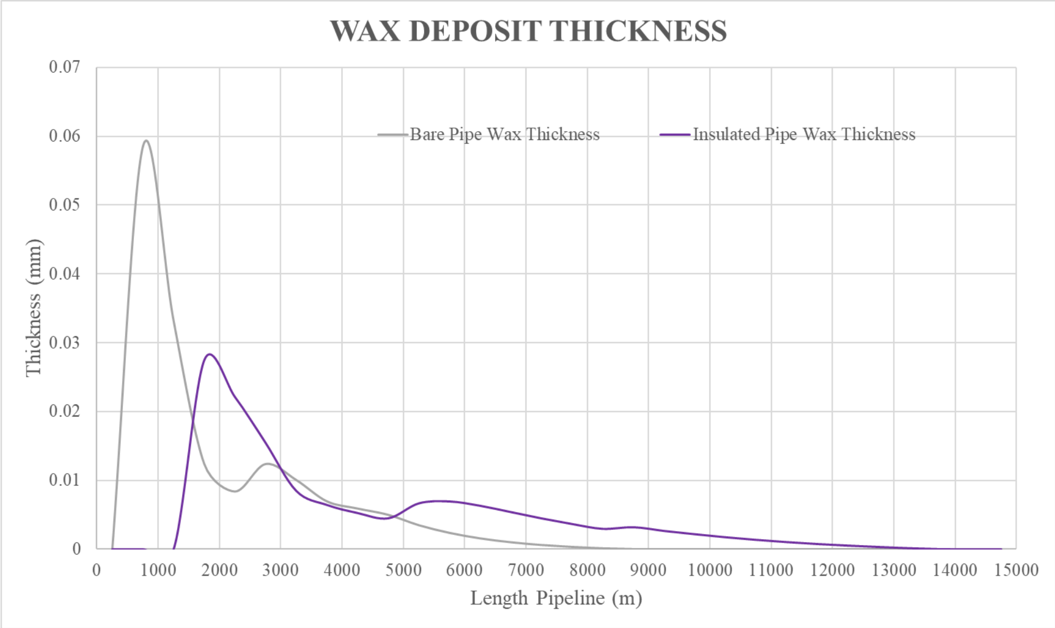

Figure 6. Wax Deposit Thickness Insulated Pipe

The thickness of the sediment formed when viewed in Figure 5. In the case of steel pipes without insulation or exposed directly to the environment, they appear thicker than pipes using insulation or wrapping materials. The main cause is a slower rate of temperature drop. However, in steel pipes with PP insulation, the second peak of deposits is thicker than those without coatings, this is because the fluid whose temperature can be held from escaping, eventually experiences enough heat dissipation to make the sediment thick enough.

The results as shown in the figure show that applying insulation to the pipe using 5mm Polypropylene material slows down the temperature drop. Apart from helping to resist heat loss to the environment, Polypropylene material also has other advantages in its application, including:

- The material has good flexibility but does not change shape easily.
- Has a good moisture resistance.
- Does not conduct electricity or very well insulators.
- Good resistance to acidic and alkaline chemicals.
- Does not cause chemical reactions when exposed to hot temperatures.

Besides its advantages, the use of Polypropylene material also has disadvantages such as:

- Has a high coefficient of thermal expansion which limits the application of this material at high temperatures (melting point of material 130 ° C).
- Susceptive to direct sunlight.
- Easily degraded by UV rays.
- Poor resistance to chlorinated solvents and aromatic chemicals.
- Difficult to apply paint or coating because it has a fairly slippery surface.
- Highly flammable.
- Susceptive to oxidation.

- Capex is large enough if it is applied along the pipe.
- Difficult to repair if there is a leak.

3.2.2. Wax Deposition Prevention Using FRP (Fiber Reinforced Plastic).

The use of plastic materials is also attempted to simulate with the consideration that plastic pipe material has a smaller surface roughness value than steel pipe, which is 0.000005 ft, while steel pipe has a roughness value of 0.00015 ft.

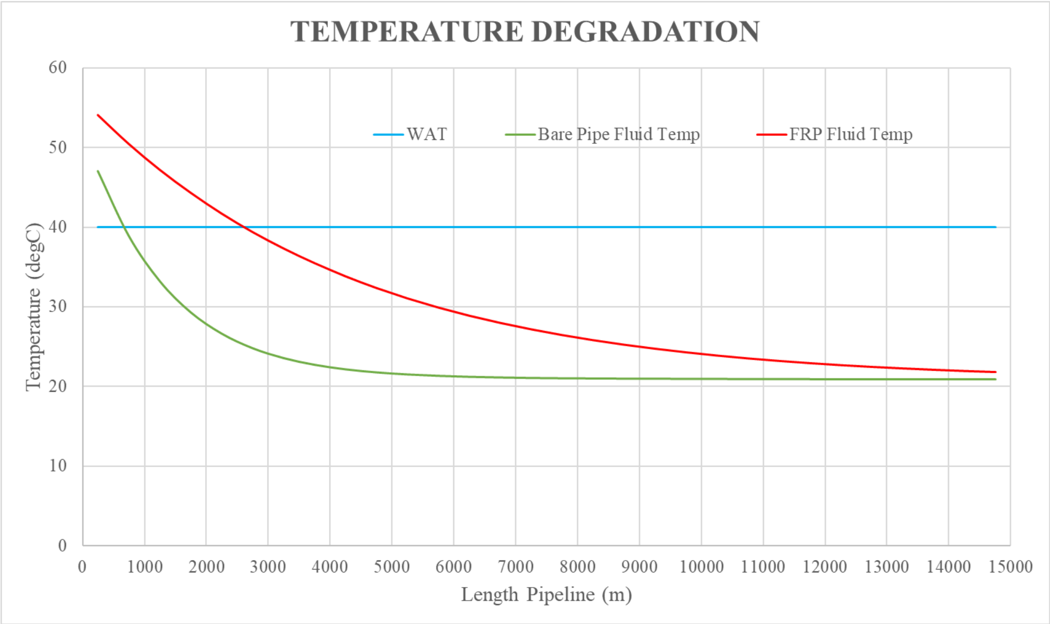

Figure 7. Temperature Degradation FRP

In Figure 7. the use of pipes made from FRP can hold temperature drops. The temperature drop in the steel pipe is very fast, at the starting point it immediately drops about 47°C from the initial temperature of the fluid in the 58 ° C tank, in the FRP pipe the initial temperature of the fluid does not drop immediately but can be held around 56°C. The scenario of using steel pipes in the simulation results shows that the fluid temperature immediately drops below WAT at around 500 m points, in the use of FRP pipes the temperature drop is quite gentle so that the fluid temperature in the new pipe touches WAT around 2500 m. By comparing the simulation results of steel pipes and FRP, it shows that FRP is better able to hold the temperature drop in the fluid.

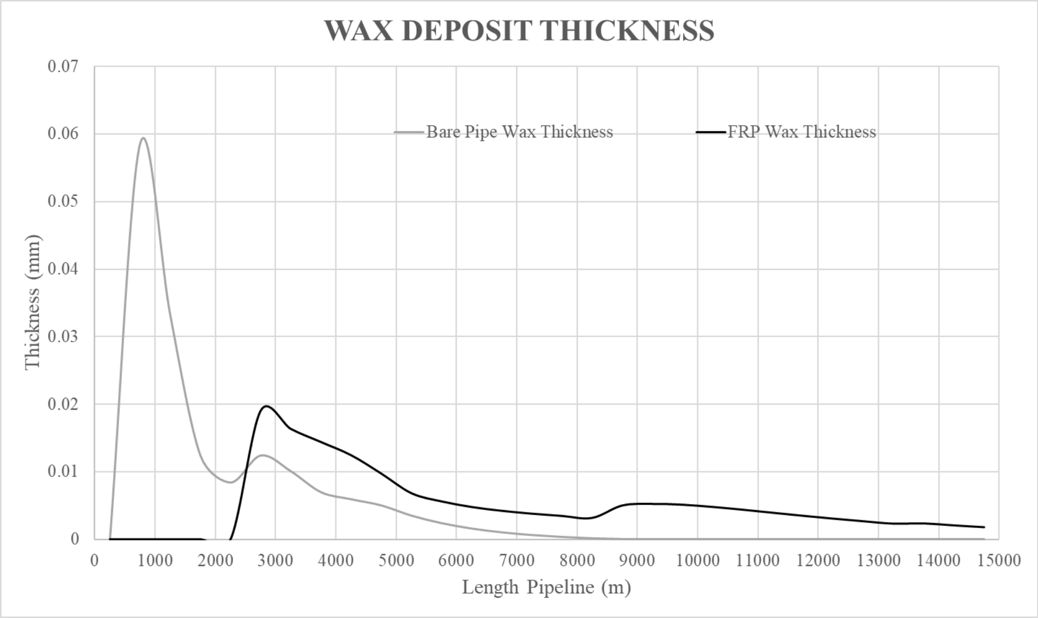

Figure 8. Wax Deposit Thickness FRP

In Figure 8. you can see the difference in wax deposits in pipes made of carbon steel and pipes made of plastic. Around kilometer 2.5 a new wax deposit is formed, in line with the graph of the temperature drop that just touched WAT at kilometer 2.5 in the FRP pipe scenario. Immediate deposition thickening occurred to a peak of about 0.02 mm and thereafter there was no thickening after the sediment peak at kilometer 3 because the temperature decreases which tends to be stable and has a constant temperature drop does not fluctuate.

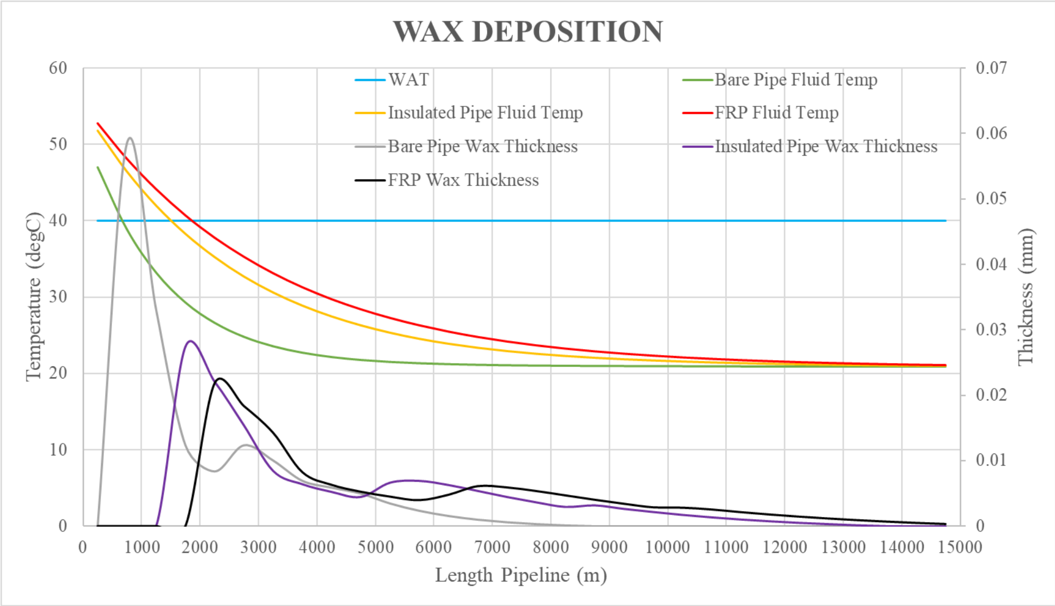

Figure 9. Wax Deposition 3 Scenarios

In the simulation, the operating time is set to 12 hours, but to see in a long period, an integration of time is made for 30 days, with the assumption that during these 30 days fluid pumping is continuous without stopping and there are no repairs and equipment failure. The purpose of doing the integration for 30 days is to see how thick the wax deposits in the pipe if pumping is carried out for that long. But in real condition, this is impossible, because equipment must be shut down for maintenance or there are no fluids to feed the pump to work 24/7 for 30 days nonstop.

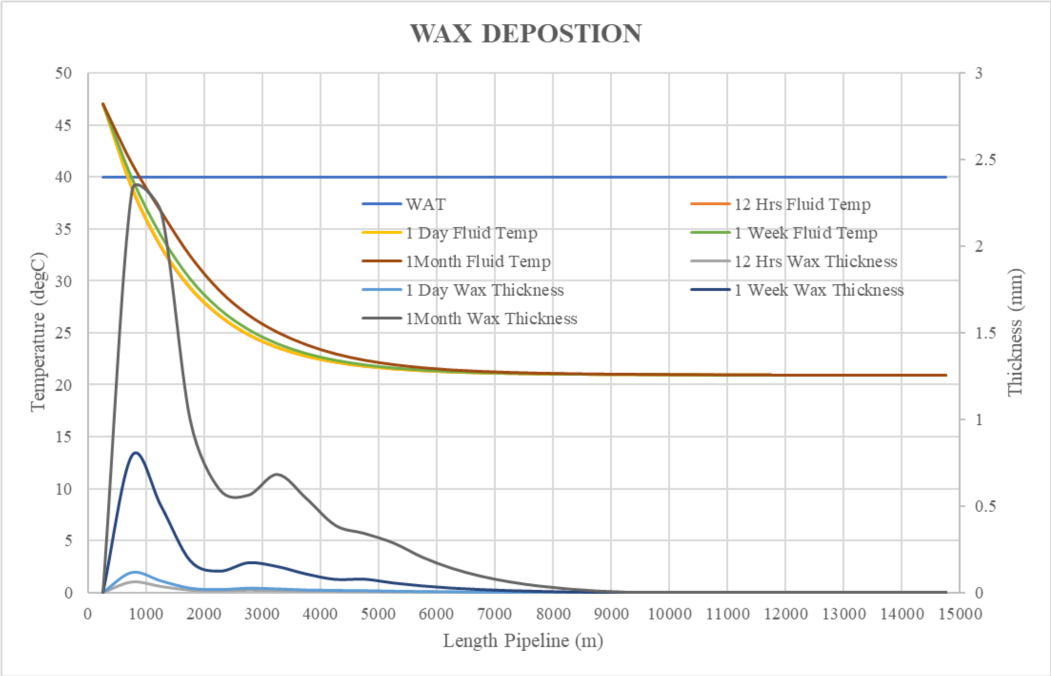

Figure 10. Wax Thickness for 30 Days Base Case

In the simulation results with integration settings for 30 days or one month of operation to flow oil through the pipe, the results are shown in Figure 10. The results showed that carrying out the fluid transfer for one month, the thickest wax deposit was about 2.5 mm when compared to the inner diameter of the 6inch or 152.4 mm pipe, the sediment had covered about 1.6% of the diameter. In the simulation using dynamic multiphase flow software using RRR correlation, it is known that deposition occurs in the entire inner pipe circumference.

Figure 10. also shows the difference in temperature drop around 0 to 5 kilometers of pipe. This is because when the initial operation is carried out there is a difference in fluid temperature with the pipe temperature, the temperature of the hot fluid adapts to the temperature of the pipe underneath so that a very rapid temperature drop occurs at the beginning of the fluid transfer operation through this pipe. Insufficient time, the pipe temperature will also rise due to the continuous exposure to heat from the fluid temperature so that the temperature in the pipe will increase and the decrease in fluid temperature can be seen on the graph which will look more sloping. This temperature adjustment can occur at a point of very rapid temperature drop. About more than 5000 m the temperature of the fluid does not increase because the temperature of the fluid is almost or even the same as the ambient temperature.

Wax deposits in the pipe can also occur if after the fluid transfer operation cleaning is not done so that the oil that is left in the pipe settles, if the fluid transfer operation is carried out again, then at the sediment point of the remaining fluid left in this pipe it can be blocked and can thicken if the wax crystals have come into contact with these deposits. So, after the operation has been carried out, cleaning the inside of the pipe is must be done.

Pipe cleaning is must be done at certain intervals or periods. Cleaning can cover the outside and inside of the pipe. Cleaning of deposits in pipes can be done using mechanical methods or using chemicals. The use of mechanical means is carried out by pushing all the impurities in the pipe with a tool called pigging, but if the sediment has hardened, chemicals are used to dissolve this sediment. Cleaning of pipes is carried out not only to remove dirt but also to inspect pipe condition, inspections can include pipe thickness, corrosion rates, leaks, conditions of joints and fittings, pipe deformation rates, and other physical inspections. In an offshore pipeline system, inspections can be carried out using wireline or ROV (Remote Operated Vehicle).

4. Conclusion

Based on the results of the research that has been done, it can be concluded that:

1. The simulation results showed there was a problem of decreasing the diameter of the pipe caused by the formation of wax deposits on the pipe walls.
2. In simulation scenarios using only steel pipes, deposition is formed from 0 to 8 km of the pipe which starts at about 500 meters with the thickness of the sediment after 12 hours of operation the thickest deposition is 0.06mm.
3. The results obtained from the simulation show that the temperature becomes the main factor that contributes to the wax deposition process. In this case, when the temperature drop, the thickness of the deposit will increase.
4. From 3 scenario simulation result, using FRP is the best choice (Results may change if an AMDAL study is conducted, do socio-cultural study to the community, and analyzes the economical of the project).

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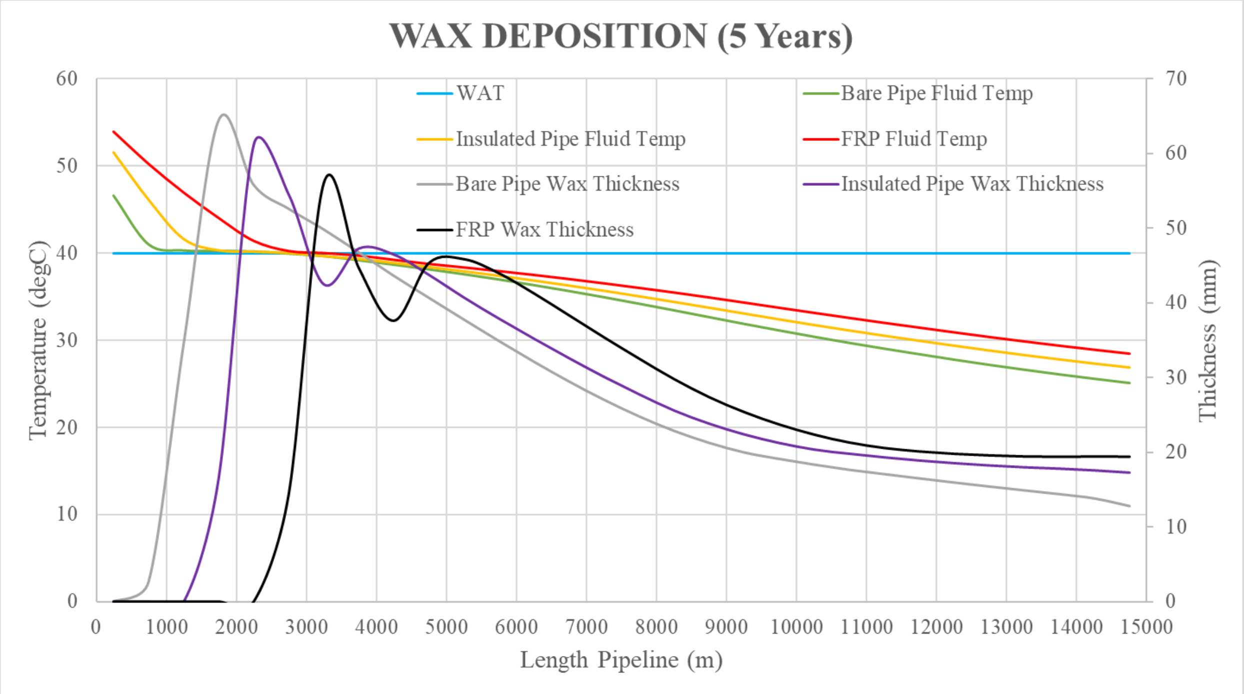
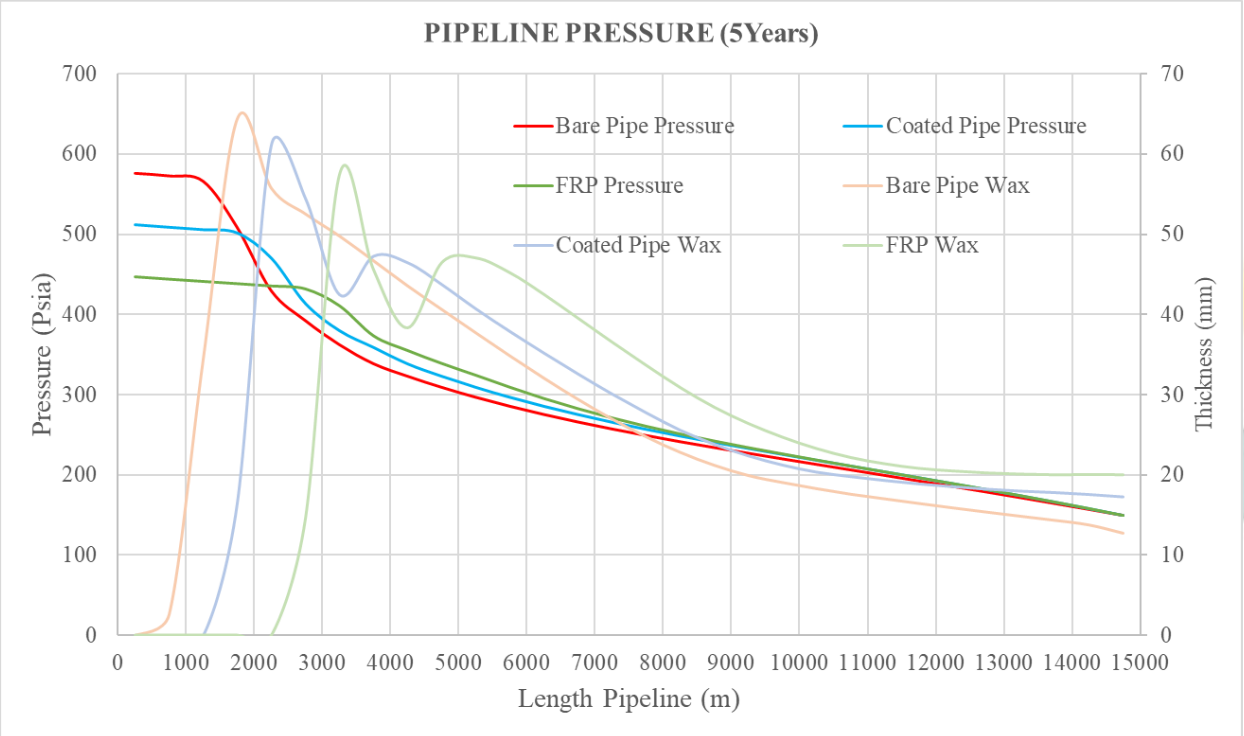
Deposition for 5 Years Operation



Pressure Vs Thickness for 5 Years Operation



Oil Viscosity Vs Temperature for 5 Years Operation