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Numerical Study: Comparison of Paraffin Deposition In The Laminar And Turbulent Regime

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***Abstract* –** The problem of paraffin deposits in oil wells and pipelines monopolizes substantial human and economic resources. Its prediction is, therefore, essential to optimize its management.

The formation of the deposit arises from a delicate interplay of hydrodynamic, thermal, and thermodynamic factors, alongside paraffin diffusion and the rheology of the crude oil. This research has resulted in a better understanding and calculation of the rates at which wax is removed. Furthermore, the study has suggested the presence of two distinct flowing regions in turbulent and laminar flow, which results in the formation of thin solid sediments attached to the pipe wall.

By conducting this numerical study using FORTRAN, we can gain insights and optimize the design and operation of pipelines and maintain efficient production. The study also involved a rough comparison between the results obtained from two different types of flow. This approach, which considers the viscoelastic behavior of paraffinic crude, allows for a more accurate prediction of deposit formation. With this enhanced understanding, we can develop improved strategies for managing paraffin build-up, minimizing resource allocation and costs associated with its removal. Ultimately, optimizing the design and operation of pipelines will contribute to the maintenance of efficient production in the oil industry.

Keywords – Wax Deposition; Paraffin; Laminar And Turbulent Regimes

I. INTRODUCTION

Potential Crude oils or natural gas fluids, consisting primarily of hydrocarbons, including paraffin, hold immense importance in the energy industry. Paraffin, represented by the chemical formula C_nH_{2n+2}, is commonly present in crude oils as long, linear molecules or in branched or cyclic structures. When normal paraffin with 16 or more carbon atoms combines, they form solid crystalline substances known as wax, which solidify at 20˚C. The quantity of wax varies based on the geographical origin of crude oil. Understanding hydrocarbon characteristics, such as paraffin and wax-forming tendencies, becomes crucial for pipelines' smooth and reliable operation in the energy infrastructure. Pipeline transportation, vital in efficiently and securely transporting large volumes of oil and its derivatives over long distances continues to gain significance globally and nationally due to increasing product quantities and energy consumption.

In the context of pipeline transportation, the ability of solid particles to diffuse toward colder walls is a critical factor in achieving the formation of a stable cold slurry without wall adherence. Merino-Garcia and his colleagues (2008) have reported on many mechanisms suggested for the movement of solids within a fluid stream, such as shear dispersion, Brownian diffusion, gravity, thermophoresis, and thermophoresis. [1] Although these mechanisms drive particles toward the wall, their impact is relatively small compared to the other two predominant mechanisms. Liquid molecules do not contribute to deposition in the absence of temperature gradients. As a result, solids predominantly remain in bulk without significant deposit. However, the limited deposition can be attributed to the waxes in direct contact with the wall, eliminating the need for diffusion to transport them (Borghi 2005). [2] Understanding solid particle behaviour and its interaction with waxes and other components becomes crucial in optimizing pipeline operations and minimizing slurry formation and wall adherence issues.

The wax deposition model has been developed to account for both laminar and turbulent flow conditions, Among the researchers who have studied the turbulent flow

Hsu 1994[3] studied in this study to understand and prevent wax deposition problems in subsea pipelines. The obtained results make it possible to determine the influence of turbulent flow conditions, oil composition, and paraffin inhibitors on the wax deposition rate. This information can be used to develop wax deposition models and optimize waxy oil transport conditions to reduce the risk of wax deposition in subsea pipelines.

Bern (1980) [4] A simple approach has been developed to assess the degree of wax deposition from crude oil pipelines. The Experiments of the Stable 40s Crude Oil.Showed that molecular diffusion is the primary process responsible for sedimentation in the Arbaeen seal. Applying this theory to in vitro testing yields results that are at least consistent with the minimum available wholesale data. Extensive studies show that sedimentation inhibitors can alleviate problems caused by wax deposits under a number of conditions. However, laboratory tests indicate that the ability of these additives to reduce sedimentation rate is very reliable under temperature conditions.

Singh (2000) [5] introduced a comprehensive mathematical model to study WD in pipelines, which can accurately predict both the thickness of wax deposits phenomenon under laminar flow conditions. The gelation of waxy oil on the cold surface, the diffusion of higher-carbon waxes towards the gel layer, internal diffusion through the trapped oil, the precipitation of wax molecules within the deposit, and the counter-diffusion of lower-carbon de-waxed oil out of the deposit are all steps in the wax formation process. These steps contribute to gel aging, leading to an increase in the solid wax content over time. Remarkably, experimental results closely align with the theoretical predictions made by Singh and al.

Boucetta (2022) [6] made a detailed mathematical analysis of the deposition problem. They studied the impact of paraffin porosity on the flow parameters concerning essentially, the thickness of the paraffin deposit, the longitudinal distribution of the temperature as well as the evolution of the flow.

Wax Deposition in Pipelines

Several factors impact the wax deposition WD process in pipelines, including pipe wall temperature (inlet coolant temperature), crude oil composition and temperature, ambient temperature, flow rate, thermal history, time, and pressure. These factors contribute to the precipitation of the solid paraffin phase on the pipe wall, which presents a significant challenge in maintaining the flow of hydrocarbons within the pipeline. [4]

Wax precipitation occurs when a paraffin petroleum reservoir fluid is cooled to the (WAT).

WAT represents the highest temperature at which solid wax molecules start to appear in the liquid and is determined using a standardized procedure known as the "cloud point"[5].

When wax deposition occurs in pipelines, the wax molecules that have precipitated near the pipe wall begin to form an initial gel. This gel is a three-dimensional network structure consisting of wax crystals and contains a notable quantity of trapped oil within it. Over time, this initial gel continues to grow, influenced by radial, thermal and mass transfer gradients caused by heat losses to the surroundings. This process is illustrated in Figure 1

In a wax precipitation curve, the highest point, Figure 2, indicates WAT, where the crystallization of waxy components in crude oil begins due to cooling. As the temperature decreases further, the precipitation curve typically shows an asymptotic trend, representing the total wax content in the oil at lower temperatures. Understanding the WAT and the wax precipitation curve is essential in managing wax-related issues and optimizing the production and flow of crude.

$$\frac{dp}{dx} = -f \frac{\rho Q^2}{4\pi^2 (R-\delta)^5} \tag{1}$$

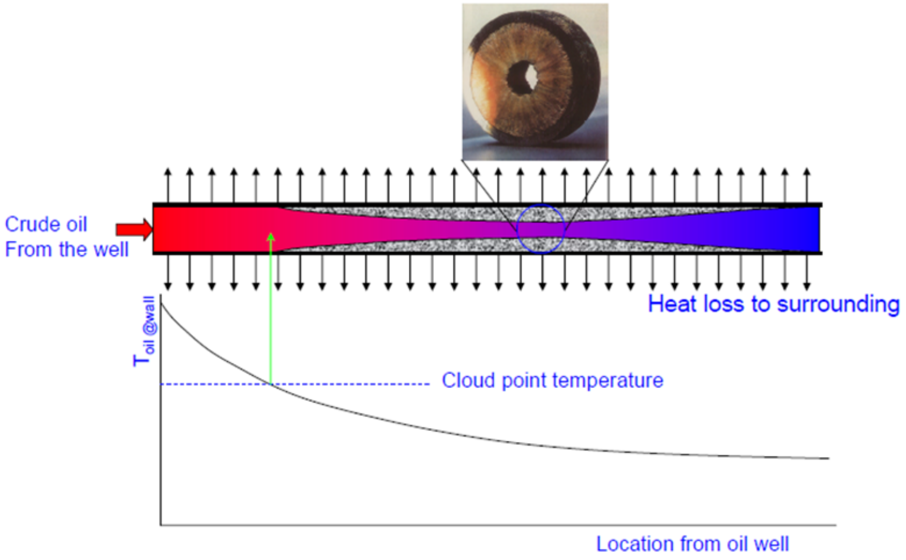


Figure 1 : Wax deposition process in the hydrocarbon pipeline.***Hata! Başvuru kaynağı bulunamadı.***

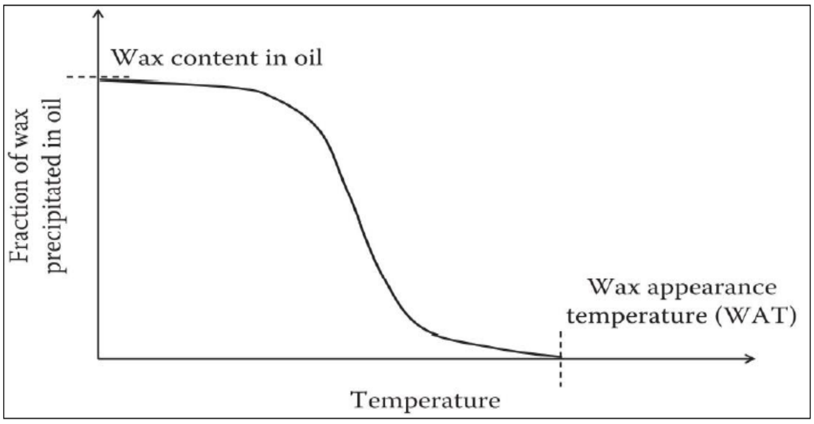


Figure 2 : the curve of wax precipitation

II. THEORITICAL MODEL

A mathematical model for quantitatively evaluating wax deposition characteristics in pipelines is presented. The model combines the energy and momentum balance equations and the molecular diffusion model by Fick's law.

A. Momentum Balance Equation

The momentum equation for Newtonian, incompressible, and unsteady single-phase fluid flow can be written as

We can formulate the pressure (p) by considering both x and t; similarly, we can define the friction coefficient (f) as a function of both x and t. The variables R, Q, and ρ correspond to the radius of the pipe, flow rate, and fluid density, respectively. The integration is carried out concerning the variables x and t

$$\Delta p = p_{in} - p_{atm} - \rho g H = \frac{\rho Q^2}{4\pi^2 R^4}\int_0^{L^*} \frac{f}{(1-\delta^*)^5}\,dx^* \qquad (2)$$

II. NUMERICAL METHOD

A numerical study can be conducted using FORTRAN to compare wax deposition in a pipe between laminar and turbulent flow. The following steps can be taken:

- ➢ The governing equations of fluid flow, heat transfer, and wax deposition are derived and discretized using numerical methods, such as finite difference, finite volume, or finite element.
- ➢ The discretized equations are implemented in the FORTRAN code, which defines the variables, arrays, and subroutines necessary for the simulation.
- ➢ The boundary and initial conditions are specified, which include the inlet and outlet conditions, fluid properties, and pipe geometry.
- ➢ The FORTRAN code is run to solve the equations iteratively, starting from the initial conditions until a steady-state solution is achieved.
- ➢ The wax deposition rate and thickness are calculated and compared between laminar and turbulent flow conditions.
- ➢ The simulation results are validated against experimental data or analytical solutions, and the accuracy and efficiency of the FORTRAN code are assessed.
- ➢ The sensitivity analysis investigates the effect of parameters, such as flow rate, temperature, wax properties, and pipe roughness, on the wax deposition in a laminar and turbulent flow.

III. RESULTS

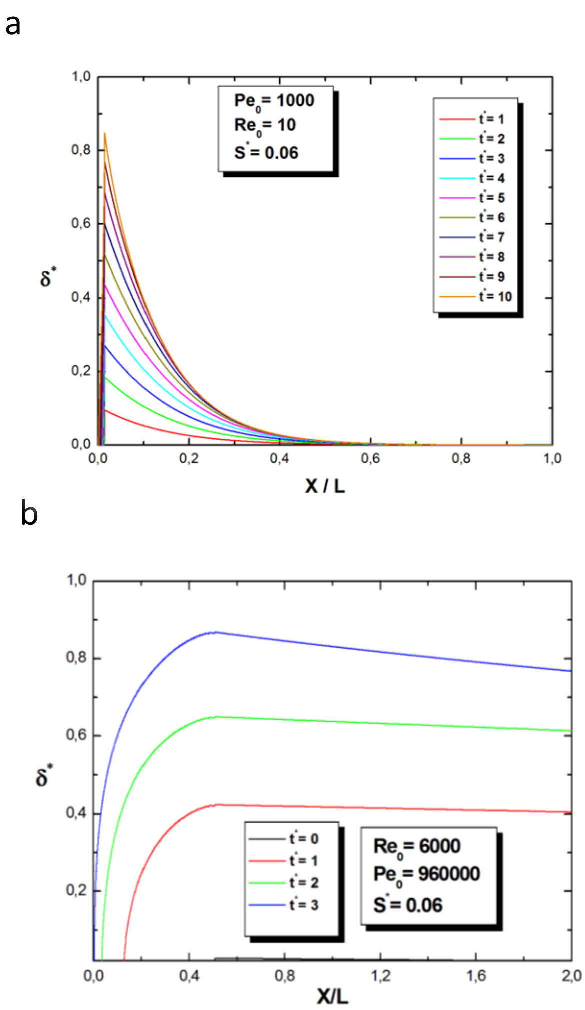
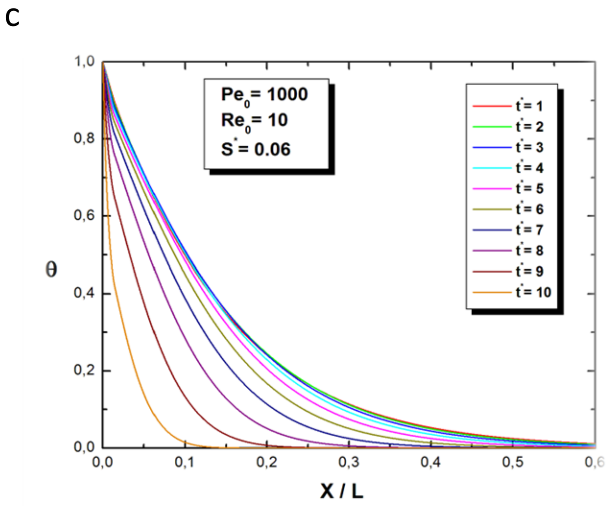


Figure 3: Longitudinal distribution of the thickness: a) Re=10, b) Re=6000



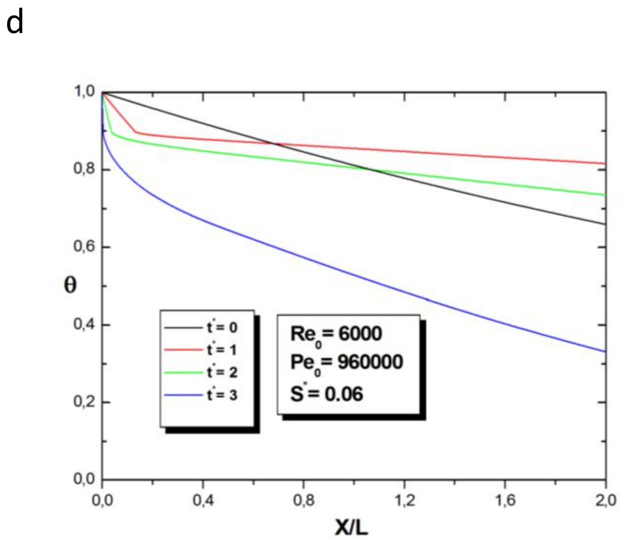


Figure 4 :Longitudinal temperature distribution: c) Re=10, d) Re=6000

In **Hata! Başvuru kaynağı bulunamadı.**, the thickness behavior of δ*(x*,t*) is compared between two cases, (a) and (b). It is observed that when t*=3, the deposit occurs in case (a) but not in case (b). This suggests a difference in the deposition behavior between the two cases, with case (a) exhibiting a faster deposition rate.

Figure 4 (c) and (d) show the temperature evolution depending on the dimensionless pipe length because of the difference between the two Reynolds numbers corresponding respectively to Re=10 and Re=6000. we observe that the heat exchange is faster in case (d) than in case (c).

IV. CONCLUSION

- Based on the results presented, it can be concluded that the flow conditions of the system, specifically the presence of laminar or turbulent flow, significantly impact the deposition behavior and heat transfer rate.
- Overall, these results demonstrate the critical role that flows conditions, specifically laminar or turbulent flow, play in the studied system's deposition behavior and heat transfer rate. These findings may have important implications for the design and optimization of industrial systems, particularly those involving fluid flow and heat transfer, where controlling the flow conditions to promote either laminar or turbulent flow may be key to achieving desired outcomes.

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