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Experimental study of the influence of Reynolds number on the growth and aging of wax deposits formed in an annular test section

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Abstract

The wax deposition on pipe walls is an unwanted phenomenon that occurs in the oil and gas industry, especially in offshore production. Heat transfer between the hot oil flowing through the pipelines and the cold marine environment can cause the oil temperature to decrease below the wax appearance temperature (WAT). As a consequence of the above, wax crystals may appear and subsequently deposit on the pipelines surfaces. Wax deposits reduce the free area available for the fluid to flow, as a result of which oil production may be reduced. The present work aims to evaluate the influence of oil mass flow on the thickness growth and aging of wax deposits. The study was conducted through well-controlled experiments in a laboratory-scale test section. The wax mixture used in the experiments consists of 80% dodecane ($C_{12}H_{26}$) and 20% paraffins ($C_{22}H_{46}$-$C_{39}H_{80}$) and WAT of 35.6°C. Wax deposits with smaller thichnesses but with larger content of heavier waxes were observed as the flow Reynolds number was increased.

Keywords

Wax deposition; Flow Assurance; Deposit aging

Introduction

Wax deposits formation remains a challenge for the oil and gas industry. In offshore production systems, where the temperature of the marine environment is low, the transported oil loses heat to the cold sea water, and heavier wax components can precipitate and solidify in regions close to the pipeline wall [1]. The wax deposits gradually accumulate on the inner wall of the pipeline, leading to a decrease in oil production, an increase in pumping power and, in the worst-case scenarios, the loss of the pipeline installation [2]. The formation, growth and aging of wax deposits are dominated by the joint interaction of several phenomena, *i.e.:* thermodynamics, momentum, heat, and mass transfer [3]. Aiming to overcome or reduce the negative effects of wax deposits, several mitigating strategies are used in the oil and gas industry, *e.g.:* mechanical removal of deposits using pigs [4]; use of chemical [5]; wax removal by heating [6] and thermal insulation [7]. Regardless of the strategy for removing or mitigating wax deposits, it is convenient to know the time evolution of the characteristics of the wax deposit to be removed, especially its thickness and aging. These two characteristics directly influence the efficiency of the removal procedure used.

The present study seeks to evaluate the influence of the mass flow rate of the wax mixture on the evolution of thickness and aging of the wax deposits formed in a loop test section.

Experimental Procedure

The wax deposition experiments were carried out in the annular region of the loop test section designed and built by Veiga et al. [8]. The experimental setup is illustrated schematically in Figure 1. The test section consists of an annular region formed by a copper pipe mounted concentrically to an acrylic pipe. The wax mixture is kept hot and homogeneous in the solution tank, then it is pumped at a constant mass flow rate from the solution tank to the annular region. The wax mixture enters the annular section at a temperature of 38°C (3.4°C higher than the WAT). The annular assembly is kept in a water reservoir that is maintained at a temperature of 38°C. The experimental setup is equipped with two thermostatic baths, one of which is maintained at a hot temperature (38°C) and the other at a cold temperature (12°C). The hot or cold water from these baths can be directed to flow through the copper pipe. With these two baths it is possible to define the cooling rate at which the wax deposition process will take place. In the case of the experiments conducted in this study, the cooling rate with which the temperature of 12°C was reached in the copper pipe is shown in Figure 2. Heating tapes were installed around the solution tank to assist in the solution melting, as well as around the flow lines to prevent unwanted wax precipitation in these lines. More details about the experimental apparatus can be found in Veiga et al. [8].

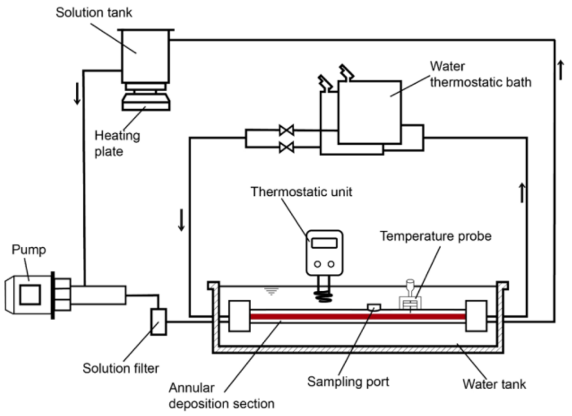

Figure 1. Schematic of the annular test section employed in the wax deposition studies. Veiga et al. (2020)

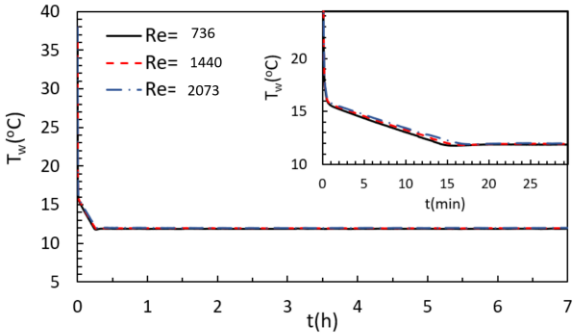

Figure 2. Cooling rate ramp for each experiment.

The composition of the wax mixture used in the experiments is shown in the chromatogram in Figure 3. It should be noted that the C12 solvent is easily identifiable, which makes it possible to conduct faster chromatographic analysis of samples from the deposits.

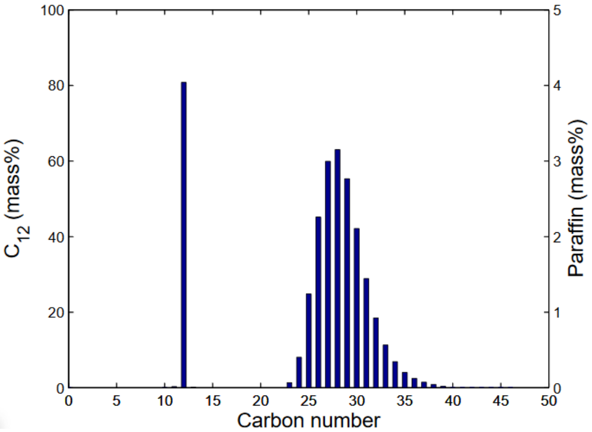

Figure 3. Chromatography of wax mixture. Veiga et al. (2020)

In the experiments, three mass flow rates were tested, represented by Reynolds numbers of 736, 1440 and 2073. The duration of each experiment was 7 hours. After this time, the wax deposit thickness was measured by a micrometer probe, and samples were extracted from the deposits for subsequent chromatographic analysis to access the aging process. The thickness measurement probe and the access port for removing samples from deposits are shown in Figure 4.

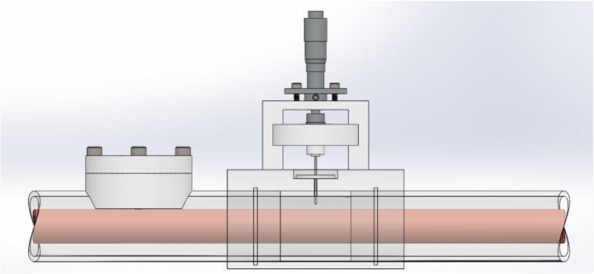

Figure 4. Port for sampling (to the left side) and micrometer mechanism (to the right side) in the annular test section. Veiga et al. (2020)

Results and Discussion

Figure 5 illustrates the results of the chromatographic analyzes carried out on samples of wax deposits extracted after 7 hours of experiments for each of the three Reynolds numbers investigated. The species presented in Figure 5 do not include the C_{12} solvent but rather paraffinic hydrocarbons. It can be seen in the Figure that, as the Reynolds number increases, the enrichment of paraffinic hydrocarbons in the deposit also increases.,

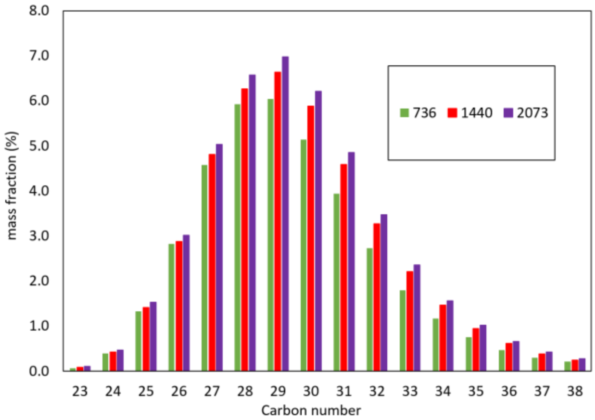

Figure 5. Chromatography of wax species after 7 hours of experiment

After 7 hours of experiments and for each Reynolds number, Figure 6 illustrates the mass fractions of the solvent (C_{12}(%)) obtained in the chromatographic analyses, and the dimensionless thickness $(\delta/\ (r_{ext}-\ r_{int})$ of the wax deposit. It is noted that the thickness of the wax deposit decreases as the Reynolds number increases, and that the amount of solvent inside the deposit also decreases, which is an indication of greater aging of the wax deposit as Re increases. It can also be seen in Figure 6 that the trend with which the thickness of the deposit decreases follows the trend with which the amount of C12 decreases inside the wax deposit.

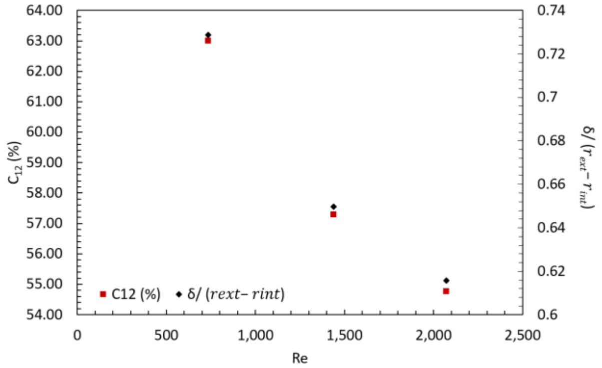

Figure 6. Mass fraction of the solvent (C_{12}) and wax deposit thickness after 7 hours of experiment

Conclusions

The present study experimentally studied the influence of the Reynolds number on the growth and aging of wax deposits. It was found that when increasing the mass flow rate of the wax mixture the thickness of the deposit decreases, however aging increases. A reduction in the wax deposit thickness is a positive factor for the transport of oil. However, since the remaining deposit presents greater hardness due to aging, it will require larger efforts to be removed.

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References

[1] Mehrotra, A. K., Ehsani, S., Haj-Shafiei, S., and Kasumu, A. S. A review of heat-transfer mechanism for solid deposition from “waxy” or paraffinic mixtures. The Canadian Journal of Chemical Engineering. 98 (12), 2463-2488, 2020.

[2] Akinyemi, O. P., J. D. Udonne, and K. F. Oyedeko., 2018. Study of effects of blend of plantseed oils on wax deposition tendencies of Nigerian waxy crude oil. Journal of Petroleum Science and Engineering, 161, 551–558.

[3] Lee, J., Mahir, L. H. A., and Larson, R. G. Experimental Investigation of Time Dependent Thickness and Composition of Multicomponent Wax Deposits on Cold Surfaces. Energy & Fuels. 34 (10), 12330-12339, 2020.

[4] Wang, W., Huang, Q., Liu, Y., and Sepehrnoori, K. Experimental study on mechanisms of wax removal during pipeline pigging. in SPE Annual Technical Conference and Exhibition, OnePetro, 2015.

[5] Anisuzzaman, S., Krishnaiah, D., and Prathaban, S. N. Comparative Study on Inhibitors Comprising Aromatic and Non Aromatic Solvents towards Flow Assurance of Crude Oil. Pertanika Journal of Science & Technology. 28 (1), 2020.

[6] Bell, E., Lu, Y., Daraboina, N., and Sarica, C. Experimental Investigation of active heating in removal of wax deposits. Journal of Petroleum Science and Engineering. 200, 108346, 2021.

[7] Sousa, A., Matos, H., and Guerreiro, L. Preventing and removing wax deposition inside vertical wells: a review. Journal of Petroleum Exploration and Production Technology. 9 (3), 2091-2107, 2019.

[8] Veiga, H. M., Boher e Souza, L., Fleming, F. P., Ibanez, I., Linhares, R. C., Nieckele, A. O., and Azevedo, L. F. A. Experimental and Numerical Study of Wax Deposition in a Laboratory-Scale Pipe Section under Well-Controlled Conditions. Energy & Fuels, 34 (10), 12182-12203, 2020