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Optimizing Pigging Frequency for dewaxing of Crude Oil Pipelines

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Abstract

Wax deposition in oil pipelines causes reduced throughput and other associated problems. Periodical pigging program can effectively minimize the cost of wax deposition. This paper shows a typical pigging case study for a field pipeline subject to wax deposition distribution by using Olga software. This paper describes the underlining wax models implemented in OLGA, depending on the laboratory analysis data of this study. OLGA software was used to simulate the wax deposition process (location and thickness) to predict the wax deposition tendencies and recommended the optimum pigging frequency. Steady State Operation for non-pigging and pigging operation at three different flow rates, to predict liquid/water hold-up, to check water slugging and pigging characteristics has been included. The deposition of wax in oil pipelines presents a costly production and transportation problem. The deposited wax is removed periodically by pigging operation in field. However, if for any reason pigging operations are suspended, frictional pressure increase will soon lead to a reduction in throughput. Different scenarios for Wax deposition and pigging frequency issues at three different flowrates has been implemented and created with respect to weather (summer and winter), including studying the effect of changing ambient temperature to match the actual wax thickness & quantities as per wax received at pig receiver trap as well as to determine an optimal pigging frequency. The findings, the model prediction results prove that the wax is distributed in a short, localized accumulation along the first quarter of pipeline. The case study of pipeline is recommended that the current pigging frequency of once per 2 weeks can be reduced (is recommended to be pigged at a frequency of 7 to 10 days) and Pigging frequency can be extended from 2 weeks to once every 4 weeks for winter and summer.

Keywords: *Wax appearance temperature (WAT), Wax deposition thickness, pigging frequency, OLGA Simulator, PVTsim.*

1. 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.[1]

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 [1]

Wax deposition poses severe risks to crude oil production systems. In order to remediate wax deposition, pigging operation is performed routinely to scrape wax deposits from the pipe wall. Proper determination of the pigging frequency is crucial to estimating the operating costs associated with the pigging operations as well as the risks of pipeline blockage by wax deposit.[7]

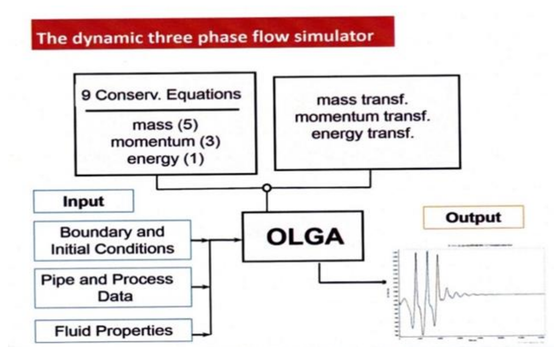
1.1 Brief about OLGA

The OLGA dynamic multiphase flow simulator models time-dependent behaviors, or transient flow, to maximize production potential. Transient modeling is an essential component for feasibility studies and field development design. Dynamic simulation is essential in deepwater and is used extensively in both offshore and onshore developments to investigate transient behaviour in pipelines and wellbores.

The OLGA Wax module calculates the deposition and transport of wax components along the pipeline. It models the effects of increases in pipeline roughness, decreases in pipeline diameter, and the increased apparent viscosity of the oil phase with precipitated solid wax particles. Wax deposition occurs on the inside surface of a flow line due to molecular diffusion when the pipe wall temperature falls below the wax appearance temperature (WAT). Wax precipitation occurs in the oil bulk flow when the bulk temperature is below WAT. The Wax module supports tuning fluid properties related to molecular diffusion, dissolution, shear related wax transport, and effective viscosity of an oil/wax mixture to dynamically model wax deposition, dissolution, and transport effects. The OLGA simulator also simulates pigging operations for wax layer removal and transport.[8]

OLGA is a multiphase flow simulator that has been widely used for several decades in the flow assurance industry, 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. OLGA software was used in this research to study wax deposition and to easily identify optimum pigging frequency.[1]

Steps of the OLGA Simulation Process



1.2 Brief about PVTsim

PVTsim is a versatile equation of state (EOS) modeling software that allows the user to simulate fluid properties and experimental PVT data. The wax module evaluates wax formation conditions from an ordinary compositional analysis, quantify the amount of wax precipitate, run flash calculations, and plot wax formation conditions through PT curves. If data is available, it is also possible to tune the wax model to an experimental cloud point or to experimental wax content in the stock tank oil.

The amount of wax precipitate may be calculated as a function of P for constant T or as a function of T for constant P and quantitative flash calculations will consider gas, oil and wax. Additionally, there is an option to account for the influence of wax inhibitors.[8]

2. Methodology

2.1. Case study

The Dissertation will take Neem Field Production Facility (NFPF) crude oil Pipeline with 100 km, and 16 inch to Diffra FPF as case study [4].

The pipe line between Neem FPF & Diffra FPF is being pigged for scrapping of wax once every two weeks irrespective of weather. Simulation has been carried out in OLGA 2015.1.2 to predict the wax deposition thickness. The fluid modeling has been carried in PVTSim19 to capture the fluid parameters.

2.2. Construction OLGA model

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 2015.1.2 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 [2].

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 pvtsim 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 pvtsim19 [2].

2.3 The Risk of Plugging

When wax builds up downstream of a pig it can lead to the blocking of the pipeline. The pig and wax plug can withstand very high differential pressures without moving. Production then stops. The mechanism by which this occurs is as follows: - [3].

a) The pigs scrape off wax from the pipe wall using guide discs or seals. The wax can be soft or harder wax.
b) Wax gathers in front of the pig and the pig applies a force to the rear of the wax buildup.
c) Due to a pressure gradient over the wax accumulation, the oil is squeezed out of the wax directly in front of the pig and it hardens.
d) Due to the harder wax and the buildup of a critical volume of wax ahead of the pig, the friction required to move the plug is too great for the pressure available and the pipeline blocks.

2.4. Wax Deposition Model Calibration

MATZAIN wax model (diffusion part):

The Matzain is a semi-empirical model, which incorporates a wax reducing mechanism, known as shear stripping, alongside molecular diffusion and shear dispersion to simulate wax deposition. In this model, shear dispersion is considered of minor importance in respect to RRR model.[6]

The rate of wax build up is calculated by an empirical modification of Fick's law as per equation (1) & (2).[6]

$$\frac{d\delta}{dt} = \frac{\pi_1}{1+\pi_2}\, D_{OW} \left[\frac{dw_w}{dT}\;\frac{dT}{dr}\right] \qquad (1)$$

Eq. (1) Wax thickness

Where:[6]

δ is the thickness of wax layer deposited on the wall (m).

$\mathbf{D_{wo}}$ is the diffusion coefficient calculated with the Wilke and Chang correlation.

C_w the concentration of wax in solution (weight %).
r is the pipe radial distance (m).
T is the fluid temperature (°C).

$$\pi_1 = \frac{C_1}{1-{C_{oil}}/_{100}} \quad (2)$$

Eq. (2) Empirical

Eq.(2) is the supplied empirical correlation for $\mathbf{\Pi_1}$, accounting for the porosity effect on the rate of wax build up and for other deposition enhancement mechanisms not considered by the diffusion coefficient.[6]

The constant $\mathbf{C_1}$ is equal to 15 whereas $\mathbf{C_L}$ defines the amount of oil trapped in the wax layer, as shown in Eq.(3):

$$C_L = 100(1 - \frac{N_{Re}^{0.15}}{8}) \quad (3)$$

Eq. (3) Amount of oil trapped in the wax layer

The dimensionless parameter $\mathbf{N_{Re}}$ is a function of the effective inside radius of the pipeline:

$$N_{Re} = \frac{\rho_{ou} v_{ou} 2r_s}{\mu_{ou}} \quad (4)$$

Eq. (4) dependent Reynolds number

$\mathbf{\Pi_2}$ accounts for the wax limiting effect of shear stripping and is defined in Eq. (5).[6]

$$\pi_2 = C_2 N_{SR}^{C_3} \quad (5)$$

Eq. (5) Accounts for the wax limiting

Where $\mathbf{C_2}$=0.055 and $\mathbf{C_3}$=1.4.

The flow regime dependent Reynolds number ($\mathbf{N_{SR}}$) is calculated for each regime as shown below. [6]

$N_{Re} = \frac{\rho_{ou} v_{ou} 2r_s}{\mu_{ou}}$ Single phase and stratified wavy flow

$N_{Re} = \frac{\rho_{mix} v_{oil} \delta}{\mu_{ou}}$ Bubble and slug flow

$N_{Re} = \frac{\sqrt{\rho_{mix} \rho_{oil}}\ v_{oil} \delta}{\mu_{ou}}$ Annular flow

These expressions show that the shear stripping effect has been modelled as dependent on the wax layer thickness, flow conditions and flowing fluid properties. The thermal gradient of the laminar sub layer for deposition is given by Eq. (6):[6]

$$\frac{dT}{dr} = \frac{T_b - T_{ws}}{k_{oil}} h_h \quad (6)$$

Eq. (6) The thermal gradient

Where $\mathbf{k_{oil}}$ is the thermal conductivity of the oil, $\mathbf{h_h}$ the inner wall heat transfer coefficient, Tb is the bulk fluid temperature and $\mathbf{T_{ws}}$ the deposit surface temperature. [6]

a) Field wax pigging return = 50 to 100 kg per two weeks pigging, as per

Table 1: Characterization of crude oil for this study

Property	Value
Density g/cm³ (15ºC)	0.8647
Specific Gravity (60/60 ºF)	0.8647
API Gravity (60 ºF)	32
Saturates Content (wt%)	71.61
Aromatics Content (wt%)	12.09
Resins Content (wt%)	16.05
Asphaltene Content (wt%)	0.25
Pour point temperature ºC	33
Wax appearance temperature (Cross Polarized Microscopy (CPM)) ºC	56.5
Wax content Mass%	33.2

Table 2: Carbon number distribution in the crude oil

Component	Molecular Weight%	Molecular Weight
C1	0.176	16.043
C2	0.094	30.07
C3	0.511	44.097
iC4	1.454	58.124
nC5	2.303	72.151
C6	3.235	86.178
C7	5.016	96
C8	6.08	107

C9	4.236	121
C10-C14	19.622	160.596
C15-C18	12.327	227.546
C19-C23	11.275	288.224
C24-C27	6.906	351.101
C28-C33	7.368	418.895
C34-C40	7.786	528.564
C41	2.802	570
C42-C44	4.963	595.455
C45-C79	3.847	669.98

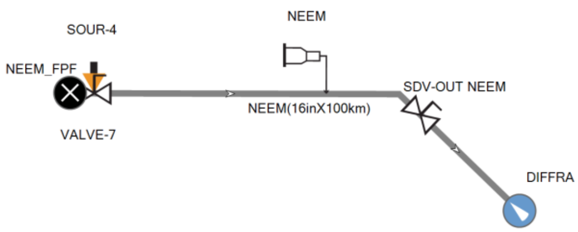


Figure 1: Schematic pipe line diagram in the OLGA software for this study

3. Result and Discussion

Figure.2 illustrate wax precipitation curve for concerned field (Neem), figure 3 illustrate crude oil viscosity, and Figures 4a & 4b shows the results of model calibration. As per Fig.5 Wax precipitation starts at 4 km until 60 km of Neem Pipeline with 12000 stb/d oil, and 22 ^{0}C for winter season . And Figure.6 Water holdup fraction approximately equal 0.10 (volume is 1140 m^3) for Neem Pipeline with 12000 stb/d oil, and 22 ^{0}C for winter season.

Figure.7 for NFPF Pipeline with 12000 standard barrel per day (stb/d) oil and winter temperature 5^{0}C the Liquid phase velocity approximately equal 0.35 m/s and Water phase velocity (average) is 0.16 m/s, found that both phases velocity < 1 m/s and solids will settle out.

According to figure.8 for the first 10 km wax build up and reaches 0.10 mm after 14 days. No Wax deposited towards Diffra field due to temperature difference becomes lower as compared to beginning of pipeline. Wax deposition rate is proportional to difference in temperature (between fluid and ambient).

Figure.9 illustrate wax amount in kg as function of days with 12000 stb/d oil, and winter temperature (22 ^{0}C). Figures.10a and 10b showing Sensitivity Cases (Seasonal effect). As well as Figures.11a and 11b Sensitivity Cases (Flowrate Effect).

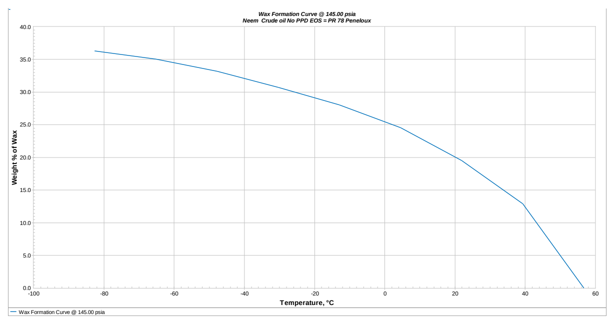


Figure 2: Neem Wax Precipitation Curve (WPC)

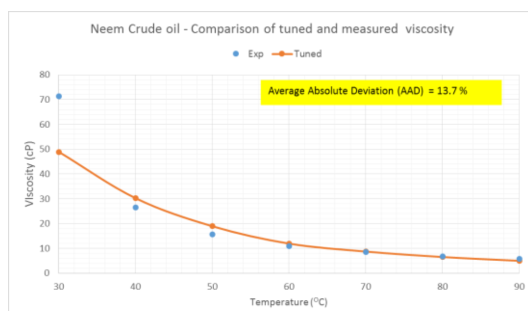


Figure 3: Neem Crude Oil Viscosity

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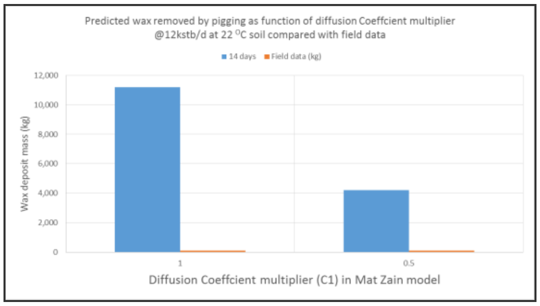

Figure 4 (a): WAX DEPOSITION MODEL CALIBRATION

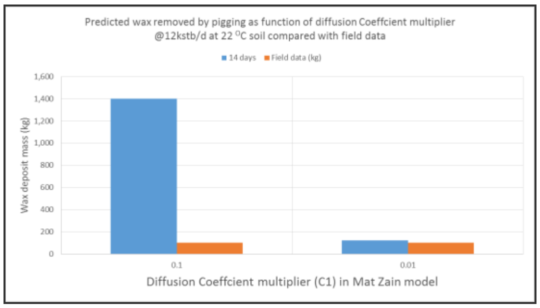

Fig. 4b Wax Deposition Model Calibration

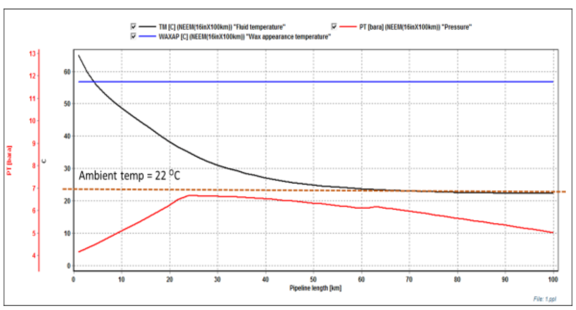

Figure 5: Wax precipitation

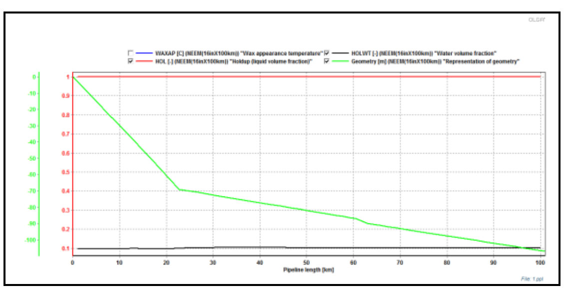

Figure 6: Water holdup fraction

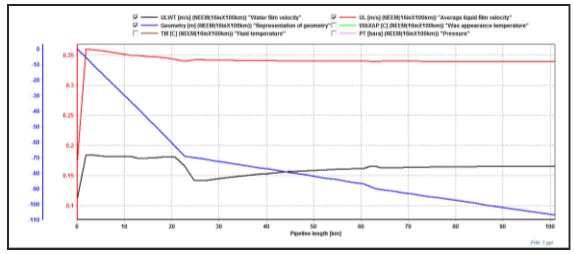

Figure 7: Liquid phase velocity

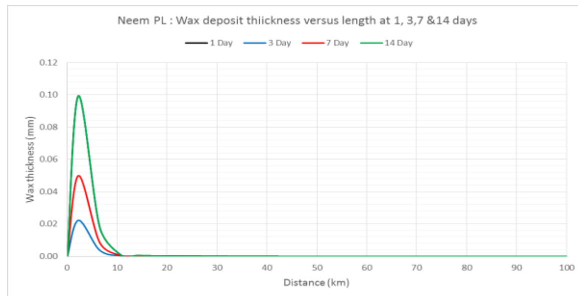

Figure 8: Wax deposit thickness versus length

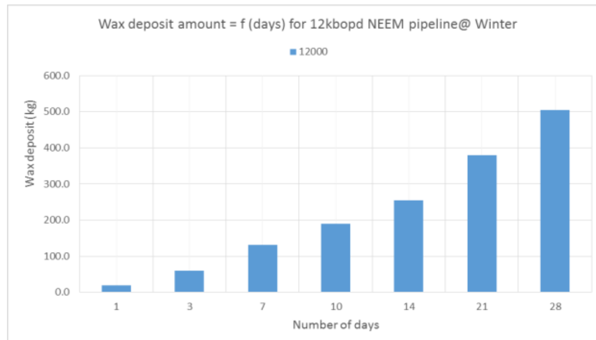

Figure 9: Wax deposit amount as function of days

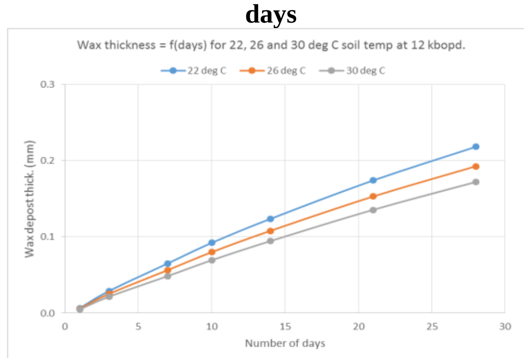

Figure 10 (a): Sensitivity Cases (Seasonal effect)

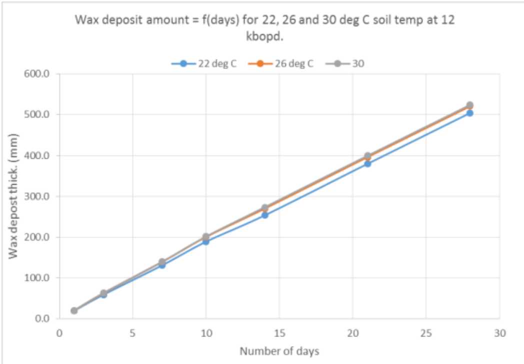

Figure 10 (b): Sensitivity Cases (Seasonal effect)

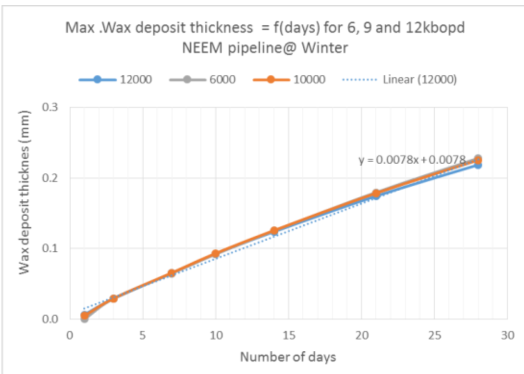

Figure 11 (a): Sensitivity Cases (Flowrate Effect)

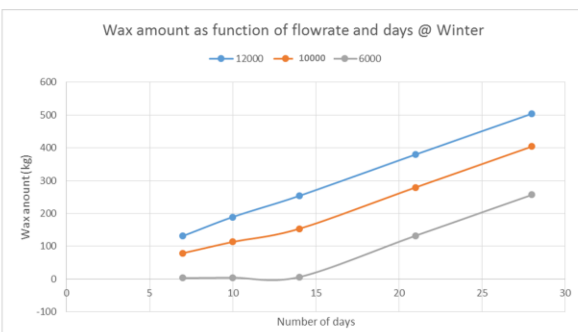

Figure 11 (b): Sensitivity Cases (Flowrate Effect)

Table 3: The results are summarized in table below@ Winter for 12 kilo barrel oil per day (kbopd)

Pigging Frequency (Once every)	Pigging travel time (days)	Amount of wax removal (kg)	Predicted max.wax thickness (mm)	Pig pressure drop (bar)
2 weeks	4	200	0.1	1.6(30%)
3 weeks	4	300	0.14	2.3(45%)
4 weeks	4	390	0.19	2.9(60%)
5weeks	4	480	0.24	3.5(70%)

Note: The percentage value in bracket refers to the increase in pressure with respect to the inlet pressure of 5 bar.

4. Conclusions

The simulation results are highly dependent on fluid and wax properties. The accuracy of lab experiments and analysis representativeness of samples is paramount for getting good match to model.

The current pigging frequency of once per 2 weeks can be reduced (is recommended to be pigged at a frequency of 7 to 10 days).

Pigging frequency can be extended from 2 weeks to once every 4 weeks for winter and summer.

Wax volume and pipeline inlet pressure to be recorded during pigging operation.

Although wax thickness and volume are still small, pressure drop across the pig increases significantly and is higher than 3 bar for pigging frequency > 4 weeks.

Acknowledgments

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