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# AN EXPERIMENTAL AND SIMULATION STUDY OF WAX DEPOSITION IN HYDROCARBON PIPELINE

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## ABSTRACT

Hydrocarbon transportation in the deepwater pipelines is affected by the low temperature causing a problem such as wax deposition and hydrate formation. The flow assurance in the deepwater pipelines is very important due to the precipitation of the solid phase of wax on the pipe wall creating blockages and reduces or stops production. There are several mitigation methods were used in the different oil fields around the world to reduce wax deposition such as inhibitors and thermal insulation.

This work describes the underlining wax models implemented in OLGA, depending on the experimental data of this study. OLGA software was used to simulate the wax deposition process to predict the behaviour of the wax deposition. A comparison between the experimental wax thickness and the predicted wax thickness was presented. Since simulations based on the default wax parameters did not achieve a complete match with experiments, it was important to find out to what extent tuning of wax parameters was necessary. Three scenarios were created to match the experimental wax thickness, including studying the effect of changing wax porosity in OLGA, changing the crude oil components and the influence of simulation time on wax deposition. The findings of the numerical simulation, after tuning the analogical properties (assumptions), show agreement with the experimental results.

***Keywords***: *Wax deposition thickness, OLGA Simulator, Tuning OLGA parameters, Improve prediction.*

## I. INTRODUCTION

The current work is a study of wax deposition, a phenomenon that is one of the main flow assurance problems faced by the oil industry, affecting numerous oil companies around the world. Wax deposition can result in the restriction of crude oil flow in the pipeline, creating pressure abnormalities and causing an artificial blockage leading to a reduction or interruption in the production. However, in an extreme case, this can cause a pipeline or production facility to be abandoned. The wax deposition also leads to formation damage near the wellbore, reduction in permeability, changes in the reservoir fluid composition and fluid rheology due to phase separation as wax solid precipitates.

Wax can precipitate and arises when paraffin components in crude oil precipitate and deposit on the cold pipeline wall when the inner wall temperature (inlet coolant temperature) drops below the wax appearance temperature. Wax appearance temperature (WAT) is the temperature at which paraffin wax start to precipitate[1]. The main factor that affects the wax deposition process is the low temperature, which means that subsea pipelines are especially vulnerable. Therefore, wax deposition prevention becomes very important in deep- water oil production. Wax deposition in crude oil production systems can be reduced or prevented by one or combination of chemical, mechanical, and thermal remediation methods. However, with the advent of extremely deep production, offshore drilling and ocean floor completions, the use mechanical and thermal remediation methods becomes prohibitive economically, as a result, use of chemical additives as wax deposition inhibitors is becoming more prevalent [2]

OLGA is a multiphase flow simulator that has been widely used for several decades in the flow assurance industry [3], in order to study and predict the wax deposition process in the hydrocarbon pipelines. OLGA is structured into modules and some of these modules include the slugging and wax deposition module that is commercially used for wax precipitation and slugging prediction and calculations in the oil and gas industry.

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OLGA software was used in this research to study the effect of the factors that control the wax deposition process and to easily study the behaviour of the wax deposition system.

The findings of the numerical simulation, using a simulator to reproduce the experimental results by tuning analogical properties (assumptions), show agreement with the experimental results.

## II. METHODOLOGY

### 2.1 Experimental Methodology

The experimental data of wax deposition thickness in the pipe of the work of Theyab and Diaz (2016a) were used during this research to estimate the predicted wax thickness using OLGA software. They have used a rig to recirculate the waxy crude oil inside the test section to measure wax thickness and to study the effects of the inlet coolant temperatures 14, 24, 33 and 40 ºC, and the effect of the flow rate 2.7 and 4.8 L/min, on wax deposition thickness.

### 2.2 OLGA Wax Modules

In order to construct an OLGA model, it was necessary to gather data (e.g. pvt file and wax file), to build the model and define the simulation case, and to run simulations and view results in the form of graphs. Wax deposition simulations performed in this work are done using the OLGA 2014 version. OLGA receives the crude oil propriety input values (for example, the weight percentage of carbon numbers, density, compressibility, viscosities, surface tension, enthalpies, heat capacities and thermal conductivity) in pressure and temperature values. These properties enter the OLGA simulator as a tab file created from the tab, generating a PVT package such as the PIPEsim [4].

The wax deposition module in OLGA further requires details about the wax component, structure, porosity, etc., converted to a wax file in a tab format generated from the PIPEsim wax interface. The wax file provides information about the wax fraction as a function of the wax forming components, temperature and pressure, and wax mixture. Results and prediction of the OLGA simulator are largely influenced by the accuracy of table values generated from PIPEsim [4]. The OLGA simulator process steps are shown in figure 1.

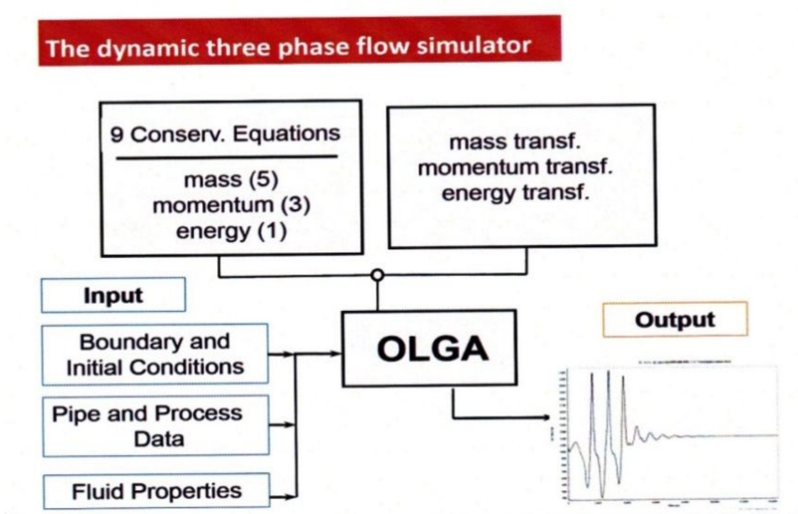


*Figure 1: Steps of the OLGA simulation process [5].*

### 2.3 Crude Oil Properties used in PIPEsim to Create PVT File

It was mentioned above in this chapter that the crude oil used in this study is from one of the oil field reservoirs in India and during characterisation the crude oil was found to be close to the crude oil of the Upper Assam oil field, India, which was used in the study of Jha et al. (2014) [6], as shown in table 1.

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In order to run the simulation using OLGA software, two types of data were borrowed from the study of Jha et al. (2014) [6], see tables 2 and 3, the data of carbon number distribution in the crude oil, and the data of distribution the normal and non-normal paraffin in wax of crude oil. Those data should be entered in PIPEsim 2013 software to convert it to a pvt tab file and wax file, respectively, in order to use it to run the OLGA simulation. Other necessary data was used from the crude oil of this study such as the percentage of saturates, aromatics resins, asphaltene, specific gravity, API, density, WAT and wax content.

A sensitivity study was done on crude oil composition, using OLGA software, to reduce the difference between the crude oils for this study and that of Jha et al. (2014) [6].

*Table 1: Characterisation of crude oil for this study and Jha et al.'s (2014) study.*

| Property | Value of Theyab and Diaz (2016a) study [2] | Value of Jha et al.'s, (2014) study [6] |
|---|---|---|
| Density g/cm³ (15ºC) | 0.85 | 0.82 |
| Specific Gravity (60/60 ºF) | 0.85 | 0.82 |
| API Gravity (60 ºF) | 35 | 40.51 |
| Saturates Content (wt%) | 74.91 | 66.46 |
| Aromatics Content (wt%) | 20.44 | 22.86 |
| Resins Content (wt%) | 4.26 | 10.34 |
| Asphaltene Content (wt%) | 0.39 | 0.34 |

*Table 2: Carbon number distribution in the crude oil [6].*

| Carbon Number | Weight% | Carbon Number | Weight% |
|---|---|---|---|
| C6 | 28.5 | C21 | 0.31 |
| C7 | 14.85 | C22 | 0.29 |
| C8 | 13.62 | C23 | 0.27 |
| C9 | 9.16 | C24 | 0.24 |
| C10 | 7.6 | C25 | 0.24 |
| C11 | 7.28 | C26 | 0.19 |
| C12 | 8.05 | C27 | 0.19 |
| C13 | 2.09 | C28 | 0.15 |
| C14 | 2.15 | C29 | 0.14 |
| C15 | 0.61 | C30 | 0.08 |

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|---|---|---|---|
| C16 | 1.97 | C31 | 0.08 |
| C17 | 0.35 | C32 | 0.03 |
| C18 | 0.4 | C33 | 0.01 |
| C19 | 0.42 | C34 | 0 |
| C20 | 0.74 | C35 | 0 |

*Table 3: Distribution of normal + non-normal paraffin in wax of crude oil [6].*

| Carbon Number | Normal % |
|---|---|
| C19 | 7.81 |
| C20 | 6.12 |
| C21 | 14.75 |
| C22 | 23.84 |
| C23 | 30.6 |
| C24 | 11.66 |
| C25 | 5.22 |

**2.4 Methodology of Wax Deposition Simulation**

The tab file of crude oil properties and the wax file is imported from PIPEsim to OLGA as a pvt file to run the simulation. The experimental rig of this study was modelled to transport the oil from the oil source (oil inlet) in the first node of pipe-1 into the flow line, as shown in figure 2. The oil enters the flow line at 44°C at a mass flow rate 0.04 kg/s or 0.08 kg/s depending on the desired flow rate. The oil flows out of the flow line at 5 bars and 42°C through a pressure node called the oil outlet.

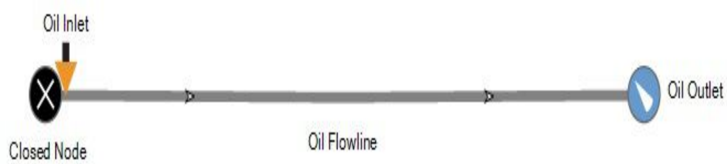


*Figure 2: Schematic flow line diagram in the OLGA software for this study.*

The test section of the rig is a horizontal pipe consisting of one section, so in order to simulate it using the OLGA software, the flowline geometry in the model is assumed to consist of 15 equal pipelines and each section to equal 10 cm; the minimum sections of pipe required to run the simulation using OLGA should be 3. Increasing the number of pipeline sections will not affect the accuracy of the simulation due to the pipeline being horizontal and the deviation angle zero.

The copper pipeline material properties used in the OLGA simulation model are 385 J/kg.ºC heat capacity, 401 W/m.k thermal conductivity, 8960 kg/m3 density and 0.0009 m pipe wall thickness.

In the wax deposition simulation, the wax deposition option is turned ON and the input parameter, including wax deposition model RRR, is as follows: wax diffusion coefficient multiplier equal to 1, wax roughness value zero, porosity of wax 0.6 (automatic default value), seabed temperature 6°C, and the simulation end time 2, 4 and 6 hours and for the study of the effect of a long time on wax deposition, the simulation end time is 12 and 24 hours.

### 2.5 Methodology of Tuning OLGA Parameters for Improved Predictions

There are some differences between the components of the crude oil in this study and that of Jha et al. (2014) [6] such as SARA, specific gravity and API. So, to avoid these differences between the experimental results and the predicted results, a tuning of OLGA parameters for improved predictions was undertaken.

Three scenarios were created to match the experimental wax thickness, including studying the effect of change wax porosity in OLGA, changing the crude oil components and the influence of simulation time on wax deposition.
A sensitivity study was carried out in OLGA simulation to study the effect of changing the wax porosity to 0.2, 0.4, 0.6 and 0.8 and its impact on the predicted wax thickness to match the experimental wax thickness.

A sensitivity study was undertaken to achieve the experimental thickness using OLGA software at an inlet coolant temperature of 14°C and wax porosity 0.6 and changing the weight percentage of carbon numbers distributed in the crude oil.

Hexane or C6 in the crude oil in high percentage leads to a reduction in the wax formation in the crude oil. Therefore, the procedure involved reducing 10, 20 and 30% respectively of C6 weight percentage and distributing the removed percentage to the remaining carbon numbers in the crude oil. Increasing the simulation time from 2 to 4, 6, 12 and 24 hours was also done to study its effects on wax deposition.

## III. RESULTS AND DISCUSSION

### 3.1 Distribution of the Single Carbon Number and the n-Paraffin in Crude Oil

Figure 3 shows a comparison of the experimental results and PIPEsim calculations of the single carbon number (SCN) distribution in the crude oil and n-Paraffin distribution in the wax of the crude oil. The comparison shows that the calculated single carbon number completely matches with the experimental results. The calculated n-Parrafin agrees with the experimental n-Parrafin in some points and differs in others.

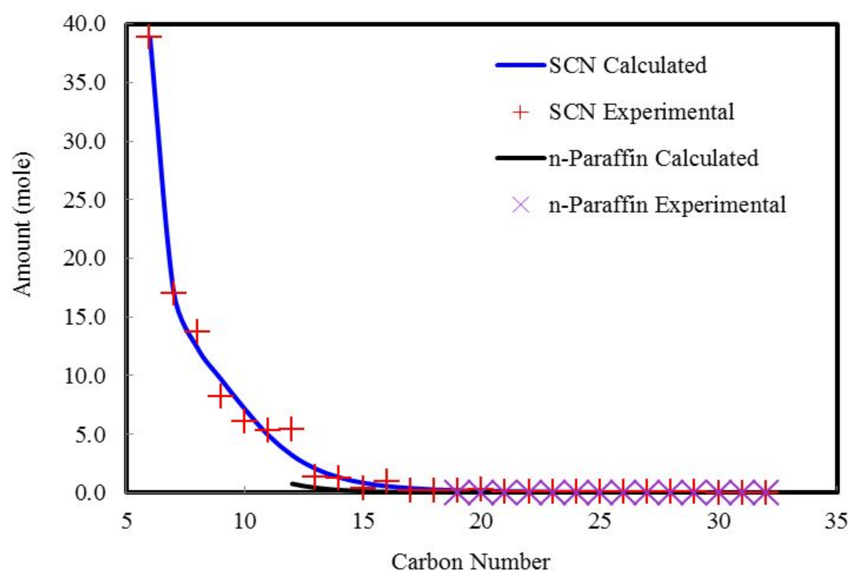


*Figure 3: Distribution of the single carbon number (SCN) in the crude oil and the n-Paraffin using PIPEsim.*

The phase envelope of the crude oil shown in figure 4 was obtained using PIPEsim 2014; this reveals a critical point of 470.56°C at 40.46 bars. Liquid fractions are present in the hydrocarbon mixture at all temperature conditions below this critical temperature. This suggests the presence of heavy fractions and the stable properties of the liquid phase at high temperatures.

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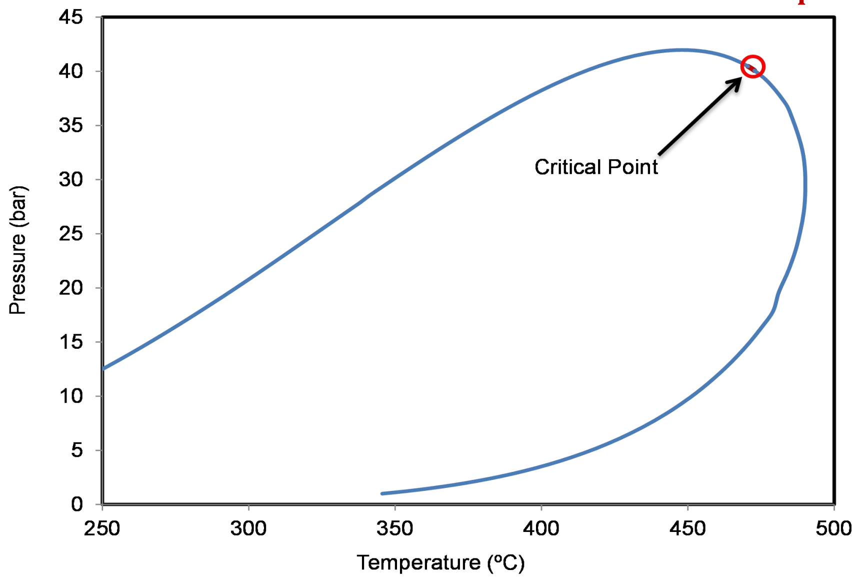


*Figure 4: Phase envelope of the crude oil used for wax simulations using PIPEsim.*

**3.2 The Base Case of Wax Deposition Simulation**

Profiles in figures 5 and 6 at flow rate 2.7 and 4.8 L/min respectively present the thickness of the wax layer deposited on the pipe wall, the mass of wax dissolved in oil, pressure, crude oil temperature and oil viscosity along the tube length. After running the simulation and at an inner pipe wall temperature less than the wax appearance temperature, a sharp growth in the amount of wax precipitated is observed resulting in a reduction of mass of wax dissolved in oil. The reason for this sharp growth in wax thickness is the high thermal conductivity of the pipe material.

The crude oil temperature reduced gradually along the pipeline due to heat loss to the surrounding area and the pressure drop increased in the system due to the wax precipitated in the pipe wall. The oil viscosity was increased gradually due to the decrease in the crude oil temperature and the loss of heat to the surrounding area through the pipe wall; this loss in the heat leads to the wax crystals forming, and therefore the oil viscosity increases and tends to transform from Newtonian to non-Newtonian behaviour. The wax deposition leads to increasing wall roughness and a reduction in the effective flow diameter of the pipe. This principle of wax deposition, as a consequence of a necessary temperature gradient between the bulk fluid and a surrounding ambient fluid, is simulated in the test section as an important flow assurance concept for handling wax deposition in subsea flow lines.

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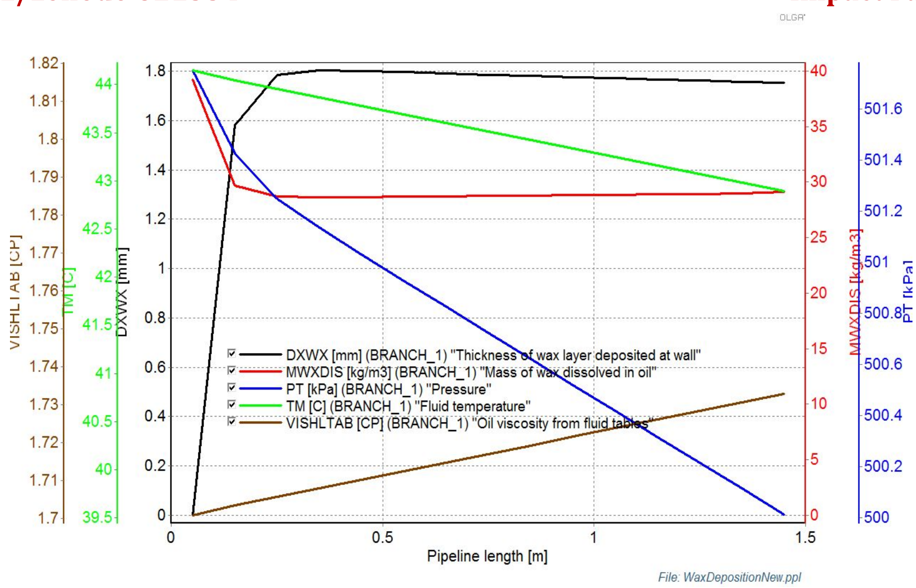


***Figure 5: Simulation output of wax deposition profile along the test section pipe of the experimental rig for this study, at a flow rate of 2.7 L/min.***

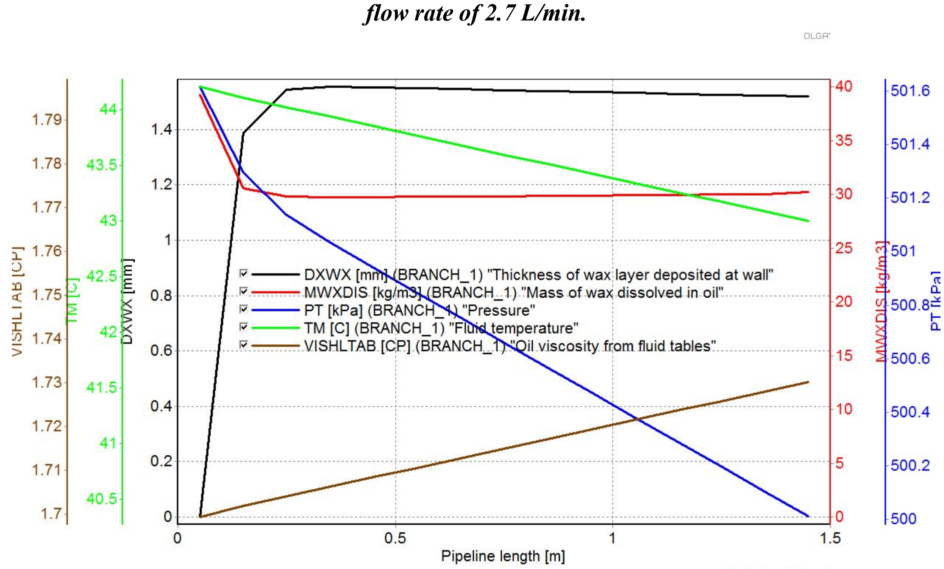


***Figure 6: Simulation output of wax deposition profile along the test section pipe of the experimental rig for this study, at a flow rate of 4.8 L/min.***

The difference between the two figures presented by the predicted wax thickness at the flow rate 2.7 L/min is higher than the predicted thickness at 4.8 L/min because increasing the flow rate leads to an increase in the shear stress and removal of the small molecules of wax to the crude oil. It can also be seen that the mass of wax dissolved in oil is higher at the high flow rate and lower at the low flow rate.

The simulation results show agreement and somewhat less accuracy than the experimental results due to using the crude oil composition of Jha et al. (2014) [6]. In order to reduce this gap between the simulated and experimental results, a sensitivity study has been undertaken as part of this work, as will be outlined below.

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### 3.3 Tuning of OLGA Parameters for Improved Predictions

Since simulations based on the default wax parameters did not achieve a complete match with experiments, as will be shown in the scenarios below, it was important to find out to what extent tuning of wax parameters was necessary. Three scenarios were created to match the experimental wax thickness, including studying the effect of changing wax porosity in OLGA, changing the crude oil components and the influence of simulation time on wax deposition.

***Scenario A: The Effect of Changing Wax Porosity***

A sensitivity study was carried out in OLGA simulation to study the effect of changing the wax porosity from 0.2, to 0.4, 0.6 and 0.8 and their impact on the predicted wax thickness to match the experimental wax thickness. The predicted wax thickness was lower than the experimental thickness at a flow rate of 2.7 L/min by using the value 0.6 as default wax porosity in OLGA. It was observed from the simulation results that increased wax porosity leads to an increase in wax deposition thickness.

Figure 7 shows the results and, as expected, the predicted wax thickness increased after increasing the wax porosity from 0.6 to 0.8 and reduced after reducing the wax porosity to 0.4 and 0.2 respectively. This gives an indication that wax porosity is one of the tuning parameters that has major effects on wax deposition thickness; a small adjustment in the wax porosity from 0.6 to 0.8 leads to the better prediction of the experimental wax thickness. Therefore, in this research, the wax porosity of 0.8 depends on OLGA calculations to simulate the wax deposition thickness at different inlet coolant temperatures, so the wax porosity values using the RRR model should be in the range of 0.6–0.9 [7], [8]. This increase in wax thickness can be explained by the fact that as the wax porosity and the trapped oil increase, this will lead to an increase in the wax deposit thickness.

The wax thickness is still somewhat under predictable, even at a wax porosity of 0.8 and a flow rate of 2.7 L/min; therefore, OLGA simulation requires additional tuning parameters, such as a change in the crude oil components, in order to match the experiment properly.

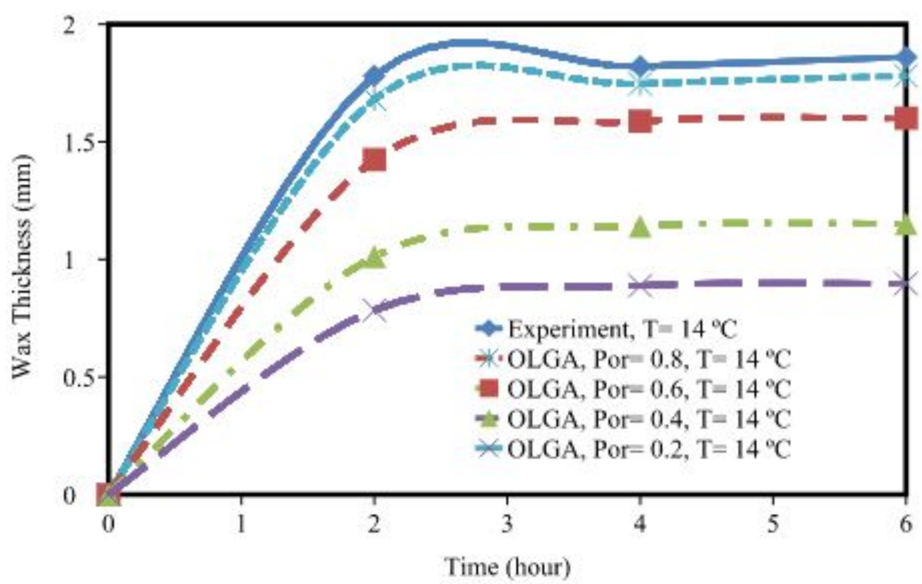


***Figure 7: The effect of wax porosity on predicted wax thickness at flow rate 2.7 L/min and an inlet coolant temperature of 14°C.***

As the flow rate increases to 4.8 L/min, lower wax porosity is expected. Figure 8 shows the results: the wax thickness is under-predicted at wax porosity 0.4, 0.6 and 0.8, but the prediction of wax thickness was over the experimental thickness at wax porosity 0.2.

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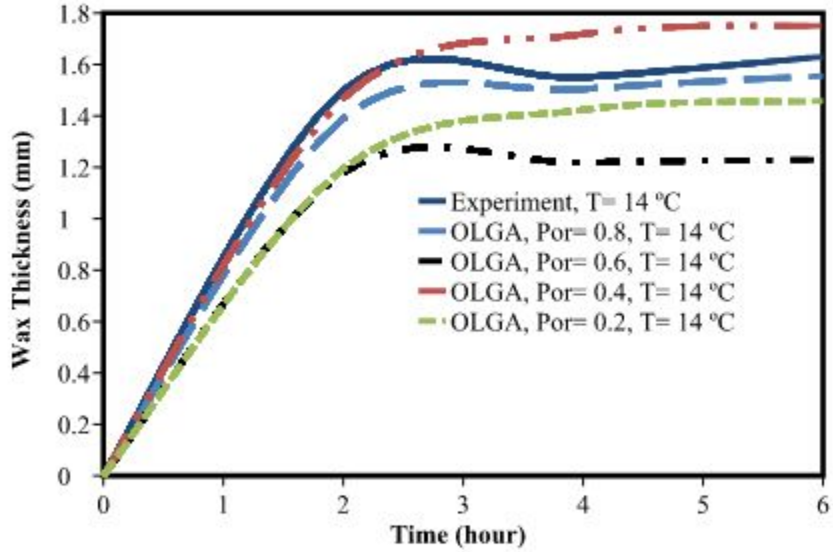


***Figure 8: The effect of changes in wax porosity in OLGA simulation on predicted wax thickness at flow rate 4.8 L/min and an inlet coolant temperature of 14°C.***

It can be seen that at a flow rate of 4.8 L/min, the value of wax porosity 0.8 provides better prediction in wax deposition using OLGA so, this value of wax porosity dependent in OLGA calculations. OLGA simulation at a flow rate of 4.8 L/min still needs some additional tuning parameters such as changes in the crude oil components in order to match the experiment properly.

***Scenario B: The Effect of Changing Crude Oil Components***

A sensitivity study was undertaken to achieve the experimental thickness using OLGA software at an inlet coolant temperature of 14°C and wax porosity of 0.6 and by changing the weight percentage of carbon numbers distributed in the crude oil.

Hexane or C6 in the crude oil in high percentage reduces the wax formation due to C6 working as a solvent, helping to dissolve the wax molecules in the crude oil. Therefore, the procedure was done by reducing 10, 20 and 30% of C6 weight percentage and distributing the removed percentage to the remaining carbon numbers in the crude oil.

This sensitivity study also included adding 10% to C6 and removing the equal percentage from the other components, as shown in table 4.

Figure 9 shows the C6 sensitivity analysis; the lower solid line represents the predicted wax thickness using the original crude oil components [6] and the difference between this and the experimental wax thickness of the upper solid line is about 0.3 mm. The predicted wax thickness increased by about 0.1 mm from the lower solid line after removing 10% of C6. Removing 20% of C6 leads to improving the predicted wax thickness and nearly reaching the experimental wax thickness; by increasing the removal percentage to 30%, the predicted thickness exceeds the experimental wax thickness in the upper solid line. On the other hand, adding 10% of C6 leads to reducing the predicted thickness to lower than the predicted thickness of the original components due to the high amount of C6 melting the wax in the crude oil.
From this study it can be concluded that reducing the C6 content by 20% presents a better-predicted wax thickness but this thickness is still not reaching the desired value; therefore, it will depend on the next simulations with a wax porosity of 0.8 to achieve the experimental wax thickness.

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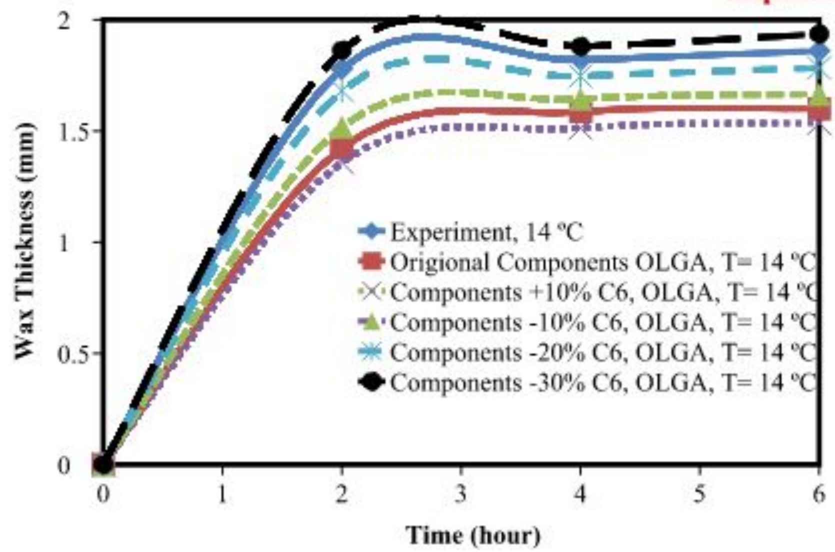


***Figure 9: The effect on the predicted wax thickness of changing crude oil components, using OLGA at a flow rate of 2.7 L/min and an inlet coolant temperature of 14°C.***

***Table 4: Weight percentage of carbon number distributed in the crude oil used in the simulation with the new weight percentage after removing 10, 20 and 30% from C6 and distributing that percentage of each case to the rest of the carbon numbers.***

| Carbon Number | Weight% Original [6] | Weight% (- 10 % C6) | Weight% (- 20 % C6) | Weight% (- 30 % C6) | Weight% (+ 10 % C6) |
|---|---|---|---|---|---|
| C6 | 28.5 | 25.65 | 22.8 | 19.95 | 31.35 |
| C7 | 14.85 | 15.27 | 15.7 | 16.12 | 14.43 |
| C8 | 13.62 | 14.01 | 14.4 | 14.8 | 13.24 |
| C9 | 9.16 | 9.42 | 9.7 | 9.94 | 8.90 |
| C10 | 7.6 | 7.82 | 8.03 | 8.25 | 7.38 |
| C11 | 7.28 | 7.49 | 7.7 | 8 | 7.10 |
| C12 | 8.05 | 8.28 | 8.51 | 8.84 | 7.82 |
| C13 | 2.09 | 2.15 | 2.21 | 2.4 | 2.03 |
| C14 | 2.15 | 2.21 | 2.27 | 2.43 | 2.09 |
| C15 | 0.61 | 0.63 | 0.74 | 0.76 | 0.59 |
| C16 | 1.97 | 2.03 | 2.18 | 2.24 | 1.91 |
| C17 | 0.35 | 0.36 | 0.47 | 0.48 | 0.34 |
| C18 | 0.4 | 0.41 | 0.52 | 0.53 | 0.39 |
| C19 | 0.42 | 0.422 | 0.54 | 0.56 | 0.41 |
| C20 | 0.74 | 0.76 | 0.88 | 0.9 | 0.72 |
| C21 | 0.31 | 0.42 | 0.43 | 0.48 | 0.30 |
| C22 | 0.29 | 0.4 | 0.41 | 0.46 | 0.28 |
| C23 | 0.27 | 0.38 | 0.39 | 0.39 | 0.26 |
| C24 | 0.24 | 0.35 | 0.35 | 0.36 | 0.23 |
| C25 | 0.24 | 0.35 | 0.35 | 0.36 | 0.23 |

| | | | | | |
|---|---|---|---|---|---|
| C26 | 0.19 | 0.295 | 0.3 | 0.31 | 0.18 |
| C27 | 0.19 | 0.295 | 0.3 | 0.31 | 0.18 |
| C28 | 0.15 | 0.2015 | 0.26 | 0.26 | 0.146 |
| C29 | 0.14 | 0.1915 | 0.25 | 0.25 | 0.136 |
| C30 | 0.08 | 0.082 | 0.13 | 0.19 | 0.078 |
| C31 | 0.08 | 0.082 | 0.13 | 0.19 | 0.078 |
| C32 | 0.03 | 0.031 | 0.032 | 0.13 | 0.029 |
| C33 | 0.01 | 0.01 | 0.018 | 0.11 | 0.009 |

***Scenario C: The Impact of Simulation Time on Wax Thickness***

From figure 10 it can be seen that at 0.6, the default wax porosity in OLGA, the wax thickness is still increasing by increasing the simulation time from 6 to 12 and 24 hours. This is illustrated due to the fact that the simulation considered the crude oil passing through the pipe to be fresh, so the wax content in the crude oil was constant and not reduced due to reducing the mass of wax dissolved in the oil, as in the case of recirculating crude oil in the rig.

Increasing the simulation time leads to an increase in the wax deposit thickness due to an increase in the wax deposit on the pipe wall. The simulation results show that the increase in the wax thickness was slight and it looks like a constant line. This can be explained by the high thermal conductivity of copper pipe as the increasing wax deposited on the pipe wall forms a layer of wax; this layer works as an insulator preventing the heat exchange through the copper pipe between the crude oil and the surrounding temperatures. Therefore, the crude oil temperature inside the pipe will be constant and the wax deposition rate will be in a balance with the removal wax rate or the deposition rate, somewhat higher than the removal wax deposition due to increasing the crude oil velocity by reducing the pipe diameter because of the deposited wax.

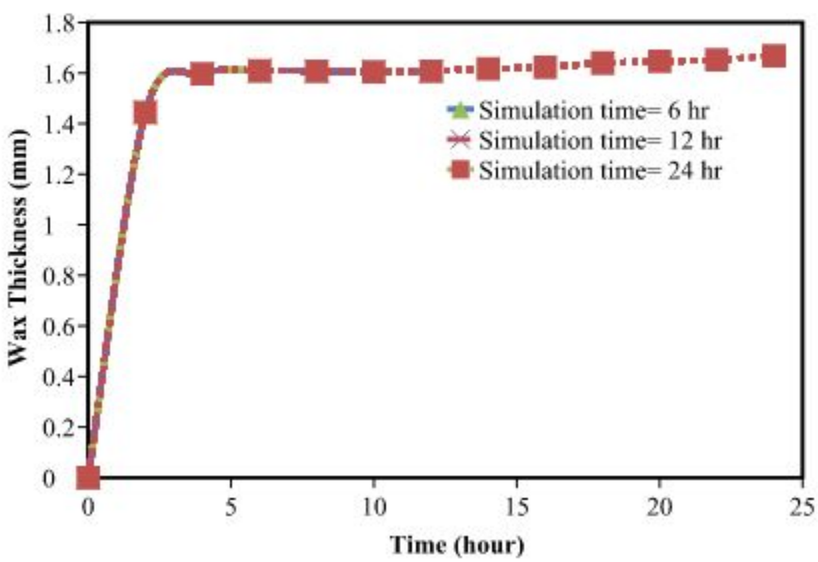


***Figure 10: The effect of simulation time on the wax thickness at 2.7 L/min, an inlet coolant temperature of 14°C and a wax porosity of 0.6.***

It can be concluded from the results of the sensitivity study of the three previous scenarios that the suitable OLGA parameters improve and match the experimental wax thickness by considering the wax porosity 0.8 and running the simulations using the effects of changed crude oil components by reducing C6 to 20%. This is due to the results of these parameters presenting agreement with the experimental results of wax deposition.

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### 3.4 Comparison of Wax Simulations with Experimental Data

All simulations run in OLGA are based on the experimental conditions of this study. The resulting wax thickness versus time was plotted using Excel in order to compare results from the experiments with the simulation results. Figure 11 illustrates a comparison between the experiments and the simulation models, showing the influence of inlet coolant temperature variation and the experimental time of 2, 4 and 6 hours, on wax thickness at a flow rate of 2.7 L/min.

Overall, the wax thicknesses of the experimental results are somewhat higher than the simulation results in the same process conditions. Whilst at an inlet coolant temperature of 14ºC, the different experimental time was about 1.8 mm, it was about 1.78 mm by using the simulation mode. At an inlet coolant temperature of 24ºC, the wax thickness decreased to about 2 mm in the experiments, while it was decreased to 1.8 mm using the model. Increasing the temperature of the pipe wall to 33ºC leads to reducing the wax thickness from 0.85 mm in the experiment to 0.84 mm in the model.

Experimentally, it was proved that the wax thickness decreased by increasing the flow rate from 2.7 to 4.8 L/min. This is the same using the simulation model, as shown in figure 12. The wax thickness decreased experimentally from 1.6 to 1.4, then 0.7 mm at inlet coolant temperatures 14, 24 and 33ºC respectively.
The predicting model shows the reduction in wax thickness from 1.55 to 1.4 and 0.7 mm at inlet coolant temperatures 14, 24 and 33ºC respectively.

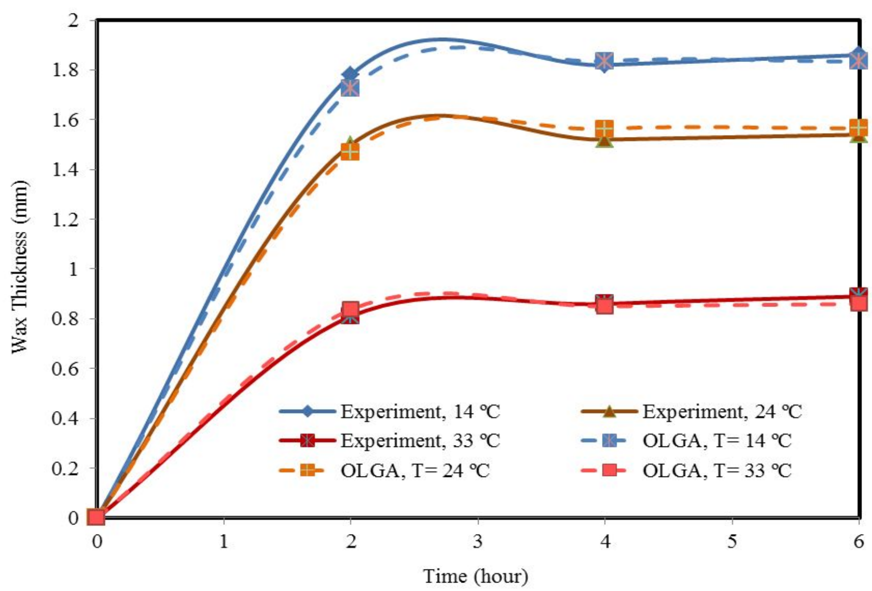


*Figure 11: Comparison between the experimental results and the simulation results at flow rate 2.7 L/min.*

The comparison indicates that the model results are slightly lower than the experimental results. These differences can be explained by the fact that there are unknowns and assumptions in the experiments; for example, the wax roughness and wax porosity is unknown, which leads to additional uncertainty in the wax simulations. Comparing simulation results to the experiments provides information on the reliability of a wax deposition model.

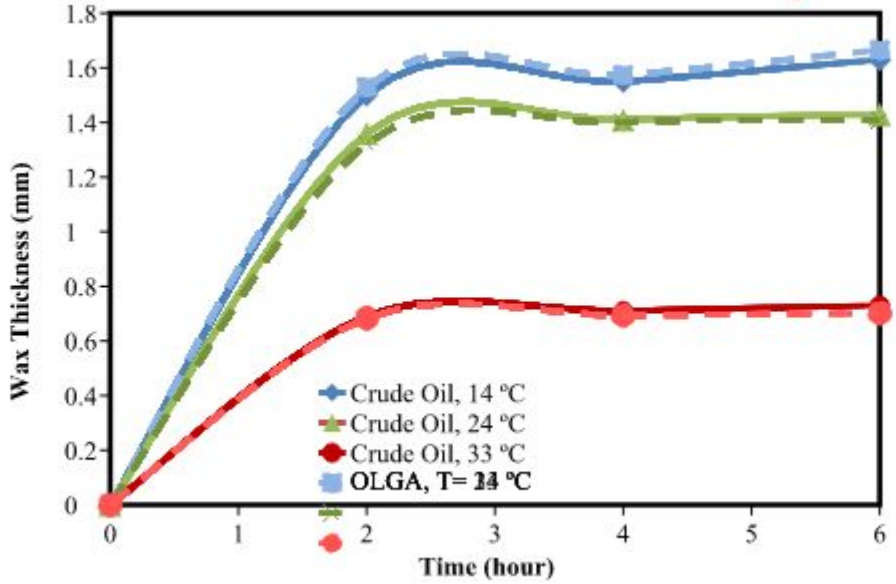


*Figure 12: Comparison between the experimental results and the simulation results at a flow rate of 4.8 L/min.*

## IV. CONCLUSION

Wax deposition on the offshore pipelines considers as one of the main fluid flow assurance challenges that face the petroleum engineers. Where, it causing an artificial blockage leading to a reduction or stop in the production.

OLGA software was used to simulate the experimental wax deposition process inside the pipe of the study of Theyab and Diaz (2016a) [2], where it was estimated the wax deposition process in the pipe and simulate the tuning OLGA parameters to improve prediction.

A comparison between the experiments and the simulation models showing the influence of inlet coolant temperatures variation and the experimental time of 2, 4 and 6 hours, on wax thickness at flow rate 2.7 and 4.8 L/min respectively. Overall, the wax thicknesses of the experimental results are higher than the simulation results at the same process conditions. Experimentally, it was proved that the wax thickness decreased by increasing the flow rate from 2.7 to 4.8 L/min. This concept is the same by using the simulation model.

The comparison indicated that the model results provided less accuracy compared to experiments results. These differences can be explained as, there are unknowns and assumptions concerning the experiments such as the wax roughness, and the wax porosity are unknown, these leads to additional uncertainty in the wax simulations. After tuning OLGA parameters such as the wax porosity, crude oil components and simulation time, the results of the simulation shows agreement with the experimental.

### Nomenclature

PT = Pressure (bar, kpa)
TM = Temperature ºC
DXWX = Thickness of wax layer deposited at wall (mm)
MWXDIS = Mass of wax dissolved in oil (kg/ m$^3$)
VISHLTAB = Oil viscosity from fluid tables (cp)

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