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An Alternative Method for Paraffin Deposition Thickness Measurement on Pipelines

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Abstract: Paraffin deposition thickness is a critical parameter for mathematical modelling and validation of deposition predictions. Various measurement techniques, such as LD-LD, pressure drop, heat transfer, and gravimetry, are commonly used, but many involve high costs and complex instrumentation. This study presents the development of a simpler, cost-effective method for measuring paraffin deposition thickness in pipelines. The approach involves placing steel coupons inside the pipeline, retrieving them after deposition, and measuring the accumulated layer. Results demonstrate that the proposed method yields thickness values within the uncertainty range of the widely accepted gravimetry method, making it a viable alternative for both scientific and industrial applications.

Keywords: Paraffin deposition, oil and gas industry, instrumentation, measurement methods, WAX.

I. INTRODUCTION

One of the major challenges faced by the oil industry since its beginning is the transportation of oil from the reservoir to the storage and processing units. When oil is in the reservoir, it presents a relative high temperature when compared to the surface temperature, which keeps the oil in a liquid state with a certain level of fluidity [1]. As the oil is extracted and transported to the surface, it begins to lose heat and undergoes structural changes. This reduces its fluidity and sometimes transformed into a gel-like substance that tends to adhere to the inner walls of the pipeline, often leading to complete blockage.

The petroleum is composed of a wide variety of chemical components, but its largest composition is hydrocarbons, which among them, the paraffin is the subject of considerable study since its solidification temperature is dependent on the amount of carbon on its structure, the greater the amount of carbon, the greater its molecular weight and the higher its solidification temperature [2]. When in the reservoir, the paraffins are solubilized in the oil, which generally remains at temperatures between 70 and 150 ºC [3]. As the oil is extracted from the reservoir, it travels through a pipeline that is at lower temperatures, for example, in offshore production (average temperature of 5 ºC). The heat exchange between the oil and the pipeline wall results in heat loss, reducing the temperature of this fluid and, therefore, the solubility of the paraffins. When the oil reaches a certain temperature, the first paraffin crystals begin to appear, precipitating and forming agglomerates. This temperature is called the wax appearance temperature or WAT [4]. The oil then becomes more viscous, and these solids tend to deposit on the pipeline wall.

Paraffin deposits cause several losses to companies, for example, a drop in oil flow due to pipeline obstruction, a drop in pressure in the pipeline, an increase in the amount of energy required to reestablish flow, a decrease in production and blocked valves. When dealing with paraffin deposition in pipelines, the most important factors are the thickness of the deposited layer, its hardness and chemical composition [5],[6]. Thickness measurements, for example, are used to validate mathematical deposition models and can also be used to evaluate paraffin removal methods [5],[7].

This article reports the development of an alternative method for measuring paraffin deposition thickness using steel coupons placed on the inner wall of the pipeline. These also undergo deposition and can then be removed from the pipeline and their thickness measured.

II. THICKNESS MEASUREMENT METHODS

There are several methods for measuring deposition thickness, including LD-LD, laser-based techniques, heat transfer analysis, pressure drop monitoring, weighing, and online heating. This paper discusses some of these methods.

A. Heat transfer method

The heat transfer method measures paraffin deposition thickness by analysing changes in the total heat transfer resistance of the fluid (oil) as it flows through a pipeline.

The presence of a paraffin layer affects heat transfer to the external environment, with its contribution being directly proportional to its thickness. To determine the deposition thickness, it is necessary to measure the external environmental temperature, the fluid temperature inside the pipe, and the heat flux through the pipe external wall. These parameters are then applied in a mathematical equation to calculate the thickness [3],[7],[8],[9].

[10] employed the heat transfer method in a Flow-loop experimental apparatus to measure paraffin deposition thickness. The results indicated that while the method is easy to use, its precision is limited when the deposition layer is very thin. However, accuracy improves as the thickness increases. When compared to the gravimetric method, the heat transfer approach was found to be less precise than gravimetric method.

A key advantage of the heat transfer method is its non-intrusive, online nature, allowing for real-time thickness measurements. However, its accuracy depends on obtaining precise heat transfer coefficients for both the inner and outer pipe walls. Additionally, this method is not suitable for multiphase flow conditions [7].

B. Pressure drop method

The method is based on the pressure drop caused by the reduction of the effective diameter of the pipe. This reduction occurs due to the paraffin de deposition. Once the value of the pressure drop is known, it can be used in a mathematical equation for obtaining the thickness of the paraffin deposition [7],[11],[12].

[13] reports paraffin deposition studies using a test bench which the thickness of the paraffin deposition is measured using various methods, including the pressure drop method. [9],[14] and [8] also show experiments using this method. The method is online and does not require pipe depressurization or restart of fluid flow.

C. Gravimetric method

In this method, a test sample is used and weighed before and after paraffin deposition, then the weights are compared. The weight values are used in an equation to determine the thickness of the deposited layer. From the deposition volume [13]. It is one of the simplest and fastest methods, however it is necessary to stop the pipe flow to carry out the measurement [7]. It is also necessary to know the density value of the paraffin deposit with certain precision.

D. On-line measurement method

This method involves applying a heat pulse to the pipeline using a heating element, such as a resistance. The element is activated for a short duration and then turned off. A temperature sensor placed on the exterior of the pipe measures the thermal transient response. To minimize heat loss, the pipeline is externally insulated.

When the heating element is switched on, heat is generated, and upon deactivation, part of the heat dissipates through the pipe wall. Since paraffin deposition acts as a thermal insulator, a thicker deposition layer results in more heat being retained within the pipe wall. Consequently, the temperature measured by the sensor will be higher, providing an indirect means of assessing deposition thickness [6].

III. MATERIALS AND METHODS

A. The coupons developed

The proposed method employs steel coupons inserted inside the pipeline, where they accumulate paraffin deposition in the same manner as the inner pipe wall. This allows for direct measurement of the deposited layer. Once the deposition process is complete, the coupons are removed from the pipeline and weighed, enabling thickness and chemical composition analyses. Figure 1 presents a three-dimensional design of the proposed coupon, which includes two tabs designed for easy insertion and removal from the pipe's inner wall. The curvature of the lower section of the coupon is designed to match the internal wall curvature of the pipeline, which varies based on the pipe diameter. Additionally, small magnets can be attached beneath the flaps at the ends of the coupon to secure it against the pipe's inner wall.

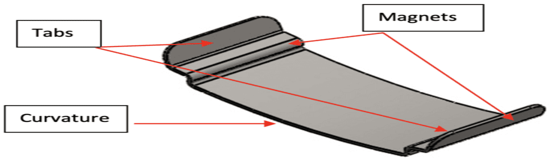

Fig. 1 The three-dimensional design of the coupon proposed for the paraffin deposition thickness measurements.

One of the key motivations behind developing this method was the limitations encountered in research projects conducted by the Optical Properties Laboratory at the Federal University of Bahia. These projects utilize pipelines with a diameter of 14 inches and a length of 1 meter, weighing over 150 kg. Due to their significant weight, the gravimetric method was impractical, and a faster, more convenient measurement technique was required.

To address this, the proposed method was applied for deposition thickness measurements. The coupons were specifically designed for this pipeline diameter and were fabricated from carbon steel sheets. Each coupon measures 60 mm in length, 1 mm in thickness, and 32 mm in width. Figure 2 presents an image of the test specimen, showing its curved shape, which was designed to conform to the internal wall of the pipeline. Additionally, neodymium magnets were incorporated at both ends to enhance fixation.

Fig. 2 Images of coupons developed for the paraffin deposition thickness measurement method.

B. Apparatus for the paraffin deposition production

To evaluate the method for measuring paraffin deposition thickness, it was applied in paraffin deposition tests conducted with the experimental setup developed by the group [15]. The setup uses a specialized apparatus designed to simulate paraffin deposition in oil pipelines. This apparatus functions by introducing hot oil into the test pipe while the pipe to rotate along its axis. As the pipe is externally cooled, the oil gradually loses heat, causing it to solidify and adhere to the inner wall of the pipe. The procedure is considered complete once all the oil has solidified and fully adhered to the pipe's inner surface. The apparatus used in these tests is shown in Figure 3.

Fig. 3 Images of the apparatus used for the paraffin deposition production with the coupons.

The oil used in the tests was kindly provided by Petrobras, it has a lot of paraffinic components of large molecular weight, which gives a WAT value of 63.84 ºC and a pour point of 43 ºC, that is, at room temperature the oil is pasty. In the tests, depositions were obtained with 3 kg and 5 kg of crude oil.

Once the weight of paraffin deposited in the pipe is known, the thickness was calculated using the gravimetric method based on equation (1) reported in [13] once the mass of oil (m) is known, in this case 3 kg and 5 kg, as well as the density of the paraffin (ρ) and the geometry of the pipe (R – radius and L – length).

IV. RESULTS AND DISCUSSION

For the deposition experiments, 9 coupons were used in 3 regions of a 14-inch pipeline, these were distributed along 1 m (1000 mm) with a 120º lag between them. The first region was 250 mm from one of the ends (coupons 1, 2 and 3), the second region was in the middle of the pipe, that is, 500 mm from the ends (coupons 4, 5 and 6) and the last region was 750 mm from one end and in turn 250 mm from the other end (coupons 7, 8 and 9). The objective was also to evaluate uniformity along length and diameter.

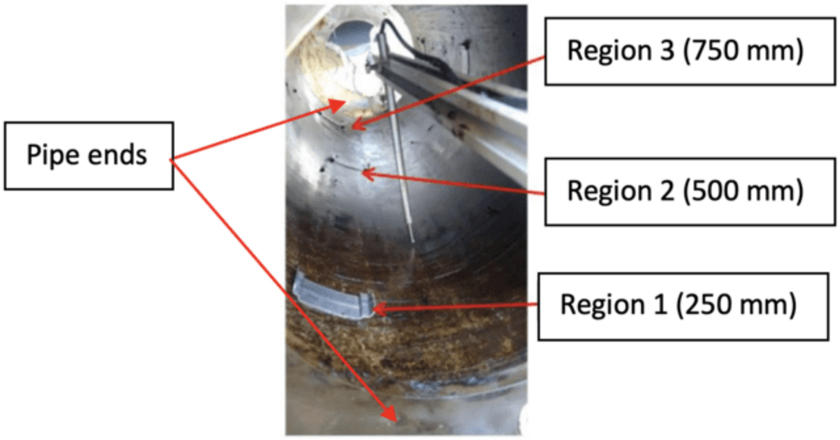

Fig. 4 Image of the coupons distributed in the three regions of the duct at positions of 250, 500 and 750 mm along a length of 1000 mm.

At the end of the deposition cycles, the coupons were removed from the internal wall of the pipe and the thickness of the depositions were measured using a digital thickness gauge Digimess with resolution of 0.01 mm. The procedure was carried out on the 9 coupons. It is possible to see in Figure 3 the 6 points used for the thickness measurements.

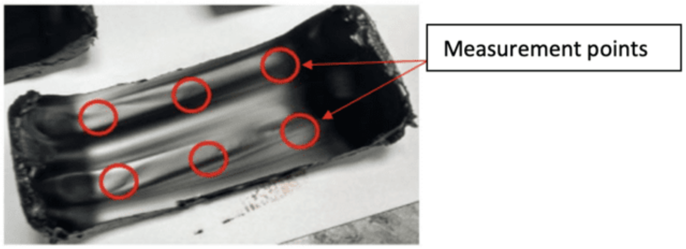

Fig. 5 Illustration of a coupon with paraffin deposition and the 6 points where the digital thickness gauge was positioned for thickness measurements.

Table 1 presents the average values for 3 kg of crude oil, while Table 2 displays the results for 5 kg of crude oil. Both tables also include the standard deviations of the measurements. The thickness values for each coupon, as well as the average thickness for all coupons, are provided. For the deposition using 3 kg of oil, the average thickness was 2.71 mm, while the deposition using 5 kg of oil resulted in an average thickness of 4.80 mm.

TABLE I

THICKNESS DATA MEASURED DURING THE PARAFFIN DEPOSITION PROCESS USING 3 KG OF CRUDE OIL.

Coupon	Thickness (mm)	Standard Deviation (mm)
1	2.69	0.09
2	2.66	0.22
3	2.62	0.11
4	2.89	0.24
5	2.70	0.10
6	2.88	0.19
7	2.88	0.31
8	2.43	0.11
9	2.65	0.18

TABLE III
THICKNESS DATA MEASURED DURING THE PARAFFIN DEPOSITION PROCESS USING 5KG OF CRUDE OIL.

Coupon	Thickness (mm)	Standard Deviation (mm)
1	4.26	0.20
2	4.59	0.44
3	4.42	0.75
4	4.93	0.48
5	4.51	0.42
6	5.34	1.22
7	5.81	1.18
8	4.65	0.37
9	4.66	0.15

For 3 kg of oil the deposition thickness calculated using the weight method was 2.96 mm with an uncertainty of ± 0.17 mm and for 5 kg it was 5.25 mm with an uncertainty of ± 0.17 mm. The estimate of the actual thickness value from the weight method, for 3 kg of oil, is in the range of 2.79 mm to 3.13 mm, while in the test specimen method it is in the range of 2.54 mm to 2.88 mm. There is overlap between the ranges of the two methods, which shows that the method proposed here is reliable when compared with the weight method used in the literature. For 5 kg of oil, the estimate of the actual thickness value from the weight method is in the range of 5.08 mm to 5.42 mm, while in the test specimen method it is in the range of 4.22 mm to 5.38 mm. As with 3 kg, there was also overlap between the intervals.

The relative discrepancy, taking the weight method values as a reference, was 8.4% for 3 kg and 8.6% for 5 kg, which are considered reasonable when considering that not all the oil is deposited along the 1 m length of the pipeline. A portion of the oil is lost, for example, at the weld interfaces between the pipeline and the steel flanges. Even when the oil in these regions has been removed and weighed, there is still a small amount of oil that is lost. Furthermore, the flaps of the coupons, where the magnets are located, create some turbulence in the liquid oil.

From the test it is possible to observe that the deposition with 3 kg of oil is more uniform than with 5 kg, just observe the uncertainty values. This was expected since in the test with 5 kg it was observed that the dripping is greater due to the greater volume of oil still in the liquid phase remaining for longer during the deposition cycle, Figure 6 shows three coupons used in the 3 kg tests with depositions and the Figure 7 shows three coupons used in the 5 kg tests, it is possible to clearly see that the deposition with 5 kg is much less uniform and with a lot of ripples and oil drip marks.

Fig 6. Images of the coupons with the paraffin deposition using 3 kg of crude oil

Fig 7. Images of the coupons with the paraffin deposition using 5 kg of crude oil

A comparison with the uniformity of depositions obtained using other devices could not be made, as no quantitative analysis of thickness or determination of measurement uncertainty was found in the literature. The method proposed here offers the advantage of allowing the observation of thickness uniformity at various points along the pipeline, which is not possible with most other methods. Additionally, the simplicity of executing this method and the fact that it does not require instrumentation within the pipeline are key benefits.

V. CONCLUSIONS

This study presents a novel, cost-effective method for measuring paraffin deposition thickness in pipelines, utilizing steel coupons to directly capture the deposited layer. The proposed method was successfully tested using paraffin deposition experiments with both 3 kg and 5 kg of crude oil. Results demonstrated that the proposed technique yields deposition thickness values that are within the uncertainty range of the widely accepted gravimetric method, validating its accuracy and reliability.

The simplicity of the method, combined with its ability to assess the uniformity of paraffin deposits at multiple points along the pipeline, provides significant advantages over traditional techniques. Unlike other methods, which often require complex instrumentation or disrupt pipeline flow, this approach is straightforward, non-intrusive, and does not rely on instrumentation inside the pipeline. The findings also highlight the impact of oil volume on the uniformity of the deposition, with larger oil quantities resulting in more irregular deposition patterns. The method versatility makes it a promising alternative for both scientific research and industrial applications, offering a reliable tool for assessing paraffin deposition and enhancing the development of effective pipeline management strategies. Further studies could explore the method’s application to other types of crude oils and its integration with online monitoring systems to offer real-time deposition assessments.

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