SPE Brazil Flow Assurance Technology Congress
Rio de Janeiro, Brazil, November 15 – 18 2022

# Evaluation of wax deposition in unconventional wells according to tubing and annulus operational strategies

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## Abstract
This work presents an evaluation of wax deposition in an unconventional well and oil production optimization analysis through numerical simulation. A field case, from Neuquen Basin, was selected where pressure, temperature, holdup, flow rates and wax thickness profiles were evaluated for different operational scenarios. The study used a multiphase flow simulator - ALFAsim - which has available wax deposition models coupled to the base module of the software, allowing to analyze the position where the deposit starts to form, in which scenario (Winter or Summer), considering a sensitivity analysis of tubing length, annulus choke orifice and production occurring by the tubing and annulus.

## Keywords
Flow Assurance; Wax Deposition; Multiphase Flow

## Introduction
Wax deposition is a recurrent flow assurance problem that occurs in the upstream production chain, specially in deep water hydrocarbon fields. Wax crystals represent heavy fractions ($C_{20+}$) of petroleum fluid composition that precipitate out of the oil phase and accumulate inside pipe walls once mixture temperature decreases below Cloud Point [1], also known as Wax Appearance Temperature (WAT).

As a consequence, wax deposition restricts the flow leading to production losses and additional costs if not effectively prevented and mitigated. In this way, some methods that can be implemented in field operation are pigging, pipeline insulation, electrical heating and chemical injection [1; 2; 3].

To allow the hydrocarbon field development project financial viability, it is indispensable the use of numerical simulation with wax capabilities which allows estimating accurately the wax phenomenon once is extremely important for the prevention and mitigation decision making by operator companies.

## Methodology
To face Oil & Gas industry challenges, numerical simulations are universally implemented in engineers' daily operations in order to assist and optimize hydrocarbon fields projects [4]. The ability to couple specific models with the state of art of multiphase flow simulator by API (Application Programming Interface) structure is a differential that allows the implementation of up to date models that assist in the decision making, allowing a customization framework.

For this work, the one-dimensional multiphase flow simulator ALFAsim was used due to its plug-ins API structure, allowing the implementation of a wax deposition model [4]. In the literature, there are several accurate models that account for the wax phenomenon prediction for example Matzain model, RRR - Rygg, Rydahl and Ronningsen and Heat Analogy [3; 5; 6; 7]. Most of them consider as the principal formation mechanism the molecular diffusion. In addition, other secondary mechanisms such as shear dispersion, Brownian diffusion and gravity settling have been proposed. The Matzain model, implemented as a plug-in of the multiphase flow simulator used in the presented study assumes as the main formation mechanisms the molecular diffusion and the shear dispersion.

In the wax deposition model implemented, the rate of buildup is calculated through an empirical Fick´s law, according to Eq. (1).

$$\frac{d\delta}{dt} = \frac{\Pi_1}{1+\Pi_2} D_{wo} \left[\frac{dF_w}{dr}\right] \qquad (1)$$

Where, δ represents the wax deposition thickness at pipe wall, $F_w$ is the wax mass fraction, $D_{wo}$ diffusion coefficient of wax in oil calculated by Walkie and Chang correlation (1955) [8], and $\frac{\Pi_1}{1+\Pi_2}$ represents the shear dispersion term.

The system modeled for 1D transient simulation considered a horizontal well with an approximate length of 5860 m and 2.441 in tubing internal diameter. Figure 1 represents the well profile. The reservoir pressure is fixed at a value of 304.0 kgf/cm$^2$ and temperature of 105.0 $^o$C. Moreover, it was taken into account a tabulated non-linear IPR for the simulation, represented in Fig. 2. Besides, it was considered a horizontal production line connected to the tubing and the annulus with 15 kgf/cm$^2$ as outlet pressure for both.

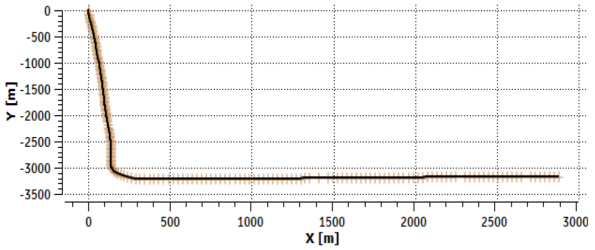


Figure 1. Well schematic and profile.

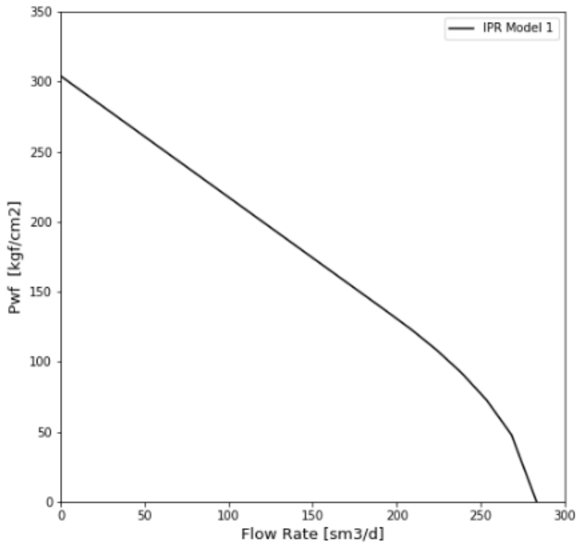


Figure 2. Reservoir Non-linear IPR.

A sensitivity analysis was conducted considering several environmental and operational conditions of surface temperature (winter and summer scenarios), production tubing length, annulus choke orifice and production by the well tubing and annulus. Table 1 describes all the sensitivity performed in the present study in order to evaluate the influence on wax deposition and total oil production according to production strategies.

Table 1. Operational Conditions taken into account for sensitivity analysis

| Scenario | Tubing Length [m] | Annulus Choke Orifice [mm] |
|---|---|---|
| Winter | 2075.0 | - |
| Summer | | - |
| Winter | | 6.0 |
| | | 8.0 |
| | 2600.0 | 12.0 |
| Summer | | 6.0 |
| | | 8.0 |
| | | 12.0 |
| Winter | | 6.0 |
| | | 8.0 |
| | 3262.0 | 12.0 |
| Summer | | 6.0 |
| | | 8.0 |
| | | 12.0 |

## Results and Discussion

For the cases in which tubing length is 2075m and production occurs exclusively on the tubing, it is verified that wax deposition occurs only for winter scenario. Moreover, it is verified that the wax deposition starts to form at 500m, where the fluid temperature falls below the WAT - 27ºC, reaching a maximum of 2.1 mm after 35 days of simulation, presented in Fig. 3.

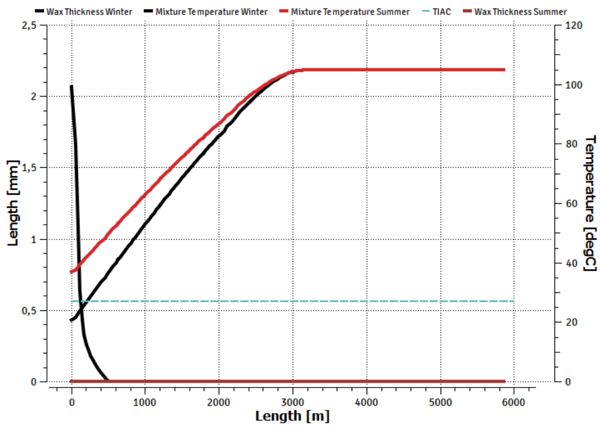


Figure 3. Fluid Temperature and Wax Thickness profiles (Tubing Length: 2075.0 m).

Besides, analyzing standard oil volumetric flow rates at the outlet of the production system, a value of 60.0 sm$^3$/d is obtained, according to the well test, according to Fig. 4.

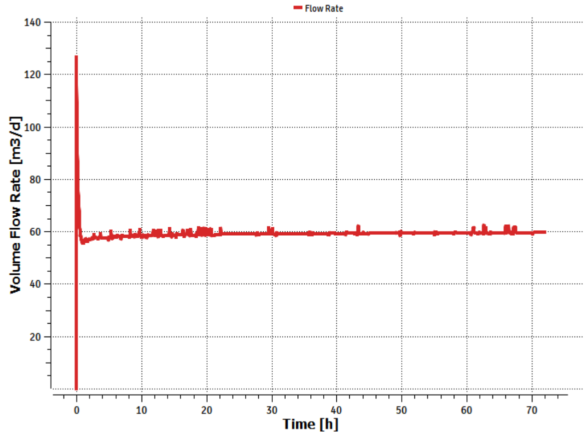


Figure 4. Calculated Oil Flow Rate.

Regarding temperature profile for the cases in which tubing length of 2600 m is taken into account, and the production occurs simultaneously by the tubing and annulus, wax deposition occurs only for winter scenario, as it can been verified in Fig. 5 and Fig. 6. In addition, a maximum total thickness of 1.71 mm, which has been formed on tubing and annulus, is verified.

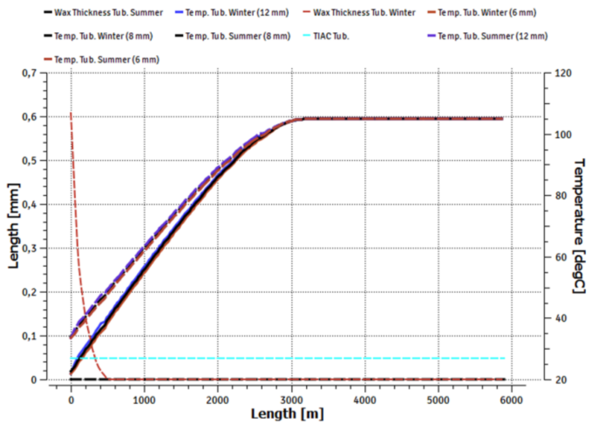


Figure 5. Tubing fluid Temperature and Wax Thickness profiles (Tubing Length: 2600.0 m).

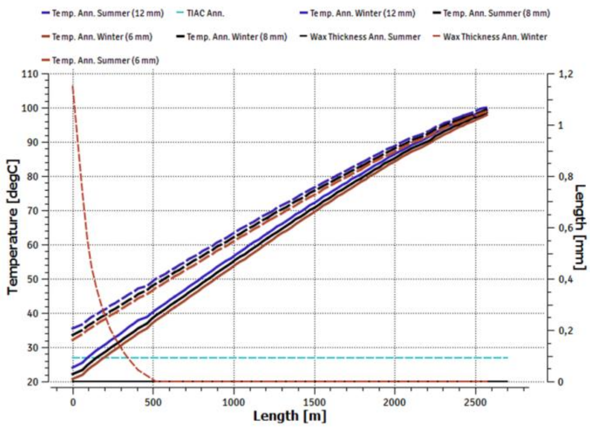


Figure 6. Annulus fluid Temperature and Wax Thickness profiles (Tubing Length: 2600.0 m).

Table 2 presents oil volumetric flow rate at tubing and annulus outlet production system, according to annulus choke orifice sensitivity. According to the values presented below, it can be inferred higher total oil flow rates once annulus choke orifice is increased.

Table 2. Tubing and Annulus Oil Flow Rates (Tubing Length: 2600.0 m)

| Annulus Choke Orifice [mm] | Tubing STD Oil Flow Rate [sm3/d] | Annulus STD Oil Flow Rate [sm3/d] |
|---|---|---|
| 6.0 | 50.0 | 15.0 |
| 8.0 | 45.0 | 30.0 |
| 12.0 | 20.0 | 65.0 |

For the cases, in which tubing length of 3262 m is taken into account, and production occurs simultaneously by the tubing and annulus, wax deposition occurs only for winter scenario, reaching a total maximum thickness of 1.75 mm, according to Fig. 7 and Fig. 8.

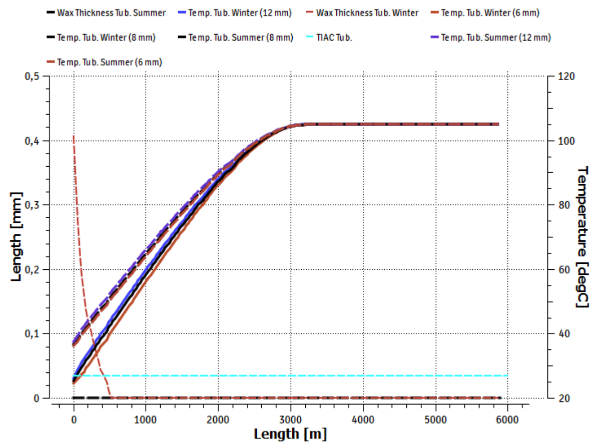


Figure 7. Tubing fluid Temperature and Wax Thickness profiles (Tubing Length: 3262.0 m).

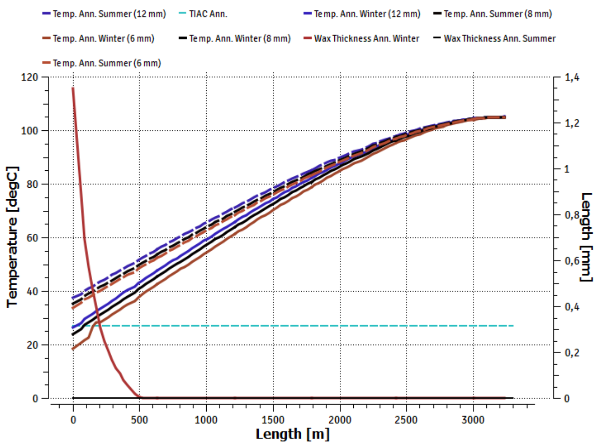


Figure 8. Annulus fluid Temperature and Wax Thickness profiles (Tubing Length: 3262.0 m).

Table 3 presents oil volumetric flow rate at tubing and annulus outlet production system, according to annulus choke orifice sensitivity, verifying higher values for the cases in which annulus choke orifice is increased.

Table 3. Tubing and Annulus Oil Flow Rates (Tubing Length: 3262.0 m)

| Annulus Choke Orifice [mm] | Tubing STD Oil Flow Rate [sm3/d] | Annulus STD Oil Flow Rate [sm3/d] |
|---|---|---|
| 6.0 | 50.0 | 15.0 |
| 8.0 | 45.0 | 30.0 |
| 12.0 | 20.0 | 65.0 |

## Conclusions

The results of this study indicate that wax starts to form at 500m ahead of wellhead position only for winter scenario. Besides, an increase in total oil production and a wax thickness reduction are verified for the cases in which production occurs by the tubing and annulus, and annulus choke orifices are taken into account.

The work described in this paper has proven to produce useful analysis for the operator company, assisting the engineers to have a better understanding of their productive system, assisting them on the decision making process.


## Acknowledgments

The authors would like to thank YPF for the support providing all data required for this study and also the permission to publish this work and ESSS for providing the software and support for the activities.


## Responsibility Notice

The authors are the only responsible for the paper content.

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