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Research Article

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Measurement and Prediction of Paraffin Wax Deposition in Oil Pipelines: A Review

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Abstract The phenomenon of wax deposition on inner surfaces of crude oil pipelines and vessels is a serious problem in oil production and transportation. This review describes some state-of-the-art directions in the field of measurement and prediction of paraffin wax deposition growth. A few mathematical models and measuring systems are discussed.

Keywords wax deposition, crude oil pipelines, simulation, measurement, prediction

Introduction

Paraffin wax is a soft solid derivable from petroleum (crude oil) that consists of a mixture of hydrocarbon molecules containing between twenty and forty carbon atoms. Paraffin waxes are mixtures of saturated n- and iso- alkanes, naphthenes, and alkyl- and naphthene-substituted aromatic compounds. A typical alkane paraffin wax chemical composition comprises hydrocarbons with the general formula C_nH_{2n+2} [1].

The crude oil contain significant amount of wax. Wax deposition is mostly a temperature driven process during production, transportation and storage of the oil, it begins under temperatures lower than paraffin freezing point, Wax Appearance Point (WAP) or Wax Appearance Temperature (WAT), at these temperatures wax start to form crystals in the oil and deposits in the vessels or pipeline walls. The deposition of wax in oil and gas pipelines represents a major challenge in oil and gas production and transportation.

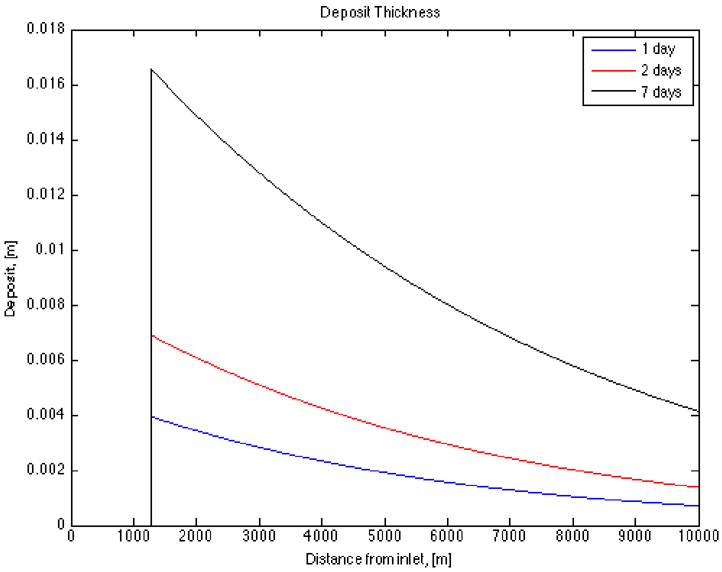


Figure 1: Deposit thickness profiles after one day, two days and seven days obtained by the analytical model. The maximum deposit thickness is obtained at 1284 meter, where the WAT is reached in the near-wall region (Illustration: Stubsjøen [2]).

Analytical and Numerical Modeling of Wax Deposition Growth

Paraffin deposition formation in oil pipeline was investigated through different studies; five effective thermal conductivity models for determination of the effective thermal conductivity of paraffin wax deposits have been evaluated. Based on the structure of the deposit, the Effective Medium Theory is found applicable. The influence of the deposit on the thermal conditions in the pipeline has been examined, and the temperature at the deposit surface is found to increase with an increasing wax deposit thickness [2]. The wax deposit profiles after one, two and seven days are plotted as shown in Figure 1. The maximum deposit thickness is found to increase from 3.9 mm to 16.6 mm from the first to the seventh day, hence, the growth rate of the deposit is found to decrease with time.

An implementation of a method to calculate the mass transfer rate which is affected by bulk precipitation is done. Simulations show that the bulk precipitation makes a slighter concentration gradient near the wall. Experimental data shows that an increase in oil or condensate's flow rate leads to a slower paraffin build up [3].

The numerical methods are used to study wax deposition in oil/water stratified flow through a channel as shown in Figure 2.

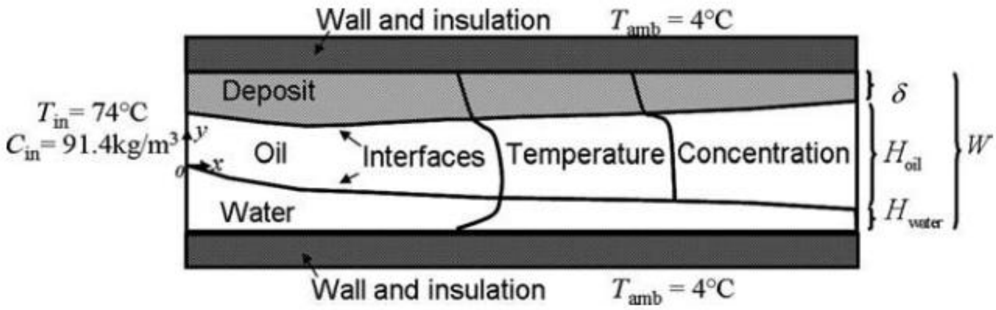


Figure 2: Schematic of wax deposition in oil/water laminar stratified channel flow (Illustration: Siljuberg [3])

A unidirectional flow analysis is used to calculate the non-isothermal hydrodynamics and mass transfer. It was found out that the change in the position of the oil/water interface throughout the channel must be taken into account for the mass balance to be valid [4].

The problem of wax deposition in pipelines and the growth model of paraffin deposits in pipelines which is based on the model developed in the Michigan University that is shown in Figure 3. The model describes the time dependence of the deposit growth basing on molecular diffusion. This model also includes the aging of the deposits that is a process of increasing of the wax fraction in the deposit due to the internal diffusion [5].

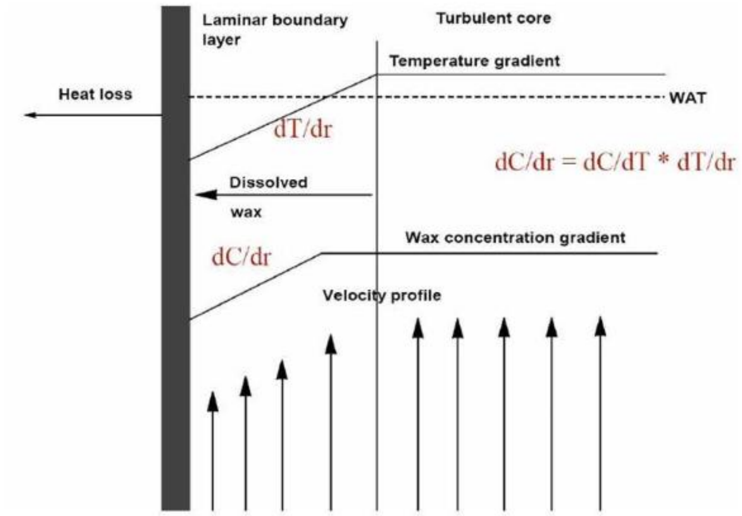


Figure 3: Molecular diffusion as a mechanism of wax deposits forming (Illustration: Strizhenko [5])

The coupled system of differential equations is needed to describe the growth and the aging of the deposit:

$$\left(-2\pi r_{eff}\right)\rho_{wax}F_w\frac{dr_{eff}}{dt}=\left(2\pi r_{eff}\right)K_M\left(C_b-C_{wo}\left(T_i\right)\right)-\left(2\pi r_{eff}\right)\left[-D_e\frac{dC}{dr}|_i\right] \quad (1)$$

$$\pi\rho_{wax}\left(r^2{}_i-r^2{}_{eff}\right)\frac{dF_w}{dt}=2\pi r_{eff}\left[-D_e\frac{dC}{dr}|_i\right] \quad (2)$$

Where ρ_{wax} *(kg/m³)* is the density of deposits, r_i *(m)* is the radius of clean pipe, C_{wo}*(kg/m³)* is the solubility of wax in oil, F_w *(-)* is the wax content, $\frac{dC}{dr}|_i$ is the concentration gradient at the wall, $\frac{dF_w}{dt}$ *(S^{-1})* is the rate of the wax fraction in deposit changing with time (aging), C_b *(kg/m³)* is the concentration of the wax in the bulk oil, T_i *(K)* is the pipe inlet temperature, D_e *(m^2/s)* is the effective diffusivity in the deposit, r_{eff} *(m)* is the effective flow radius at the time of interest and K_M*(m/s)* is the mass transfer coefficient.

Automated Monitoring Systems of Wax Deposition Growth

Based on radioisotope measuring system (RIMS) an automatic non-contact measuring system for pipeline wall paraffin deposit was developed [6]. With RIMS it is possible to monitor the deposit layer thickness on pipeline walls and to obtain the information regarding the character and the composition of the flow transported, and, in turn, based on the results obtained, oil extraction and transportation processes may be further improved.

Radioisotope method based on Compton scatter and photoelectric absorption of gammas. It consists of two components: primary converter that interacts with environment and gives informative parameter and secondary device that processes and grades the value obtained (Figure 4). Paraffin layer thickness measurement method in an oil pipeline includes exposing the oil flow to narrow radiation beam, recording the radiation that passed through the medium monitored in different points of pipeline cross-section and creating corresponding information signals in form of sampled readouts. Next, paraffin layer thickness is determined via processing the previous irradiation results to have different intensity and character for different media – pipeline material, paraffin layer, moving oil. The interval between measurements is about 0.2 s.

The proposed device is rather reliable, simple for service, interchangeable. The disadvantages are the necessity of use a gamma radiation source and high voltage in the electronic detector.

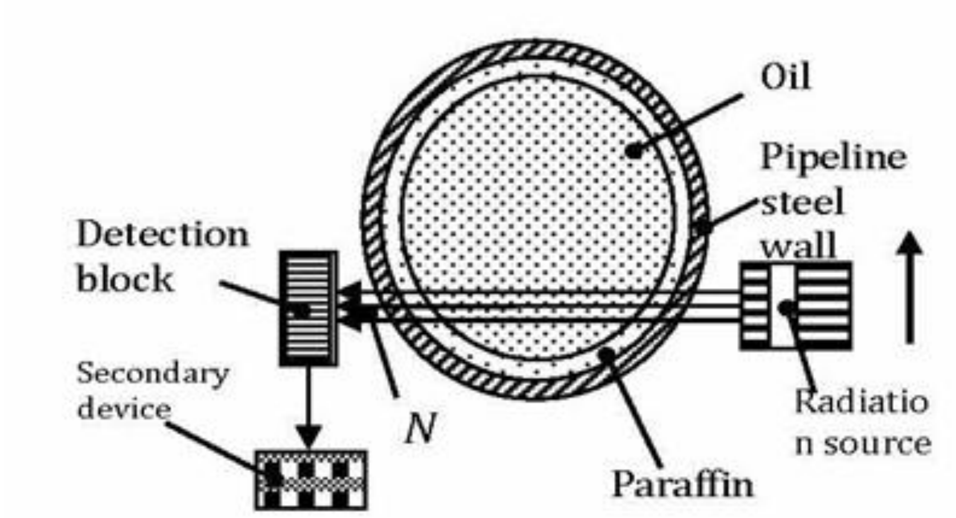


Figure 4: The radioisotope device for measuring the paraffin layer thickness (Illustration: Kopteva [6])

The computational challenges of robotic applications and translations of actions using sensors have been used. It combines robot agent based technologies with sensing technologies for efficiently locating health related events and allows active and corrective monitoring and maintenance of the pipelines. In addition, it permits a good tracking of the mobile sensors. Using the output of event analysis, a robot agent gets command from the controlling system, travels inside the pipelines for detailed inspection and repairing of the reported incidents (e.g., damage, leakage, or corrosion) [7]. Self-adjusting from motion singularity position to successful motion position is shown in Figure 5 and the Illustration of a pipeline topology and a prototype robot mission is shown in Figure 6.

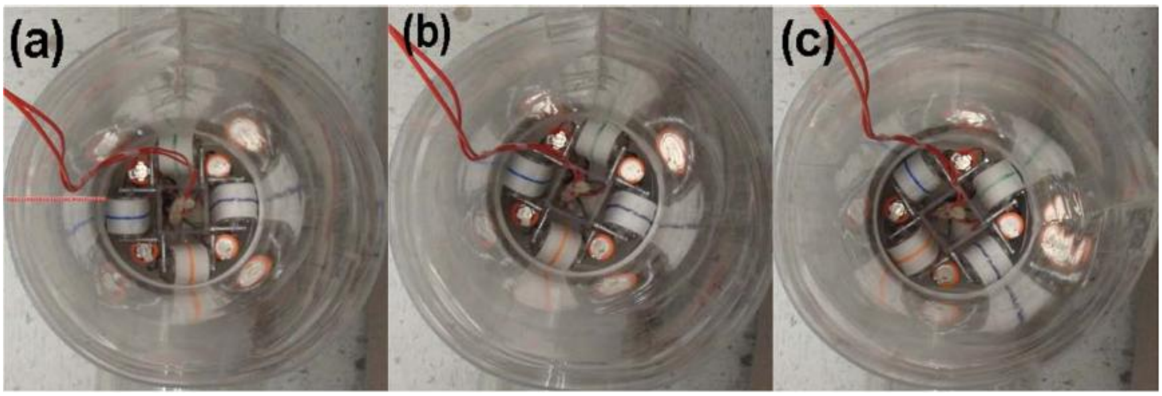
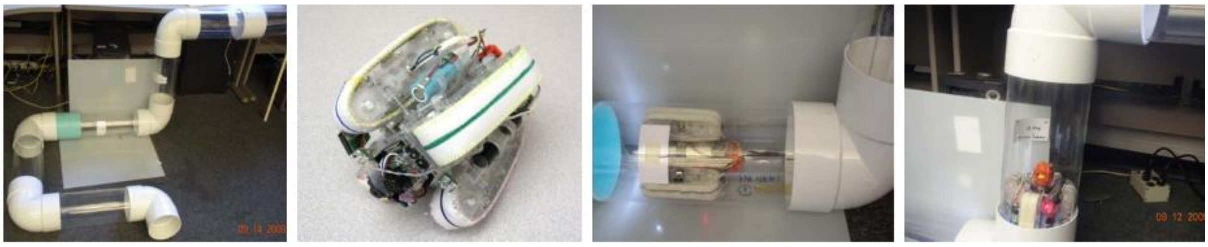


Figure5: Self-adjusting from motion singularity position to successful motion position (Illustration: Kim [7])



a) A pipeline topology (b) A robot agent (c) Robot performing horizontal motion (d) Robot performing vertical motion

Figure 6: Pipeline topology and a prototype robot mission (Illustration: Kim [7])

A preliminary feasibility study is carried out in order to investigate the possibility of utilizing photon scattering for scale detection in multiphase oil/water/gas pipelines. The initial stages of the design of a photon scatter gauge for scale monitoring and characterization were considered as a scatter gauge would, as opposed to transmission gauges, eliminate the need for access to both sides of the pipe work for the required measurements [8]. For scale detection and characterization, however, a well-defined measurement voxel is not considered to be necessary. Therefore, the method described and discussed in this work was based on using uncollimated detectors whereas collimation was considered only for the photon source as shown in Figure 7.

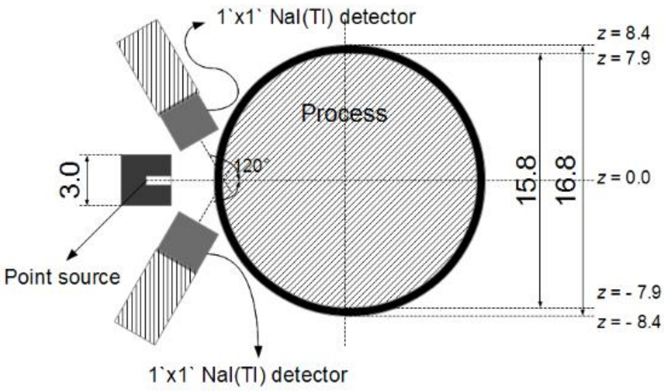


Figure 7: The initial problem geometry for scale detection implemented in MCNP5. The detectors are placed near the source at 120 relative to the incident beam direction. The source collimator has an opening of 1 mm diameter. All dimensions are given in cm (Illustration: Meric [8]).

A rigorous wax deposition model combined with the wax precipitation kinetics in the boundary layer was developed using a computational heat and mass transfer analysis. This model accurately predicted the deposition and aging rates for lab scale and pilot plant scale flow loop tests under laminar and turbulent flows. The model was also extended to make prediction in subsea field pipelines [9]. The growth of the deposit thickness as a function of time is shown in Figure 8.

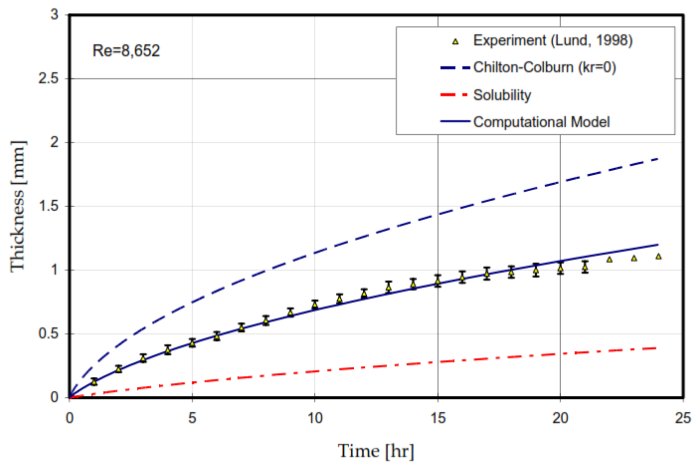


Figure 8: Deposit thickness versus time under turbulent flow. Theoretical predictions with the Chilton-Colburn analogy, the solubility method (Venkatesan and Fogler, 2004) and the theoretical model with precipitation kinetics (Illustration: Hyun [9]).

MATLAB simulator is used to predict wax deposited in a onshore pipeline using MATZAIN model. It provides idea of how wax is being deposited in pipeline and also suitable suggestions are also provided. The study showed that for the first day total wax deposited is 0.52 cm towards end of pipeline and for the first week (7 days) total wax deposited is 3.62 cm towards end of pipeline. Also by the end of 20 days the pipeline is completely plugged as maximum thickness of wax is 10.5 cm [10] (Figure 9).

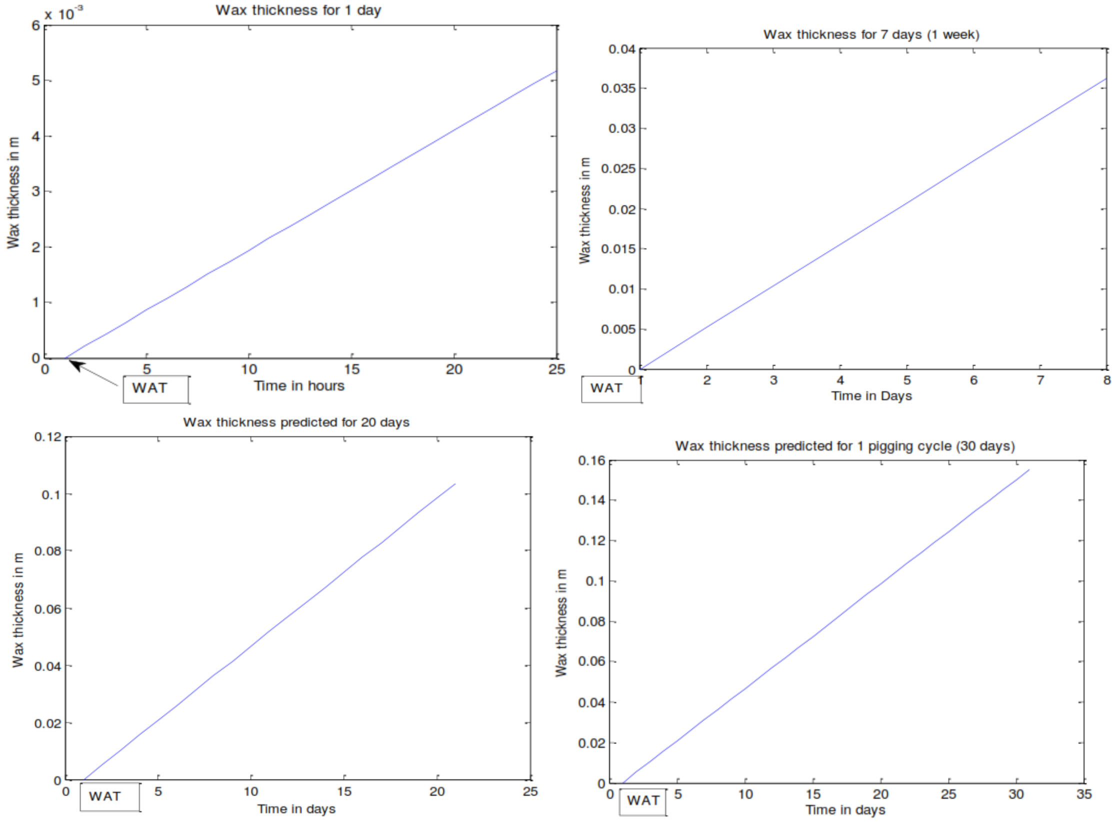


Figure 9: Wax deposition thickness variation with respect to time (Illustration: Parameshwar [10])

A series of wax deposition experiments involved the sloughing effect was performed in the laboratory flow loop, and a model was established to predict the wax deposition distribution along the pipeline. These results were used to implement a pigging program. In addition, a practical experimental method by testing the viscosity of deposit-in-oil slurry ahead of the pig was specially designed to measure the volume of deposit during pigging in actual field. The model predictions agreed with the field measured results excellently with a relative error being 10.9% [11].

The wax deposition characteristics in the investigated pipeline in the winter were studied and simulated firstly in a flow loop with the oil temperature at 11.0 °C and the wall temperature at 5.0 °C. The change in thickness of deposit layer with test time was observed throughout the test. In such a process, deposition occurred in parallel with sloughing. It was expected to approach a balance in the deposit layer thickness after certain times and the deposit layer thickness stayed unchanged. Then, simulation parameters were adjusted to simulate wax deposition during spring with the oil temperature and the wall temperature was 14.5 °C and 13.6 °C, respectively. In the first run for summer simulation, the oil temperature was fixed at 20.8 °C, while the wall temperature was set at 19.9 °C; (2) In a subsequent experiment, the oil and wall temperatures were raised to 24.7 °C, respectively. The change in thickness of the deposit layer with time is demonstrated in Figure 10.

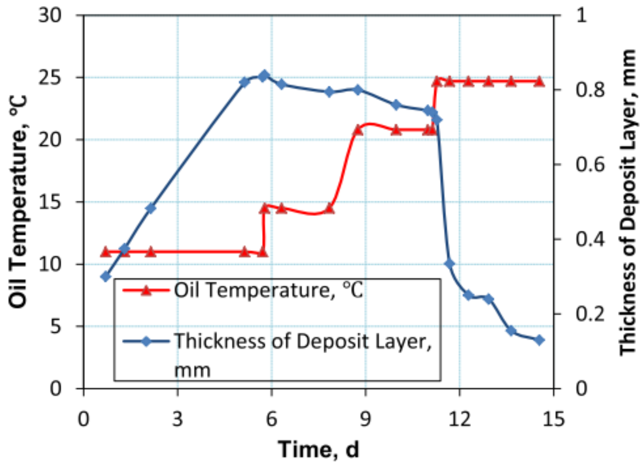


Figure 10: Thickness of deposit layer with increasing oil temperature and/or time (Illustration: Parameshwar [10])

Conclusions

Wax deposition is considered one of the most critical problems causing blockages of oil transportation pipelines, leading to production losses and even cases damaging of smooth oil flow in transformation pipeline. Since the oil transportation pipeline have severe wax deposition problems especially during winter seasons, so, different techniques were used to predict and measure wax deposition growth in the inner surfaces of oil transportation pipe lines. Further developments probably will use various physical effects and contemporary informational technologies (such as artificial neural networks) for prediction of wax deposition growth.

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