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Analysis of the Effect of Tubing Material and External Insulation to Wax Deposition Formation in Vertical Waxy Oil Well

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Abstract

Flow Assurance is a nomenclature in the oil and gas industry which can be interpreted as guaranteeing the success of hydrocarbons (oil and gas) flowing from the reservoir to the point of sale and avoiding flow assurance issues, one of them is due to wax deposition (Ansyori, 2013). Waxy oil, also known as HPPO (High Pour Point Oil) is an incompressible type of oil, with high saturate, aromatic, and paraffin content (Joesoef, 1978). In principle, waxy oil will form a wax deposit, either in the pipe or tubing if the temperature of the flowing fluid has touched the Wax Appearance Temperature (WAT), or the highest temperature at which the wax particles begin to precipitate (Ansyori, 2013). This research was conducted using synthetic databases collected from several published journals with the aim of modelling the flow of waxy oil in vertical onshore production wells, identifying problems that may occur during the oil production, simulating the starting point of wax deposition, and comparing several scenarios regarding the factors that affect deposits. The results of this study indicate that one of the most influential parameters in the process of forming wax deposits is when the fluid temperature is below the Wax Appearance Temperature (WAT). The simulation results from the scenarios, it is found that the higher the thermal conductivity of a tubing material, the faster the wax deposition occurs, and produces the highest thickness of wax deposits. Other research results obtained are, with simulations using insulation, show that tubing with an insulating material Fiberglass with a high insulation thickness is proven to be the most effective in preventing the wax deposition process. The presence of wax deposits in the tubing has a negative impact, one of which is a reduction in the inner diameter of the tubing, so that it will reduce the flow rate, and which in the end the wax will create a plug which makes the crude oil unable to be produced again.

Keywords: Flow Assurance, Flow Rate, Temperature Loss, Wax Thickness, Waxy Oil.

Introduction

Flow Assurance includes all sources, processes, facilities and conditions that affect the successful flow of hydrocarbons from the reservoir to the point of processing/sales (PPSDM Migas, 2016). Some of the focuses of flow assurance include gas hydrates, waxy oil, slugging, scale deposits, and heavy oil flow methods. Piping or transportation problems in Indonesia are generally caused by a blockage that interferes with the flow process, the blockage is formed due to the presence of solids or minerals deposited on the pipe wall which causes the inside diameter of the pipe to decrease. Waxy oil is an oil that contains a lot of wax or wax, saturates, and aromatics which at a certain temperature will cause crystallization of the wax. 80% of the global energy needs are oil and gas. Waxy oil production is predicted to increase due to a decrease in conventional oil production, of which around 20% of world oil reserves are waxy oil (Theyab, 2018). The current production of waxy oil has increased from 1960 around 1 million barrels per day up to 24 million barrels per day in 2009 (Chala, 2017).

Waxy oil can cause various complex production problems, because at a certain temperature it can cause wax deposits which will eventually hinder the transportation process. Temperature reduction is the most common cause of wax deposition because wax solubility in hydrocarbon fluids decreases as the temperature is lowered. Wax Appearance Temperature (WAT) is another term for cloud point, which is commonly used for waxy oils. The amount of WAT in waxy oils will be higher than oils that have little or no paraffin. WAT can be interpreted as the highest temperature at which paraffin begins to form crystals for the first time (Emmanuel, et.al, 2016). In accordance with the nature of waxy oil, where when the temperature passes through WAT, it will create wax deposits for the first time which is marked by the start of the rising precipitation curve of the wax deposits (Z.Huang et al., 2015).

There are several factors that cause the formation of wax deposits in pipes or tubing (Prasetyo, A, 2019), namely:

- The composition of wax in crude oil, the more the thickness of the wax deposit increases
- Decrease in temperature, if the temperature drop is high, the wax deposition will increase
- The physical condition of the pipe or tubing, such as roughness; bending; diameter; and inclination
- Flow rates and flow patterns in pipes or tubing

Based on Sousa, A.M et al, 2020, simply the process of forming wax deposits begins with the presence of a thin gel layer around the tubing wall which is formed due to the temperature having passed the WAT, which at a certain time the wax deposit will increase and harden. So, based on this mechanism, the presence of wax deposits in the tubing will cause several problems, including Bern, 1980:

- Decreased production due to reduced tubing diameter
- Tool damage
- The need for experts and materials is increasing
- Increased production cost

Based on the problems that may be caused by the production of waxy oil, this research has a main focus, namely knowing the process of forming wax deposits in tubing. In addition, this research also focuses on efforts to prevent wax deposits from forming in tubing, namely by conducting research on tubing materials used with different heat conductivity, as well as conducting trials on the use of external insulators on tubing with various materials and insulator thicknesses as an effort. prevention or minimizing the rate of decrease in the temperature of the fluid in the tubing to the environment, so that the resulting wax deposits can also be minimized.

The recommendations given are very likely to be carried out, taking into account that the regulation of the flow rate, the selection of tubing materials and the need for insulators related to the prevention of wax deposits will be much easier and is expected to minimize the costs that will later be incurred in remedial action if waxed. has formed in the tubing.

Methodology and Data

- **Methodology**

This research was conducted using synthetic data with some adjustments made. The research begins by collecting data used, such as reservoir fluid data, well schemes, tubing materials and insulating materials used.

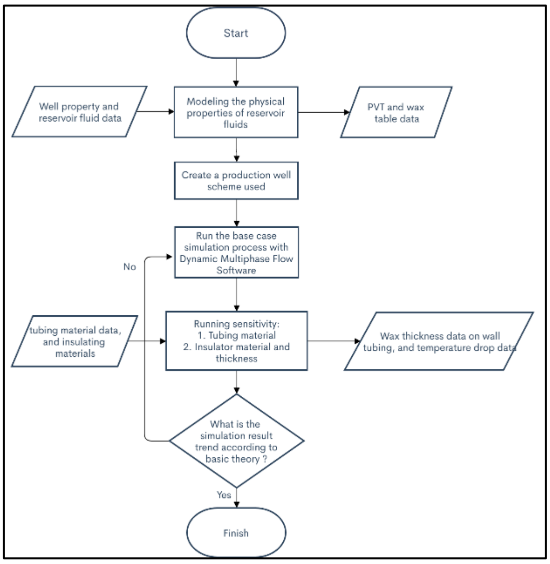

Figure 1. Methodology

- Equation of Fluid Temperature Drop in Tubing

Calculation of temperature distribution can be calculated using Shie & Beggs (2008) correlation, as follows:

$$T = T_d - G_t\left(D - A\left(1 - e^{\frac{D}{A}}\right)\right) \quad (1)$$

where,

$$A = 0.0063 Wt^{0.4882}\, d^{-0.3476} API^{0.2519} \rho_L{}^{2.915} Pwh^{0.2219} \quad (2)$$

Where A = correlation constant; Wt = total mass flow (lb/s); Td = formation temperature (F); Gt = Geothermal gradient; D = depth (ft); and d = tubing diameter (in).

- Equation of Wax Deposit Thickness Rate in Tubing

The rate of formation of wax deposits in tubing is in accordance with Fick's Law of Diffusion, namely:

$$Wm = \rho_w A D_m \frac{dC}{dT}\frac{dT}{dr} \quad (3)$$

Where *Wm* = wax deposition rate (kg/s); ρ_w = *wax density* (kg/m^3); A = tubing area (m^2); *Dm* = diffusion coefficient (m2/s); *dC/dT* = wax concentrate to change of temperature (1/C); and *dT/dr* = temperature radial gradient (C/m).

- Effect of Material on Temperature Loss

Fourier's law examines heat transfer through solid materials whose magnitude is relative to the outer area and wall thickness of the tubing which is also affected by the temperature difference between the inside and outside of the tubing (Serway & Faughn, 2003).

$$q = k\, A\, \frac{dT}{s} \quad (4)$$

Where q = *heat transfer per unit time* (W, Btu/hr); A = *heat transfer area* (m^2, ft^2), k = *thermal conductivity* of tubing material (W/mK or W/mC); dT = temperature difference between fluid and material (C); s = material thickness (m).

- **Data**

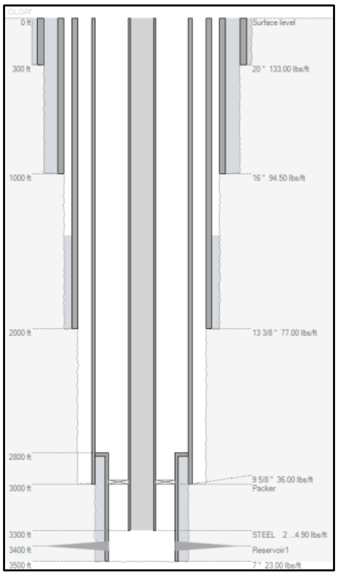

Figure 2. Well Schematic

The picture above is a schematic of the well used in the simulation. The well is an onshore vertical well which has 1 reservoir zone.

Reservoir and Production Data	
Reservoir Pressure (psi)	2002
Reservoir Temperature (°C)	62
Surface Temperature (°C)	33
BHP (psi)	1200
Wellhead Pressure (psi)	300
Surface Temperature (°C)	33
Productivity Index (PI) (bbl/d/psi)	1.5
Production Estimation (bbl/d)	1203
Water Cut (fraksi)	0
Fluid Density (kg/m3)	870
Mass Flow (kg/s)	1.9

Table 1. Reservoir and Production Data

The table above is a table of reservoir and production data used in this simulation.

Base Case Data	
Well Type	Vertikal
Mass Flow (kg/m3)	1.9
Water cut (%)	0
Fluid Density (kg/m3)	870
WAT (°C)	50.5
Tubing Interval (ft)	3300
OD Tubing (inch)	2 5/8"
Tubing Thickness (mm)	4.8425
Tubing Material	Carbon Steel
Heat capacity (J/kg-C)	485
Heat Conductivity (W/m-C)	50
Roughness Tubing (ft)	0.000164042
Insulation	No
Duration of Simulation (days)	30

Table 2. Base Case Data

Result and Discussion

- **Reservoir Fluid Simulation**

Reservoir fluid simulation is carried out by entering the composition of oil and natural gas according to known data. Simulations are carried out using PVT-Sim software which aims to determine the distribution of the reservoir fluid properties for each certain temperature and pressure.

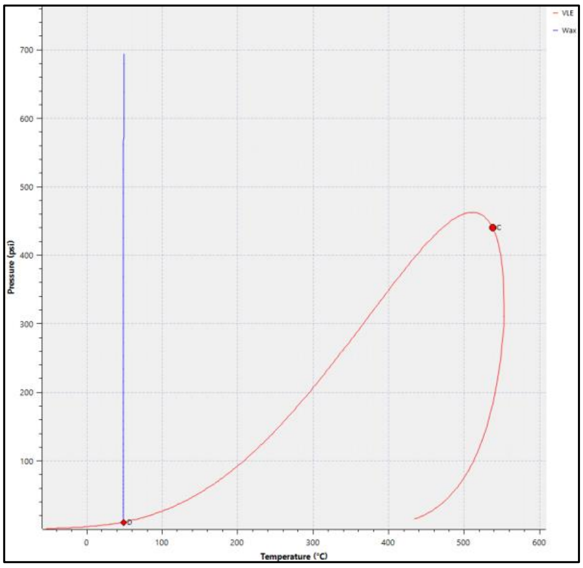

Figure 3. P-T Diagram

The reservoir fluid data used in this simulation is oil with a weight of 31.27°API with a GOR of 150 ft^3/bbl. Figure 4.1 above is a graph of the pressure to temperature curve of the simulated reservoir fluid. Based on the simulation results, the WAT is 48.5 °C and the wax content is 18.2%.

- **Sensitivity of Tubing Material**

The next simulation carried out in this study is the sensitivity of the type of tubing material that has different thermal conductivity values to the decrease in temperature and the resulting wax deposits on the tubing. In the study of tubing material sensitivity, 4 types of materials were used, namely Carbon Steel, Copper, Teflon, and PFA which have different conductivity. However, these four materials have the same diameter, roughness, and thickness, so the resulting output is purely due to the difference in the magnitude of the thermal conductivity.

Material *Tubing*	*Heat Conductivity (W/m-K)*
Carbon Steel	54
Copper	401
Teflon, PTFE	0.4
PFA	0.14

Table 3. Types of Tubing Materials

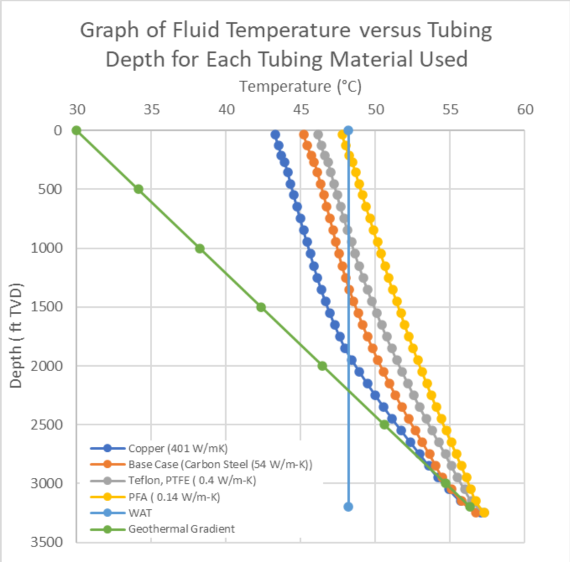

Figure 4. Graph of Fluid Temperature for Each Tubing Material

Figure 4. above is a temperature reduction curve for each type of material used. Based on the graph above, it can be seen that the fastest rate of temperature reduction occurs in tubing with Copper material, then Carbon Steel, then Teflon, and the lowest temperature decrease rate is achieved when tubing uses PFA material. From this figure, it can be seen that for Copper material the temperature drop curve touches the WAT at about 1900 ft TVD depth from the wellhead; for Carbon Steel material at a depth of 1450 ft TVD, for Teflon material at a depth of 900 ft TVD; and for PFA material at a depth of 100 ft TVD from the wellhead.

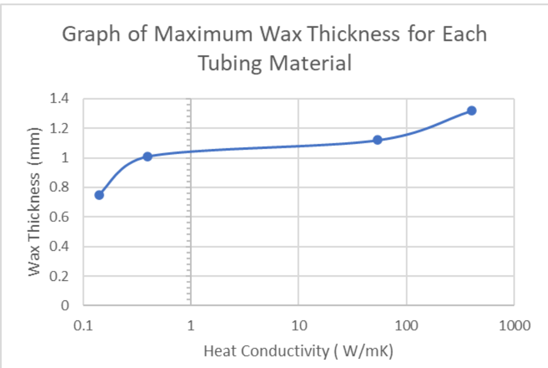

Figure 5. Graph of Heat Conductivity to Wax Deposition Thickness

Figure 5. above is a curve of the thickness of the wax deposits formed in the tubing for each type of material used. Based on Figure 4., it is known that the fastest temperature decrease rate occurs in Copper and Carbon Steel, and the smallest occurs in PFA material. Based on the picture above, it can be seen that the highest wax deposition occurred in Copper material which was 1.31 mm, then for Carbon Steel material was 1.15 mm, then for Teflon material was 0.95 mm, and for PFA material was 0.75 mm at the point where the curve touches the WAT for each material.

This is purely due to the different thermal conductivity of the four types of materials, where the highest thermal conductivity is Copper, which is 401 W/mK, then Carbon Steel, which is 54 W/mK, then Teflon with 0.4 W/mK, and the most small is the PFA with a large 0.14 W/mK. This is in accordance with the theoretical basis used, namely the higher the thermal conductivity of a material used, the material will easily absorb heat from the system and release it to the environment, resulting in the temperature of the system will easily experience a decrease in temperature. Thus, it is easier for the system to experience a decrease in temperature, the faster the fluid will reach WAT, so that wax will form more quickly and with the same simulation time, the wax deposition produced is the thickest compared to materials with low thermal conductivity.

- **Sensitivity of External Insulator Material and Thickness**

After conducting research and simulations regarding the effect of several types of physical properties of the tubing used, the authors conducted further research using Dynamic Multiphase Flow software to model the effect of the use of insulation on the tubing used and the thickness of the insulation on the rate of decrease in the temperature of the fluid in the tubing. and its effect on the process of formation of the resulting wax deposits.

Material and Thickness of Insulator			
Type of Insulator	External Insulator		
Thickness of Insulator	0.1 Inch	0.5 Inch	1 inch
Material Insulator	*Polypropylene Foam (PPF)*		
	Calcium Silicate (CS)		
	Fiberglass ICS)		

Table 4. Insulator Material and Thickness

In this study, three types of materials were used as insulators, namely Polypropylene Foam (PPF), Calcium Silicate (CS), and Fiberglass (FG) using three types of thickness in the simulation, namely 0.1 inch; 0.5 inch; and 1 inch.

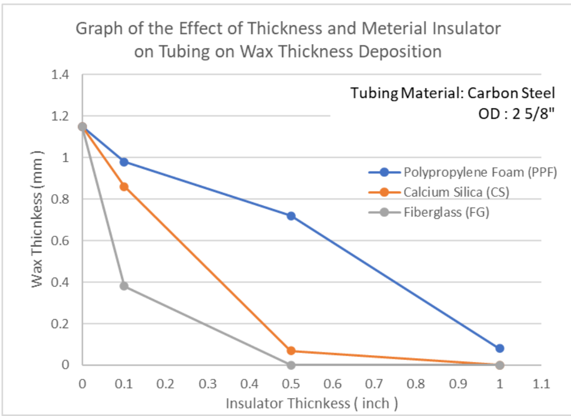

Figure 6. Graph of Insulator Material and Thickness to Wax Deposition Thickness

The three types of insulation provide the same trendline, namely the thicker the insulator, the smaller the wax thickness as the temperature drop in the system decreases. This is in accordance with Fourier's Law (Equation 4. above), it can be seen that with the type of material, the area of the fluid flowing, as well as the same thermal conductivity, the greater the thickness of a given insulation will produce a smaller or inversely proportional heat transfer, so it seems - if it gives a blanket effect, where the process of heat transfer between the system to the environment will have a smaller rate when compared to a thin insulator thickness. Ignoring the economic factor, it can be seen that when an insulator thickness of 0.1 inch is used, FG material is proven to be effective in preventing wax formation. At a thickness of 0.5 inch, FG and CS materials are proven to be effective in preventing wax formation in tubing, and at a thickness of 1 inch, all three types of materials are proven to be effective in preventing wax formation in tubing.

Conclusions

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

- The type of reservoir fluid used has a wax deposition content of 18.3 % , and has been proven to have the potential to form wax deposits in the tubing.
- Based on the sensitivity results of the tubing material used, it was found that the PFA material had the best performance because it produced the smallest wax deposits.
- Based on the sensitivity results of the insulator material, it is concluded that by using the same tubing material, the Fiber Glass insulator material has the best performance because it produces the smallest wax deposits due to low heat conductivity. For the three types of insulator materials, it is also concluded that the thicker the insulator is used, the better it will be in preventing temperature loss to the environment, and preventing wax deposits from forming.

The suggestions given by the author to the research of this final project are:

- Evaluate the simulation results by means of validation to the laboratory and the results of operations in the field.
- Performing simulations by adding more complex parameters or variables, such as the presence of a deviation well or the presence of downhole equipment that can increase restrictions and can be a point where wax is deposited.
- Economic analysis needs to be carried out along with efforts to prevent wax deposition processes in order to obtain the most economical and efficient method.

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Attachment

Komponen	*Mole (%)*	Komponen	*Mole (%)*
C2	0.177	C11	3.733
C3	1.57	C12	4.067
i-C4	1.05	C13	3.53
C4	2.887	C14	2.919
i-C5	2.468	C15	3.2544
C5	3.017	C16	3.63
C6	5.55	C17	3.58
C7	9.8	C18	3.62
C8	11.86	C19	5.01
C9	7.09	C20+	17.23
C10	3.977		

(1)

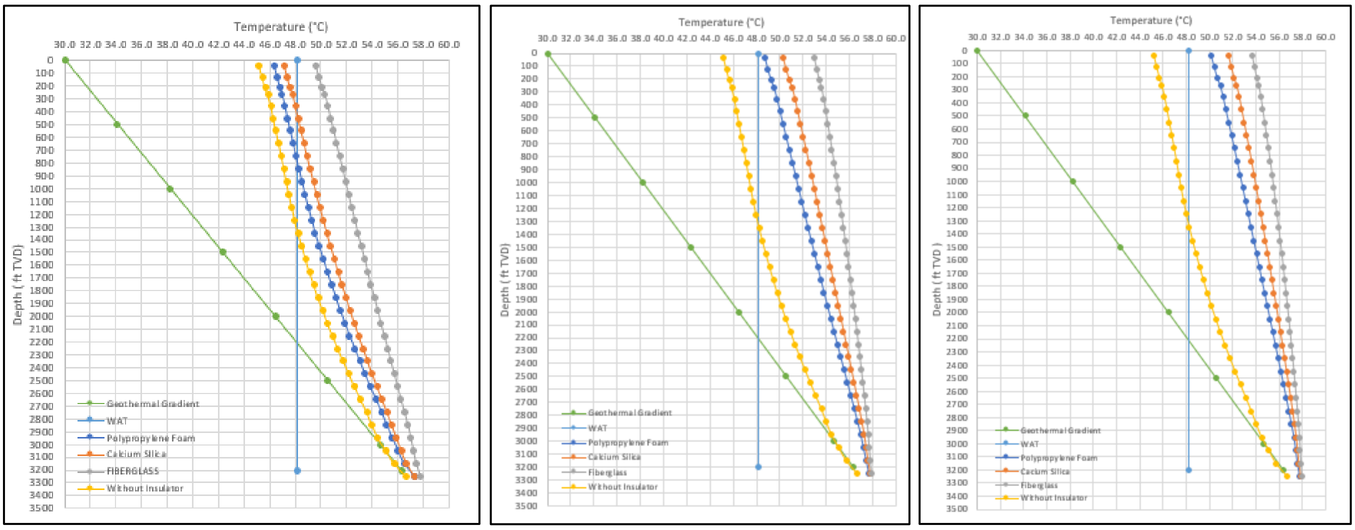
Komponen	*Mass (%)*
Metana	84.5
Etana	6.5
Propana	4
Butana	2.5
Pentana	1.5
Heksana	0.5
CO2	0.5

(2)

Parameter	*Symbol*	Unit	Nilai
Wax content	-	wt%	19
API Gravity	-	API	31.27
Wax Appearance Temperature	WAT	Celcius	49.62
SG Gas			0.7
SG Minyak			0.86
GOR	-	cuft/bbl	150

(3)

Figure 7. Oil Properties (1); Gas Properties (2); and Reservoir Fluid Properties (3)



(1) (2) (3)

Figure 8. Fluid Temperature Profile with External Insulator 0.1 inch (1); 0.5 inch (2); and 1 inch (3)