IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 23, Issue 2 Ser. 1 (Mar - Apr 2026), PP 35-41
www.iosrjournals.org

Predictive Modelling Of Wax Deposition Effect On Concentration For Corrosion Of Crude Oil Pipeline

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Abstract:
The aim of this research is to develop a Predictive model for wax deposition effect on concentration for corrosion of crude oil pipeline. Wax is one of the most common components in crude oil and generates corrosion inhibition by wax deposition or formation on the internal surface of the pipeline, reducing the corrosion. Waxy crudes characteristics vary from location to location. A flow loop was designed and developed to carry out series of experiment for the crude oil pipeline for the effect of wax deposit on CO_2 corrosion. The linear polarization resistance technique was used to measure the corrosion rate in mils per year (mpy) against time (minutes) using MS1000 Corrosion Meter. A mathematical model was developed to predict the concentration effect on wax deposit on corrosion for a cylindrical crude oil pipeline based on principle of mass, heat and material balance of mass. MATLAB software was used for simulation with the experimental results and the input parameter from the wax physical properties and operating conditions. Based on the analysis, it was observed that at flow rate of 10.21 L/min and temperature at 15°C during the corrosion inhibition. At time 18 minutes, the experimental result predicted a significant reduction of corrosion rates and excellent corrosion protection and the model result predicted a significant reduction of corrosion rates while others gave only moderate or negligible protection to the crude oil pipeline. From the profile plot, the values of the corrosion rate (mpy) against time (min) of the experimental and model results are 3 (0.68 mpy, 0.81 mpy), 6 (0.82 mpy, 0.696 mpy), 9(0.54 mpy, 0.582 mpy), 12 (0.61 mpy, 0.468 mpy), 15 (0.35 mpy, 0.354 mpy), 18 (0.15 mpy, 0.24 mpy). But the variation of the experimental and model results in terms of deviation indicate that both results are insignificant in variation, showing positive agreement between the experimental and model results. It has been found that as the deposition of the paraffin wax increases the corrosion rate decrease. This proves that paraffin wax deposition on the steel pipe act as a protective layer to inhibit corrosion.

***Keywords** – crude oil, modelling, pipeline, deposition, corrosion*

Date of Submission: 16-03-2026 Date of Acceptance: 26-03-2026

I. Introduction

Paraffin wax is a nuisance to flow assurance in transportation pipelines as it tends to deposit at the pipeline wall which causes interruption to the flow assurance. Paraffin wax deposition in production systems constitute a critical concern to crude exploration and production operations (Antropov, 2001). The unwanted effect of wax deposition could cause serious production impairment and other hazardous risk; while its curative approaches and production losses add to colossal economic sabotage to the petroleum industry. Wax deposition is a complex process of which its solubilities have a combined dependency on many variables including temperature, flow rate, and wax concentration. The ability to determine the severity of wax deposition is an extremely important issue, particularly in the design and development of deepwater oilfields. The menace of paraffin wax problem would become more pronounced as oil exploration activities extend to offshore environments (Asan, 2006).

Moreover, another problem faced by the oil and gas industry is that of the CO_2 corrosion which can cause damage in the pipeline material by deteriorating the pipelines material. As stated in the background study, internal corrosion in the pipeline has cost billions of U.S dollars for treatments and replacing the current steel pipeline with corrosion resistant alloys (CRAs) will only increase the cost even more. There is an additional layer of paraffin wax forms naturally within these steel pipelines during crude oil transportation (Callister, 2007). Many experiments have been conducted individually on finding the factors causing wax precipitation and deposition on corrosion of crude oil pipeline. Depending on the paraffin concentration in oil, the effect on corrosion changes. For example, if the paraffin wax content in the crude oil is high, it forms a protective layer within the pipelines. If less the protective layer will be containing pores which could expose the steel to CO_2 corrosion. Though paraffin wax restricts the flow in the pipeline, it acts as a corrosion inhibitor by covering the inner wall of pipeline. Waxy crudes and its effect on corrosion of pipeline from Niger Delta oil fields in Agbada I flow station in Ikwerre Local Government Area Rivers State have not received sufficient research attention compared to other crudes globally.

So, there is need to develop a mathematical model to predict wax deposition effect on corrosion of crude oil pipeline, considering factors such as concentration, between the waxy crude and pipe wall (Bailey, 2004). A comprehensive wax deposition experimental investigation were undertaken to enhance the understanding of the deposition process and for assessing the potential severity of any given wax-related operational problems and its effects on corrosion of crude oil pipeline, with the flow loop test providing the best direct representation of oilfield production system, furthermore it can give a better scenario and accurate result to investigate factors affecting wax deposition on corrosion of crude oil pipeline.

II. Materials And Methods

Materials

A flow loop system was developed, designed and fabricated which can give a better scenario of crude oil pipeline and accurate result to investigate the effect of concentration on corrosion of crude oil pipeline. The flow-loop was built in form of a water fountain with 1" steel pipe. Two cylindrical open stainless-steel reservoirs (waxy crude oil reservoir 1 and return reservoir 2), 6 Litre stainless steel reservoirs with (internal diameter = 0.152m; Height = 0.33m), with a 0.5hp pump for recirculating the waxy crude oil. A flow meter with a temperature probe, ball valves for regulating the flow of the fluid and handheld infrared thermometer for temperature measurement. A straight stainless-steel pipe with (0.0266m x 0.0133m (internal diameter and inside radius) x 0.0334m x 0.0167m (outer diameter and outside radius) x 2.007m x 0.0034m (pipe length and thickness) and MS1000 Corrosion Meter were used in this study.

Methods

To study the effect of concentration on wax deposit on corrosion of crude oil pipeline, the crude oil sample is pumped into the flow-loop set up under different operating conditions. The range of the inlet temperature of the waxy crude oil was (10-40^{o}C). The experiment was conducted 5 times, at time interval of 3-18 minutes, temperature was varied between 15-35^{o}C and concentration were also varied between 10.21-50.70 L/min. The experiment was carried out at varying temperature with time while concentration is kept constant. At temperature of 15, 20, 25, 30 and 35^{o}C and time at 3, 6, 9, 12, 15 and 18 min while keeping concentration constant for each experimental run at 10.21, 20.37 30.45, 40.28, 50.70 L/min, to determine the corrosion rate against time.

Simulation of the Model

The wax deposition model was implemented using MATLAB software, solved analytically and the model were developed based on principle of mass, heat and material balance of mass, the material balance of mass is also known as the law of conservation of mass. Based on the model developed.

$$(\mathbf{C}(\boldsymbol{\theta},\mathbf{t}) = \frac{2}{l}\sum_{r-l}^{\infty}\left\{\int_0^l \mathbf{f}(\boldsymbol{\theta})\sin\frac{r\pi\theta}{l}\,d\theta\right\} e^{-\lambda_r^2 t}\sin\frac{r\pi\theta}{l} \qquad 2.1$$

Equation 2.1 is the wax concentration model used for simulation to determine the effect of concentration on wax deposit on corrosion rate (mpy) against time (min) in crude oil pipeline. The results from computer simulation of the model were recorded, graph plotted and analyzed to compare the experimental and model data of the effect of concentration on wax deposit on corrosion rate (mpy) against time (min).

III. Results And Discussion

Results of Matlab Simulation of the Effect of Concentration on Wax Deposit on Corrosion Rate (mpy) against Time (min) at Flow Rate of 10.21 L/min while altering the Temperature (15, 20 , 25, 30 and 35^{o}C)

Table 1A: Matlab Simulation of the Effect of Concentration on Wax Deposit on Corrosion Rate (mpy) versus Time (min) at Flow Rate of 10.21L/min while adjusting the Temperature (15, 20, 25, 30 and 35^{o}C)

Time (min)	Corrosion Rate (mpy) @ 10.21(15^{o}C)	Corrosion Rate (mpy) @ (10.21(20^{o}C)	Corrosion Rate (mpy) @ 10.21 (25^{o}C)	Corrosion Rate (mpy) @ 10.21(30^{o}C)	Corrosion Rate (mpy) @ 10.21(35^{o}C)
0	0.924	1.1193	0.788	0.7827	0.936
1	0.886	1.0683	0.7682	0.7693	0.914
2	0.848	1.0173	0.7484	0.7559	0.892
3	0.81	0.9663	0.7286	0.7425	0.87
4	0.772	0.9153	0.7088	0.7291	0.848
5	0.734	0.8643	0.689	0.7157	0.826
6	0.696	0.8133	0.6692	0.7023	0.804
7	0.658	0.7623	0.6494	0.6889	0.782
8	0.62	0.7113	0.6296	0.6755	0.76
9	0.582	0.6603	0.6098	0.6621	0.738
10	0.544	0.6093	0.59	0.6487	0.716
11	0.506	0.5583	0.5702	0.6353	0.694
12	0.468	0.5073	0.5504	0.6219	0.672

13	0.43	0.4563	0.5306	0.6085	0.65
14	0.392	0.4053	0.5108	0.5951	0.628
15	0.354	0.3543	0.491	0.5817	0.606
16	0.316	0.3033	0.4712	0.5683	0.584
17	0.278	0.2523	0.4514	0.5549	0.562
18	0.24	0.2013	0.4316	0.5415	0.54

Table 1B: Experimental Result for the Effect of Concentration at 10.21 L/min on Corrosion Rate (mpy) against Time (min) on Wax Deposition

Time (min)	Corrosion Rate (mpy) @15°C	Corrosion Rate (mpy) @ 20°C	Corrosion Rate (mpy) @ 25°C	Corrosion Rate (mpy) @ 30°C	Corrosion Rate (mpy) @ 35°C
3	0.68	0.82	0.57	0.71	0.92
6	0.82	0.93	0.66	0.85	0.78
9	0.54	0.74	0.85	0.63	0.67
12	0.61	0.57	0.62	0.48	0.56
15	0.35	0.25	0.46	0.53	0.88
18	0.15	0.19	0.32	0.65	0.42

Table 1–3 and Figure 1-3: Comparison of Experimental and Model Results on the Effect of Concentration on Wax Deposit on Corrosion against Time at 10.21 L/min while varying the Temperature (15 °C, 20 °C, 25 °C).

Table 1: Comparison of Experimental and Model Results on Concentration of Wax Deposit on Corrosion Rate (mpy) against Time (min) at Flow Rate of 10.21 L/min and Temperature at 15°C

Time (min)	CR EXP (mpy)	CR MODEL (mpy)	ERROR
3	0.68	0.81	-0.13
6	0.82	0.696	0.124
9	0.54	0.582	-0.042
12	0.61	0.468	0.142
15	0.35	0.354	-0.004
18	0.15	0.24	-0.09

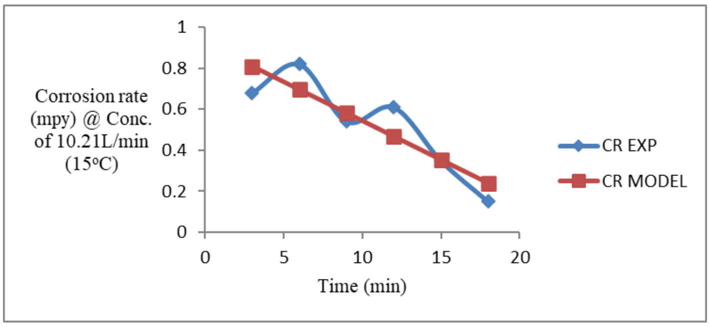

Figure 1: Comparison of Experimental and Model Results on Concentration of Wax Deposit on Corrosion Rate (mpy) against Time (min) at 10.21 L/min and Temperature at 15°C

Figure 1: illustrate the variation profile plot of experimental and model results of the effect of concentration on wax deposit on corrosion rate (mpy) against time (min) at 10.21 L/min and temperature at 15°C during the corrosion inhibition.

At time 18 minutes, the experimental result predicted a significant reduction of corrosion rates and excellent corrosion protection and the model result predicted a significant reduction of corrosion rates while others gave only moderate or negligible protection to the crude oil pipeline.

From the profile plot, the values of the corrosion rate (mpy) against time (min) of the experimental and model results are 3 (0.68 mpy, 0.81 mpy), 6 (0.82 mpy, 0.696 mpy), 9(0.54 mpy, 0.582 mpy), 12 (0.61 mpy, 0.468 mpy), 15 (0.35 mpy, 0.354 mpy), 18 (0.15 mpy, 0.24 mpy). But the variation of the experimental and model results in terms of deviation is (0%) indicating that both results are insignificant in variation, showing positive agreement between the experimental and model results.

Table 2: Comparison of Experimental and Model Results on Concentration of Wax Deposit on Corrosion Rate (mpy) against Time (min) at 10.21 L/min and Temperature at 20°C

Time (min)	CR EXP (mpy)	CR MODEL (mpy)	ERROR
3	0.82	0.9663	-0.1463
6	0.93	0.8133	0.1167
9	0.74	0.6603	0.0797
12	0.57	0.5073	0.0627
15	0.25	0.3543	-0.1043
18	0.19	0.2013	-0.0113

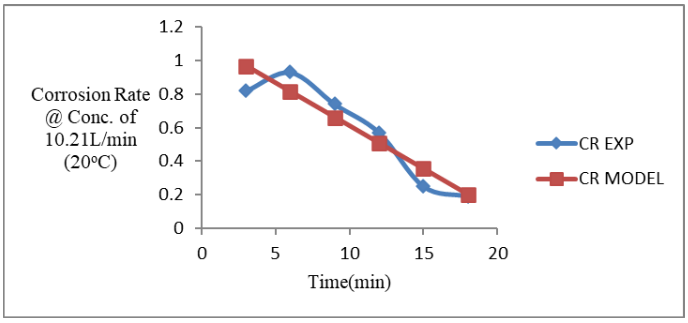

Figure 2: Comparison of Experimental and Model Results on Concentration of Wax Deposit on Corrosion Rate (mpy) against Time (mpy) at 10.21 L/min and Temperature at 20°C

Figure 2: illustrate the variation profile plot of experimental and model results of the effect of concentration on wax deposit on corrosion rate (mpy) against time (min) at 10.21 L/min and temperature at 20°C during the corrosion inhibition.

At time 18 minutes, the experimental and model results predicted a significant reduction of corrosion rates and excellent corrosion protection while others gave only moderate or negligible protection to the crude oil pipeline.

From the profile plot, the values of the corrosion rate (mpy) against time (min) of the experimental and model results are 3 (0.82 mpy, 0.9663 mpy), 6 (0.93 mpy, 0.8133 mpy), 9(0.74 mpy, 0.6603 mpy), 12 (0.57 mpy, 0.5073 mpy), 15 (0.25 mpy, 0.3543 mpy), 18 (0.19 mpy, 0.2013 mpy). But the variation of the experimental and model results in terms of deviation is (0.08%) indicating that both results are insignificant in variation, showing positive agreement between the experimental and model results.

Table 3: Comparison of Experimental and Model Results on Concentration of Wax Deposit on Corrosion Rate (mpy) against Time (min) at 10.21 L/min and Temperature at 25°C

Time (min)	CR EXP (mpy)	CR MODEL (mpy	ERROR
3	0.57	0.7286	-0.1586
6	0.66	0.6692	-0.0092
9	0.85	0.6098	0.2402
12	0.62	0.5504	0.0696
15	0.46	0.491	-0.031
18	0.32	0.4316	-0.1116

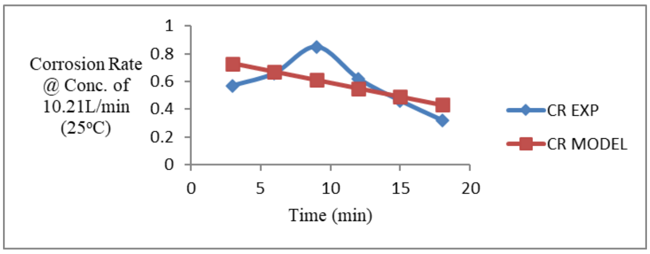

Figure 3: Comparison of Experimental and Model Results on Concentration of Wax Deposit on Corrosion Rate (mpy) against Time (min) at 10.21 L/min and Temperature at 25°C

Figure 3: illustrate the variation profile plot of experimental and model results of the effect of concentration on wax deposit on corrosion rate (mpy) against time (min) at 10.21 L/min and temperature at 25°C during the corrosion inhibition.

At time 18 minutes, the experimental and the model results predicted a significant reduction of corrosion rates and while others gave only moderate or negligible protection to the crude oil pipeline

From the profile plot, the values of the corrosion rate (mpy) against time (min) of the experimental and model results are 3 (0.57 mpy, 0.7286 mpy), 6 (0.66 mpy, 0.6692 mpy), 9(0.85 mpy, 0.6098 mpy), 12 (0.62 mpy, 0.5504 mpy), 15 (0.46 mpy, 0.491 mpy), 18 (0.32 mpy, 0.4316 mpy). But the variation of the experimental and model results in terms of deviation is (0.02%) indicating that both results are insignificant in variation, showing positive agreement between the experimental and model results.

Table 4: Comparison of Experimental and Model Results of Concentration of Wax Deposit on Corrosion Rate (mpy) against Time (min) at 10.21 L/min and Temperature at 30°C

Time (min)	CR EXP (mpy)	CR MODEL (mpy)	ERROR
3	0.71	0.7425	-0.0325
6	0.85	0.7023	0.1477
9	0.63	0.6621	-0.0321
12	0.48	0.6219	-0.1419
15	0.53	0.5817	-0.0517
18	0.65	0.5415	0.1085

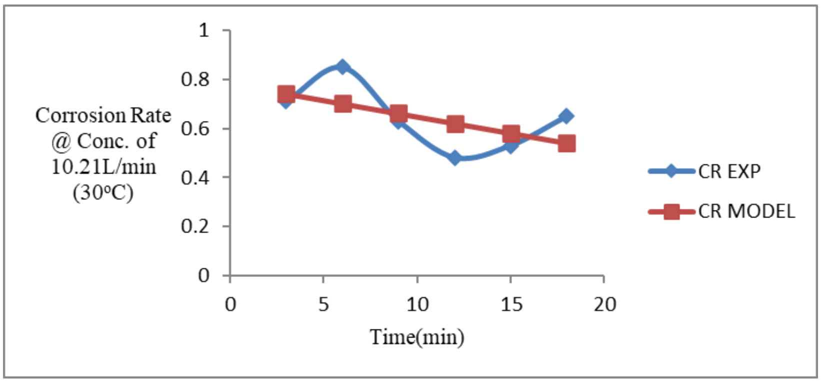

Figure 4: Comparison of Experimental and Model Results on Concentration of Wax Deposit on Corrosion Rate (mpy) against Time (min) at 10.21 L/min and Temperature at 30°C

Figure 4: illustrate the variation profile plot of experimental and model results of the effect of flow rate on wax deposit on corrosion rate (mpy) against time (min) at 10.21 L/min and temperature at 30°C during the corrosion inhibition.

At time 12 and 18 minutes, the experimental and model results predicted a significant reduction of corrosion rates while others gave only moderate or negligible protection to the crude oil pipeline

From the profile plot, the values of the corrosion rate (mpy) against time (min) of the experimental and model results are 3 (0.71 mpy, 0.7425 mpy), 6 (0.85 mpy, 0.7023 mpy), 9(0.63 mpy, 0.6621 mpy), 12 (0.48 mpy, 0.6219 mpy), 15 (0.53 mpy, 0.5817 mpy), 18 (0.65 mpy, 0.5415 mpy). But the variation of the experimental and model results in terms of deviation is (0.05%) indicating that both results are insignificant in variation, showing positive agreement between the experimental and model results.

Table 5: Comparison of Experimental and Model Results of Concentration of Wax Deposit on Corrosion Rate (mpy) against Time (min) at 10.21 L/min and Temperature at 35°C

Time (min)	CR EXP (mpy)	CR MODEL (mpy)	ERROR
3	0.92	0.87	0.05
6	0.78	0.804	-0.024
9	0.67	0.738	-0.068
12	0.56	0.672	-0.112
15	0.88	0.606	0.274
18	0.42	0.54	-0.12

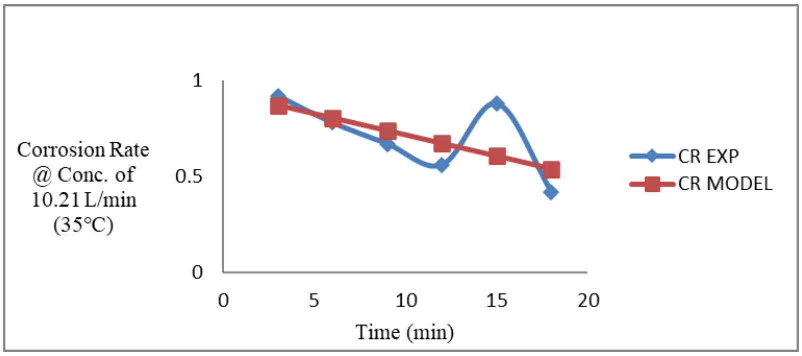

Figure 5: Comparison of Experimental and Model Results on Concentration of Wax Deposit on Corrosion Rate (mpy) against Time (min) at 10.21 L/min and Temperature at 35°C

Figure 5: illustrate the variation profile plot of experimental and model results of the effect of concentration on wax deposit on corrosion rate (mpy) against time (min) at 10.21 L/min and temperature at 35°C during the corrosion inhibition.

At time 18 minutes, the experimental and the model results predicted a significant reduction of corrosion rates and while others gave only moderate or negligible protection to the crude oil pipeline.

From the profile plot, the values of the corrosion rate (mpy) against time (min) of the experimental and model results are 3 (0.92 mpy, 0.87 mpy), 6 (0.78 mpy, 0.804 mpy), 9(0.67 mpy, 0.738 mpy), 12 (0.56 mpy, 0.672 mpy), 15 (0.88 mpy, 0.606 mpy), 18 (0.42 mpy, 0.54 mpy). But the variation of the experimental and model results in terms of deviation is (0%) indicating that both results are insignificant in variation, showing positive agreement between the experimental and model results.

IV. Conclusion

The presence of a paraffin wax film on the surface reduces general corrosion rates significantly, yet localized corrosion has been detected due to the paraffin layer's loss of integrity. This demonstrates that the deposition of paraffin wax on the steel pipe acts as a protective coating that prevents corrosion. As a result, temperatures, flow rates, and concentrations below the wax appearance temperature must be researched in order to evaluate the influence of wax deposition on crude oil pipeline corrosion. When a wax layer is applied to a steel surface, it slows corrosion by preventing corrosive species from diffusing to the surface. By coating the inner wall of the pipeline with paraffin wax, it works as a corrosion inhibitor while also restricting flow. The paraffin wax on the surface of the crude oil pipeline provides good corrosion protection, whilst others only give poor or no protection. However, due to the long chain paraffin layer being physically removed from the surface during periods of elevated temperature or flow rates, the majority of the corrosion protection has been lost. The protection provided by paraffin is assumed to be due to physisorption, which is caused by weak intermolecular interactions such as van der Waals forces. Despite the lack of surface chemical activity, paraffin can form on the pipe surface at low temperatures, below the so-called wax appearance temperature. When the wax layer covers the steel surface, it can slow down corrosion by preventing corrosive species from diffusing to the surface.

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