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Insulation Thickness: An Underlying Factor for Wax Precipitation and Deposition Reduction in Flowlines

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Article

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Abstract

The study seeks to alleviate the formation of wax deposits with insulation thickness by tracking the point of wax appearance, wax deposit thickness and wax mass precipitation rate in flow line divided into 10 pipe segments of 2850ft each. Different production scenarios were created by varying the production rate (10000bbl/day, 12000 bbl/day, 14000 bbl/day, 16000 bbl/day, 18000 bbl/day and 20000 bbl/day) with insulation thickness (5mm, 10mm, 15mm, 20mm and 25mm) and the flowline size (12in, 14in and 16in). By using both experimental and synthetic field data, an OLGA model was constructed using the specified fluid samples previously characterized with the Multiflash simulator and simulation was run for period of 100days of production. Two fluid samples were compared and results showed that the waxier crude sample had more wax precipitation and deposition tendencies. At a production rate of 10000bbl/day with insulation thickness of 5mm and flowline size of 12in, the wax precipitation points/ wax deposit thickness of sample 1 and 2 were 2700ft/0.56mm and 2300ft/0.65mm respectively. Results reveal that higher production rates and insulation thickness delays the wax precipitation point (WPP) and reduces the wax deposit thickness (WDT) while wax mass precipitation rate did not show any uniform trend.

1. Introduction

The precipitation of paraffin component in crude oil results to wax deposition in flowlines. Wax precipitation and deposition in flowlines is a very big concern in crude oil production. Besides the flow assurance issues with heavy economic implication, the problem of wax deposition in production lines can cause severe impairment to the production facilities and other hazardous risks [1-7]. Hence, predicting the point of wax precipitation and its severity (wax deposit thickness) are good preventive measures for more efficient performance of the flowlines. Several methods have been generally applied in removing or reducing the risk of wax precipitation in production lines [8, 9]. The use of chemical inhibitors, thermal insulation and mechanical pigging have been identified by several authors as efficient ways of managing wax deposition in flowlines. Wax deposition in production lines is a function

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of several factors such as the oil composition of the crude sample, production rate, temperature gradient, fluid temperature, mechanical stress or shear, crude oil viscosity and production duration or time [10-12].

Several investigations have been made by previous authors to understudy some key concerns relating to wax deposition in pipelines. Seyfaee et al. (2012) studied the influence of temperature, pressure and flow rate on wax deposition using experimental procedures [13]. The thickness of wax deposit was calculated using chemical analysis technique and the results compared with calculation methods based on heat transfer and pressure drop. Temperature difference existing between the crude oil and the pipe wall was identified as major factor that decides deposit thickness of wax and the content of resin - asphaltene deposited on the wall surface of the pipe [14]. They observed a direct relationship between deposit thickness and temperature differential existing between the crude oil and pipe wall. Hence, increasing the temperature differential increases the wax deposit thickness. Kelechukwu et al. (2010) noted that oil flow rate has significant impact on wax deposition time and thickness [3]. Zougari (2010) provided a detailed study on the dynamics of the wax deposition on the walls of crude oil pipeline by considering varying temperatures at different times [15]. According to Oyekunle and Adeyanju (2011), wax formation and deposition are affected by operating pressure and the crude oil composition [16]. Hu et al. (2014) pointed that amongst the factors identified to influence wax deposition, insulation properties selection of pipeline has not been extensively explored to reduce wax precipitation and deposition [17]. Hu et al. (2015) studies the role of insulated pipeline on rate of wax deposition (using experimental method) and concluded that increasing the insulation thickness decreases the wax deposition rate at specific temperature condition. They proposed a deposition rate model with linear regression using SPSS software [18].

The significance and impact of insulation thickness selection on wax precipitation and deposition has limited research and not fully explored. Proper selection and determination of an optimum insulation thickness that will reduce or prevent wax precipitation and deposition will save the industry from spending much to solve the problem when it occurs. Therefore, this work will investigate the selection of insulation thickness through simulation that will minimize wax deposition in pipeline and also reduce both economic and operational costs.

2. Methodology

2.1. Characterization and Simulation Data

The input data and crude oil properties with field parameters for simulation are presented in Tables 1 and 2. The flow line equipment material data and corresponding configuration of each pipe segment is presented in Table 3 and Table 4. As shown in the tables, each crude oil sample was subjected to the same simulation conditions for comparative analysis.

Table 1. Input Data for Simulation

Parameter	Value
Pipe length (L)	28500ft
Pipe ID (d)	12inches, 14inches, 16inches
Inlet temperature (T)	180°F
Arrival pressure (P)	60psig
Arrival Temperature	30°F
Ambient Temperature	60°F
Wax porosity, φ	0.6
Wall Roughness	0.028mm
Hmininnerwall	6.8W/m2 –C
Hambient	50 W/m2 –C
Wax roughness	0
Wax deposition model	RRR
Simulation Run Time	100days
Largest time step allowed (MAXDT)	1000s
Smallest time step allowed (MINDT)	1s
Initial time step (DTSTART)	1s
Simulation start time (Start Time)	0s

Table 2. Crude Oil Data/Properties

Sample	Properties	Values
Crude Sample 1	Crude oil viscosity @ 27°C	4.11cp or 0.0028 lb/ft-s
	Crude oil density@ 27°C	0.9384 g/ml or 58.5824 lb/ft3
	Pour point	2.4°C
	Wax content	6.71%
Crude Sample 2	Crude oil viscosity @ 27°C	11.95cp or 00.80 lb/ft-s
	Crude oil density@ 27°C	0.9570g/ml or 59.7436 lb/ft3
	Pour point	3.2°C
	Wax content	11.03%

Table 3. Pipeline Material Data

Material	Thickness (m)	Conductivity, k (W/m.K)	Density, ρ (kg/m3)	Heat capacity, Cp (J/kg.K)
Steel	0.0118	43.25	7850	500
Enamel	0.006	0.6	1465	2115

Table 4. Pipeline Profile

Pipeline Segment	Pipe-1	Pipe-2	Pipe-3	Pipe-4	Pipe-5	Pipe-6	Pipe-7	Pipe-8	Pipe-9	Pipe-10
Length [ft]	2850	2850	2850	2850	2850	2850	2850	2850	2850	2850
Elevation [ft]	0	0	0	0	0	0	0	0	0	0

2.2. Simulation Procedure

Multiflash version 6.1 [19] and OLGA 2017.1.107 dynamic simulator [20] were used with experimental and field data obtained from a Niger Delta oil field. The experimental data (crude oil density, crude oil viscosity, wax content, pour point, crude oil composition by weight, wax appearance temperature, pressure and temperature) were inputted in Multiflash to modeled the crude and gain data file readable by OLGA software to design the flow line model for investigating different insulation thicknesses on wax deposition. The crude oil was characterized with the SuperTRAPP as the transport model for both viscosity and thermal conductivity. PVT Laboratory Analysis was done for the crude with the composition of the waxy crude oil using Soave–Redlich–Kwong (SRK) model and exported in to OLGA as a PVT table file to model the flow line and run the simulation. The simulation end time was set at 100days. Different insulation thicknesses of 5mm, 10mm, 15mm, 20mm and 25mm were selected respectively using a production rate of 10000bbl/day, 12000bbl/day, 14000bbl/day, 16000bl/day, 18000bbl/day and 20000bbl/day and flowline sizes of 12-inch, 14-inch and 16-inch. A base case with an insulation thickness of 5mm was created for each of the production rates and pipeline sizes. Thereafter, the effect of varying the insulation thickness was simulated by considering thicknesses of 10mm, 15mm, 20mm and 25mm respectively. The flowline which was modelled to be transporting crude oil from well head (entering point) in the pipeline (PIPE-1) into the line is presented in Figure 1. The oil flows in at a temperature of 180°F exit at 30°F and pressure of 60psig. The simulation flow chart is presented in Figure 2.

Figure 1. Oil flow line

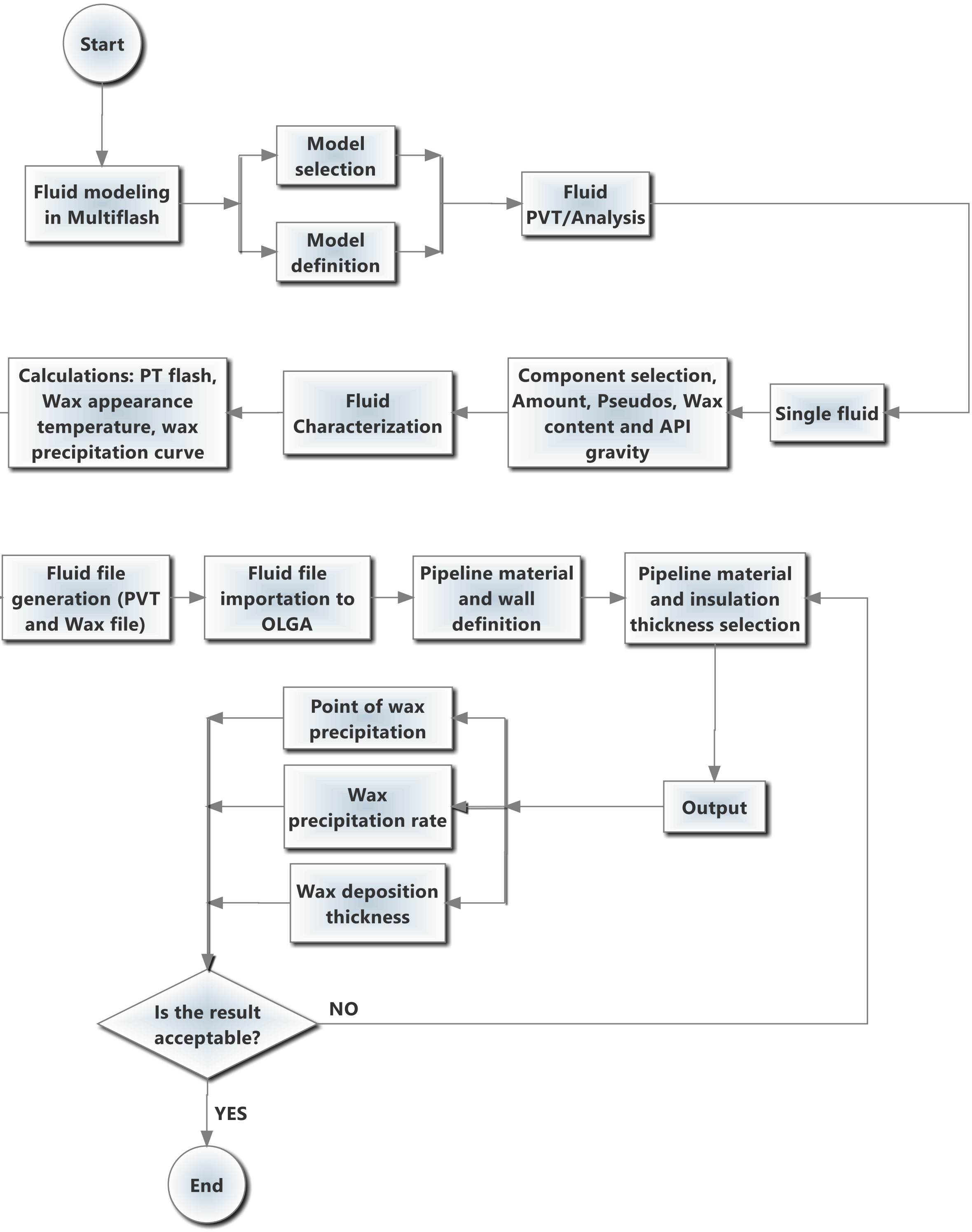

Figure 2. Simulation Flow Chart

3. Results and Discussion

The results generated were based on the simulation algorithm described in Figure 2. The 10-segment pipe section used were consistently analysed from an upstream condition at 0ft (wellhead) to a downstream condition at 28500ft (reference terminal). Different production scenarios were generated by varying the production rate from 10000bbl/day to 20000bbl/day at a regular increment of 2000bbl/day and insulation thickness of 5mm to 25mm at a regular increment of 5mm. At each production case, the point of wax appearance and the corresponding wax mass precipitation rate and wax deposit thickness were tracked using fluid temperature (FT) – wax appearance temperature (WAT) match criteria. Flow line tracking results (production parameters) of some selected production scenarios are presented in Figure 3 to 8 for crude sample 1 and 2.The FT-WAT match result of Figure 3 (crude sample 1) shows that at 10000bbl/day and 12-in flow line, the wax precipitation point (WPP) was estimated at 2700ft (within the first pipe segment). The build-up of wax deposit attains a peak value of 0.56mm at a pipe length of 4400ft while a maximum wax precipitation rate of 0.014Kg/s was found at an approximate pipe length of 7000ft. The observed continuous decline in pressure is a clear indication of the flow assurance issues caused by the wax accumulation in the flow line.

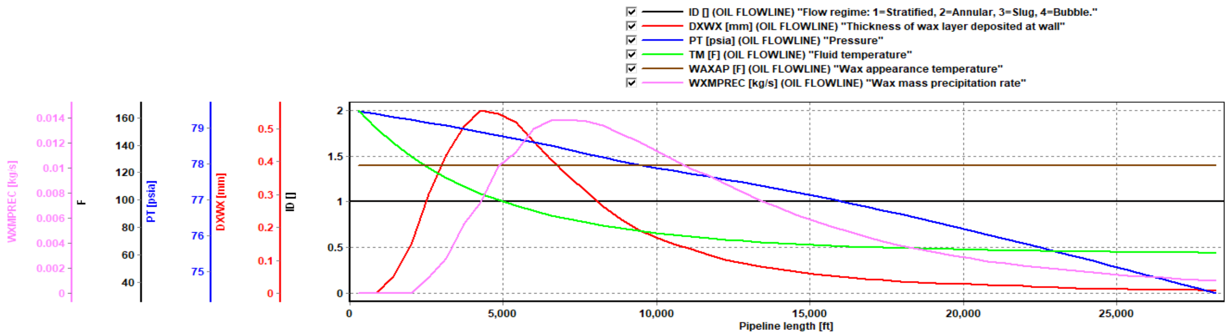

Figure 3. Crude Sample 1 for 10,000 bbl/day in 12inches flow line with 5mm insulation thickness

Crude sample 2 was subjected to similar production conditions as presented in Figure 4 and the result shows that crude sample 2 exhibited earlier WPP at approximately 2300ft of pipe length owing to higher wax content and cloud point when compared to crude sample 1. This resulted to higher peak wax deposit thickness (0.65mm) and wax precipitation rate of 0.029Kg/s at 3800ft and 7000ft pipe lengths respectively. Similar analysis of the tracked results was performed at other production scenarios and the resulting sensitivity runs.

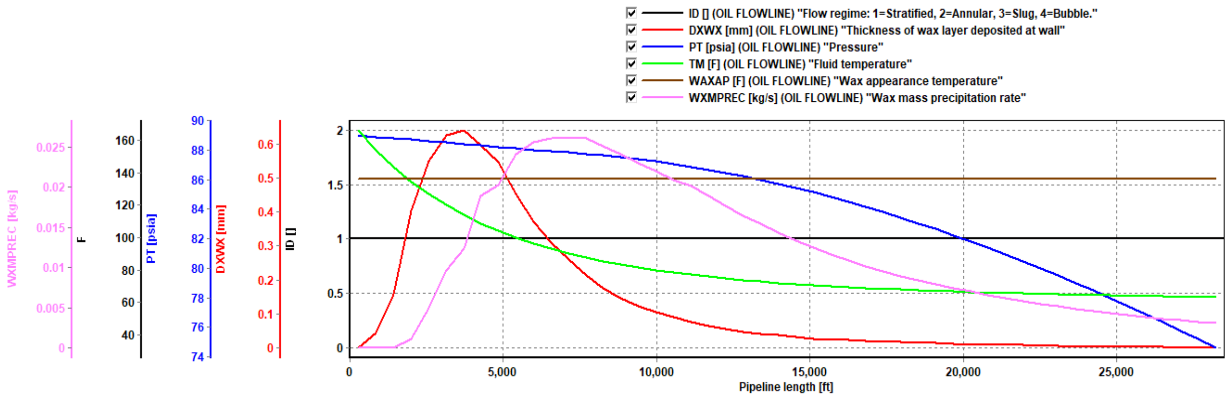

Figure 4. Crude Sample 2 for 10,000 bbl/day in12inches flow line with 5mm insulation thickness

Figure 5 shows crude sample 1 subjected to production rate of 14000bbl/day in a 14inches flow line with 10mm insulation thickness. Wax precipitate at 3143ft from the wellhead at a precipitation rate of 0.01kg/s with a deposit thickness of 0.31mm at an equal fluid temperature (FT) to wax appearance temperature (WAT) condition. The build-up of wax deposit thickness (WDT) attains a value of 0.48mm within 6000 to 7500ft along the flow line and declines with the fluid temperature. Also, a peak precipitation rate value of 0.013kg/s was observed within 9000 to 12000ft along the flow line. This is attributed to low wax content and the composition of the crude sample.

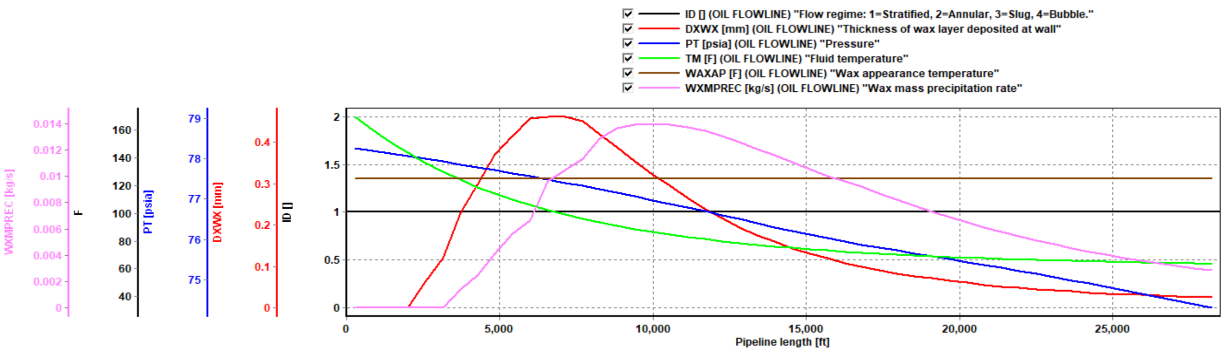

Figure 5. Crude Sample 1 for 14,000 bbl/day in 14inches flow line with 10mm insulation thickness

Crude sample 2 presented in Figure 6 shows an earlier wax precipitation point of 2568ft with a high wax deposit thickness of 0.44m and at a precipitation rate of 0.02kg/s when compared with crude sample 1 of the same condition in Figure 5. Crude sample 2 has a higher peak wax deposit thickness of 0.56mm at 5000ft along the flow line with a higher maximum precipitation rate of 0.025kg/s within 8000 to 11000ft of the flow line. The results indicate that higher wax content increases the rate of precipitation and wax deposit thickness peak value.

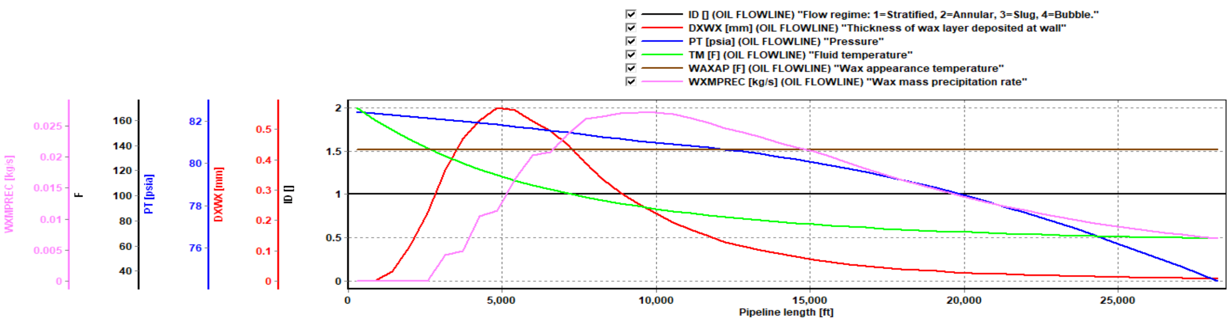

Figure 6. Crude Sample 2 for 14,000 bbl/day in14inches flow line with 10mm insulation thickness

Crude sample 1 result for wax precipitation point, deposition thickness and precipitation rate for 20000bbl/day in a 16inches flow line with 25mm insulation thickness is presented in Figure 7. Wax precipitate at 6558ft from the wellhead with a wax deposit thickness of 0.23mm and rate of 0.0075kg/s. A wax deposit thickness peak value of 0.34mm was observed within 13500 to 14800ft along the flow line. 25mm insulation thickness gave a lower peak value of wax deposit thickness when compared to 10mm insulation thickness of Figure 5 and Figure 6 respectively.

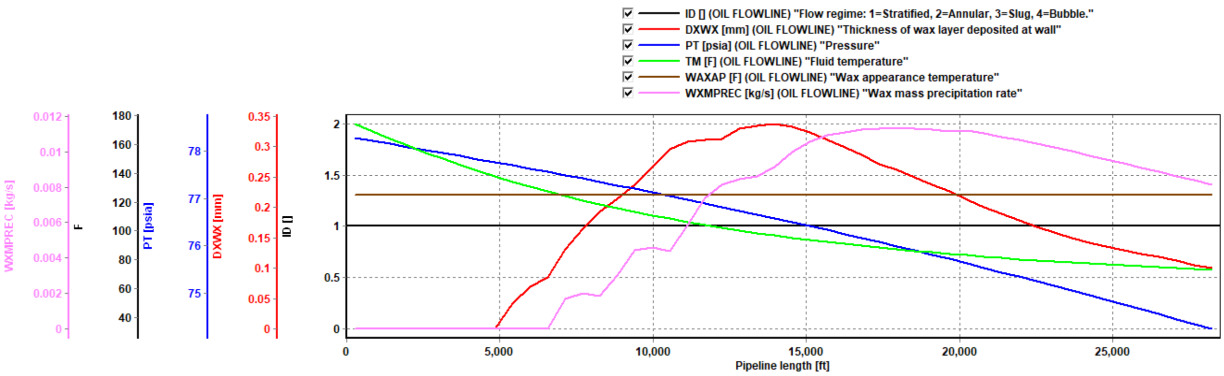

Figure 7. Crude Sample 1 for 20,000 bbl/day in16inches flow line with 25mm insulation thickness

Figure 8 shows crude sample 2 for 20000bbl/day in 16inches flow line with 25mm insulation thickness. An earlier wax precipitation at 4865ft for equal fluid temperature to wax appearance temperature with a deposit thickness of 0.3mm and a precipitation rate of 0.016kg/s was observed. The wax deposit thickness is higher as it precipitates earlier for crude sample 2 and with high peak value of 0.4mm for deposit thickness when compared with crude sample 1 of the same condition.

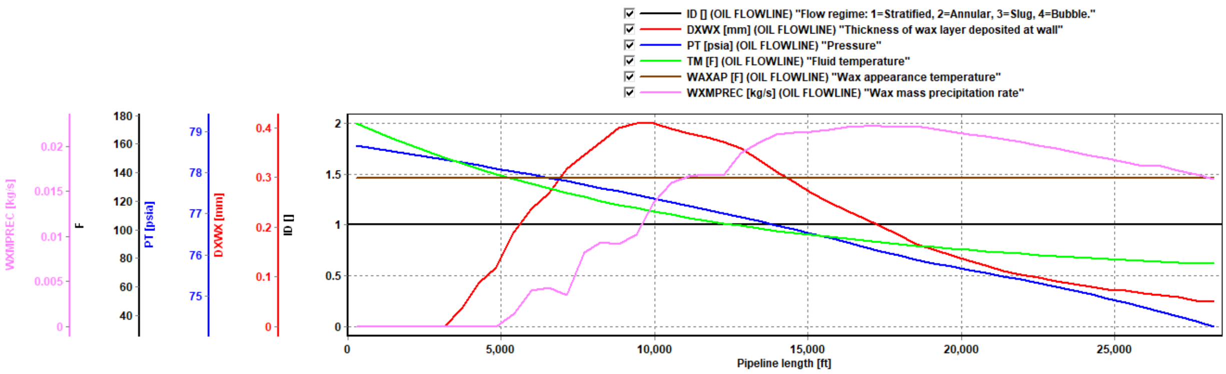

Figure 8. Crude Sample 2 for 20,000 bbl/day in 16inches flow line with 25mm insulation thickness

3.1. Effect of Insulation Thickness on Wax Precipitation Point (WPP)

The sensitivity of wax crystals to temperature makes thermal insulation a desirable option to prevent early WPP near the upstream conditions. In this study, the efficiency of insulating the entire flowline segments were evaluated at different flow line sizes (diameter), insulation thickness and production rate investigated with sensitivity analysis.

Figures 9 and 10 show the comparison of the effect of insulation thickness on the two crude samples for a 12-inch flow line. The result shows that producing at constant rate and increasing the insulation thickness will cause the WPP to move towards downstream. Similar trend is observed if the production rate is increased at a constant insulation thickness. Crude sample 2 with high wax content showed earlier tendency of wax precipitation and deposition for all the considered flow line size as shown in the Figure 9 to 14. Results reveal that increasing the flow line nominal diameter at constant production rate and insulation thickness results in earlier WPP development. This arises because of higher pressure drop due to large flow line size and consequently, temperature drop that facilitates early WAT attainment. For the same flow line size of 12inches, producing at any rates did not intercept or have same value for crude sample 1 (Figure 9) but crossed for 12000STB/D and 10000STB/D with 15mm insulation thickness which is attributed to the fluid temperature and wax appearance temperature for crude sample 2 (Figure 10). Also, producing at 18000STB/D and 16000STB/D with 15mm insulation thickness for 14inches flow line as evident in Figure 11 have same value for point of precipitation along the flow line due to fluid temperature drop with wax appearance temperature. Similar result was observed for 14000STB/D and 16000STB/D as shown in Figure 12 for crude sample 2.

The results presented in Figures 9 to 14 show good agreement with the works of Hu et al.[18]. Hence, using smaller flow line sizes and more thick insulation materials could help to delay WPP and possibly, up to the reference terminal (flow station or separator points) thereby minimizing the necessity of chemical or mechanical treatment of the flow lines.

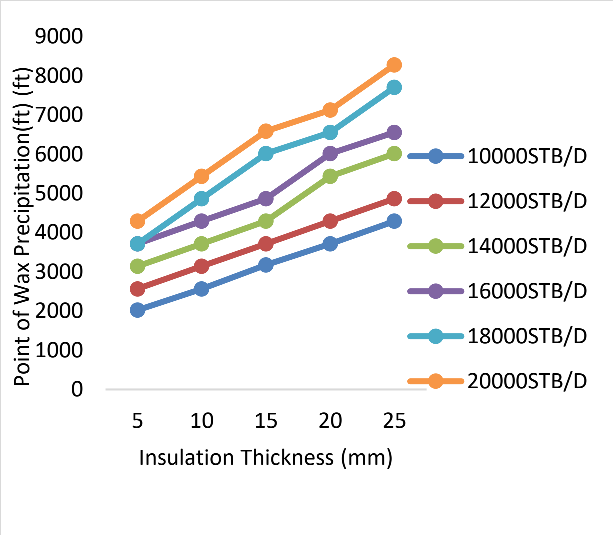

Figure 9. Effect of Insulation Thickness on WPP – Crude Sample 1, 12-in flow line

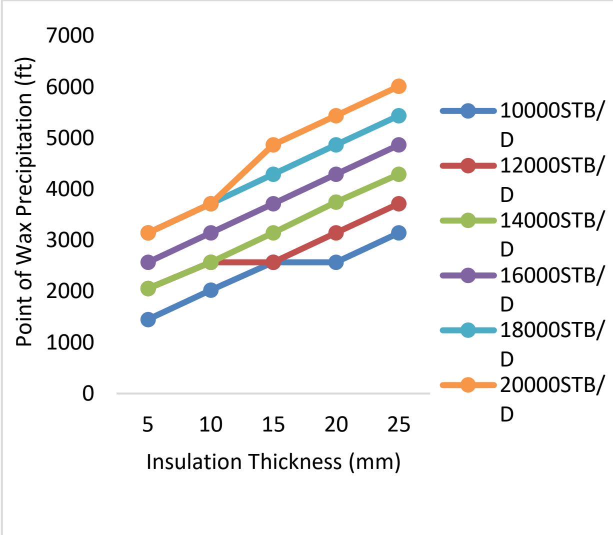

Figure 10. Effect of Insulation Thickness on WPP – Crude Sample 2, 12-in flow line

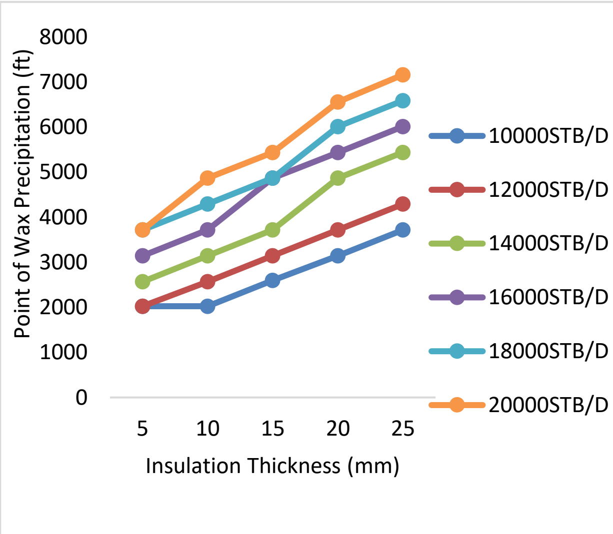

Figure 11. Effect of Insulation Thickness on WPP – Crude Sample 1, 14-in flow line

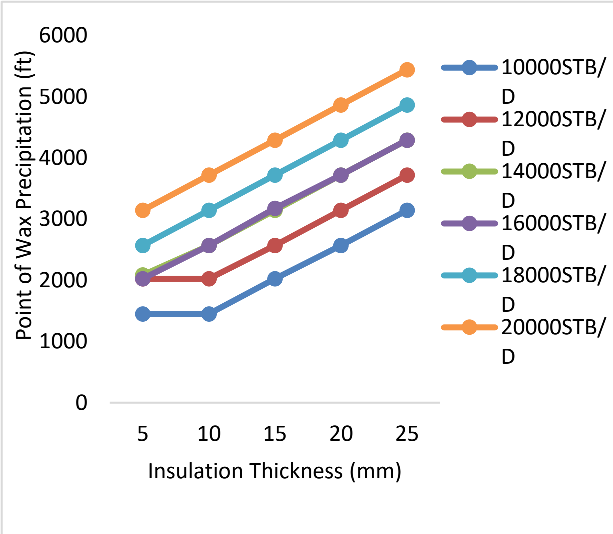

Figure 12. Effect of Insulation Thickness on WPP – Crude Sample 2, 14-in flow line

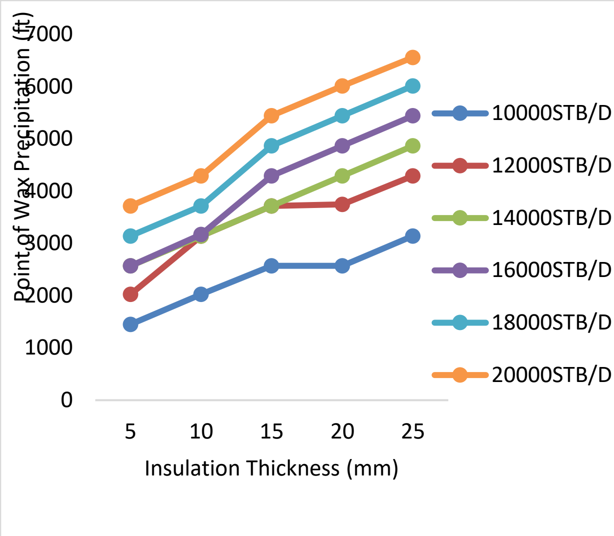

Figure 13. Effect of Insulation Thickness on WPP –Crude Sample 1, 16-in flow line

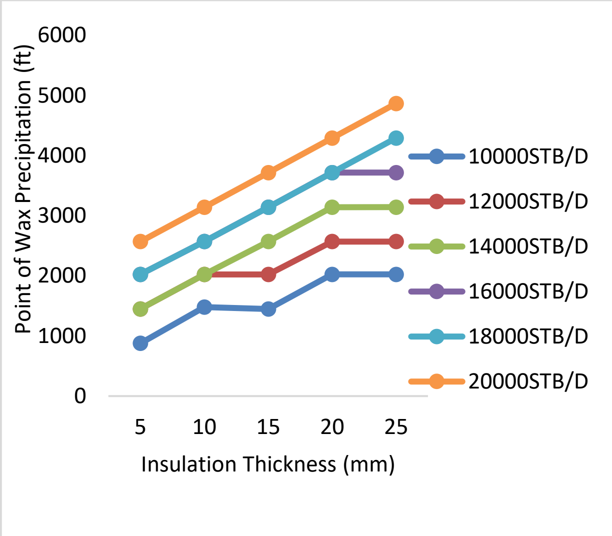

Figure 14. Effect of Insulation Thickness on WPP – Crude Sample 2, 16-in flow line

3.2. Impact of Insulation Thickness on Wax Deposit Thickness (WDT)

Besides extending the WPP, insulation of flow lines are also directed towards achieving minimal or zero wax deposit thickness in order to enhance the flow assurance of the entire production line. Results presented in Figure 15 to 20 shows that as insulation thickness increases, the resulting wax deposit thickness reduces. However, the impact of flow rate on wax deposit thickness seems to be less pronounced as insulation thickness increases from 5mm to 25mm at a flow line size of 12in (Figure 15 and 16). At larger flow line size (14in and 16in), insulation thickness showed a more significant influence on the WDT as production rate increases.

Crude sample 2 showed consistent higher wax deposition tendencies than crude sample 1 as predicted by the WDT versus insulation thickness as shown in Figure 15 to 20.The significant change observed in Figure 16 with 5mm insulation thickness for 10000STB/D for crude sample 2 having lower WDT than 10mm insulation thickness is due to a slight drop in the temperature when tracking. Similar change occurred for crude sample 2 with 16inches flow line size as seen in Figure 20. As has been previously stated, the fluid properties data identified crude sample 2 to be waxier than crude sample 1. Hence, the issue of wax deposition in production lines is a direct function of the nature and composition of the produced fluid.

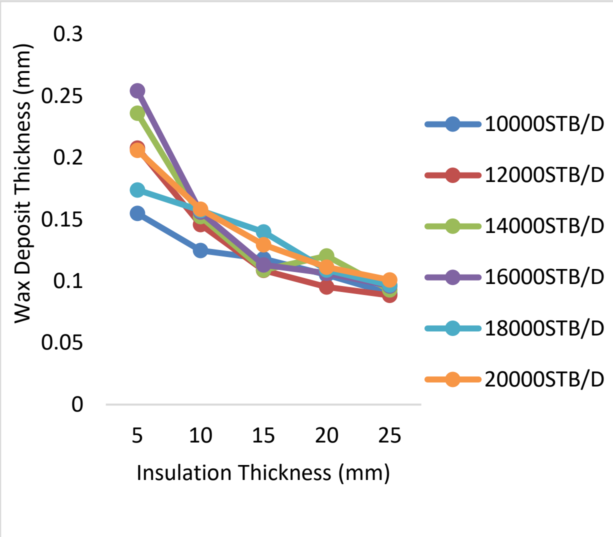

Figure 15. Effect of Insulation Thickness on WDT – Crude Sample 1, 12-in flow line

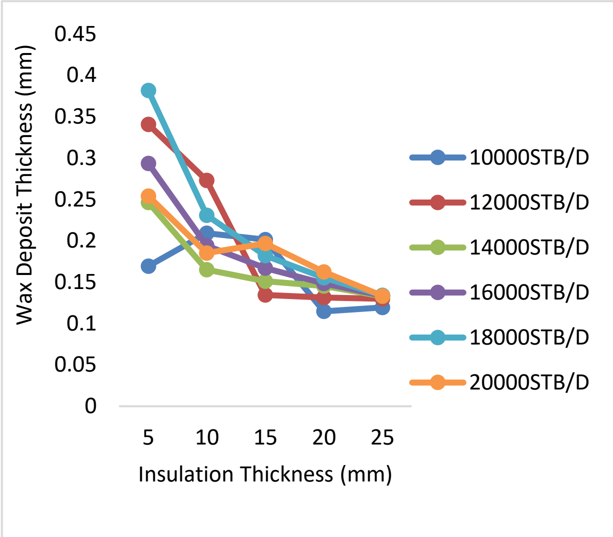

Figure 16. Effect of Insulation Thickness on WDT – Crude Sample 2, 12-in flow line

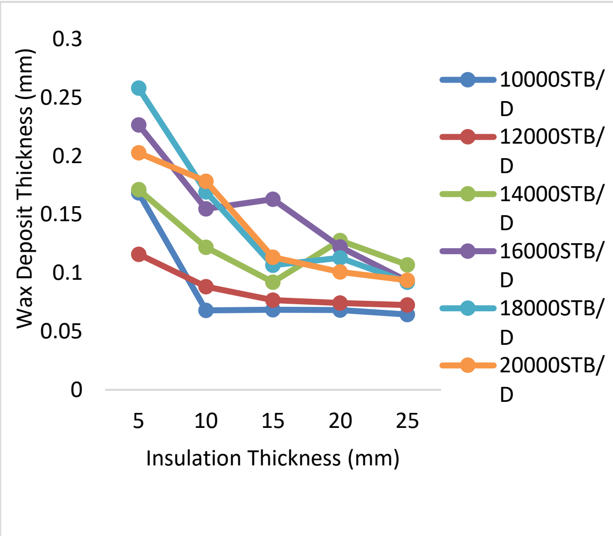

Figure 17. Effect of Insulation Thickness on WDT – Crude Sample 1, 14-in flow line

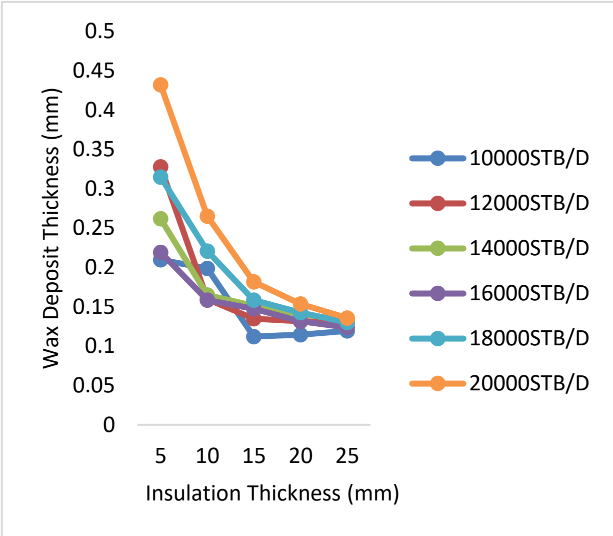

Figure 18. Effect of Insulation Thickness on WDT – Crude Sample 2, 14-in flow line

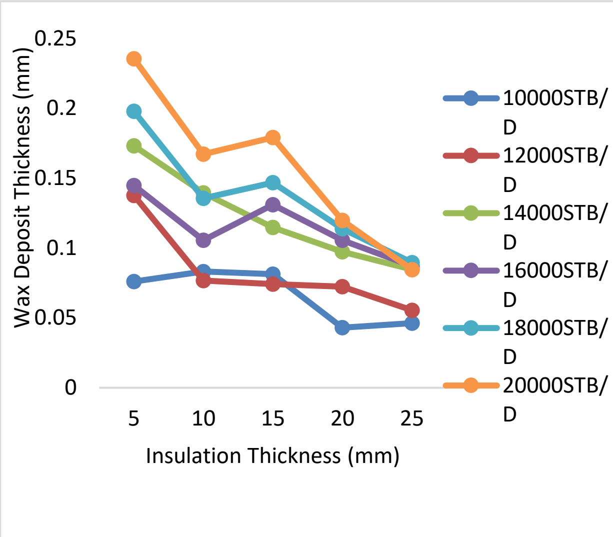

Figure 19. Effect of Insulation Thickness on WDT – Crude Sample 1, 16-in flow line

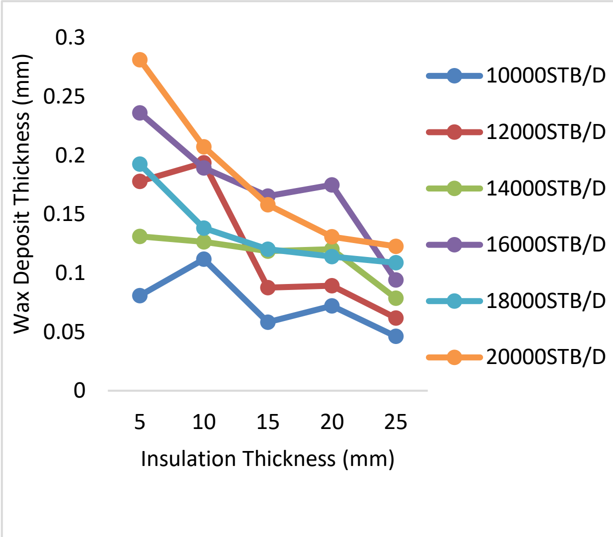

Figure 20. Effect of Insulation Thickness on WDT – Crude Sample 2, 16-in flow line

The contribution of flow line size (diameter) to wax deposit thickness has also been studied in the Figure 15 to 20. Results indicate that as flow line size increases from 12in to 16in at a constant production rate, the thickness of the deposited wax on the inner pipe walls reduces. This is as a result of increased surface area of deposition. Results have shown that producing at higher rates will be beneficial since it resulted in higher WPP and lower WDT. Therefore, the possibility of pipe walls erosion and molecular agitation via friction and turbulence, caused by high production rates jointly play a vital role in eliminating or limiting the wax deposit thickness.

3.3. Effect of the Thickness of Insulation on Wax Mass Precipitation Rate (WMPR)

Figures 21 to 26 showed insulation thickness influence on wax mass precipitation rate at different production rates and different flow line size. The complex trends show that achieving a low wax mass precipitation rate may not necessary be arrived at by increasing or decreasing the insulation thickness. However, comparison of crude sample 1 and 2, indicates that at each flow line size, crude sample 2 showed slightly higher wax mass precipitation rate as shown in Figure 22, 24, and 26. Results from Figure 21 to 26 reveals that precipitation rate is predominantly a function of the composition and physical properties of the crude. It is observed that insulation thickness did not have a direct relation with the wax mass precipitation rate.

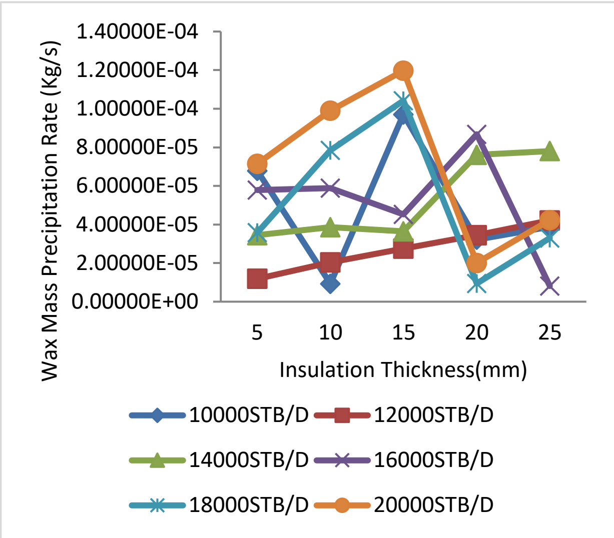

Figure 21. WMPR versus Insulation Thickness – Crude Sample 1, 12-in flow line

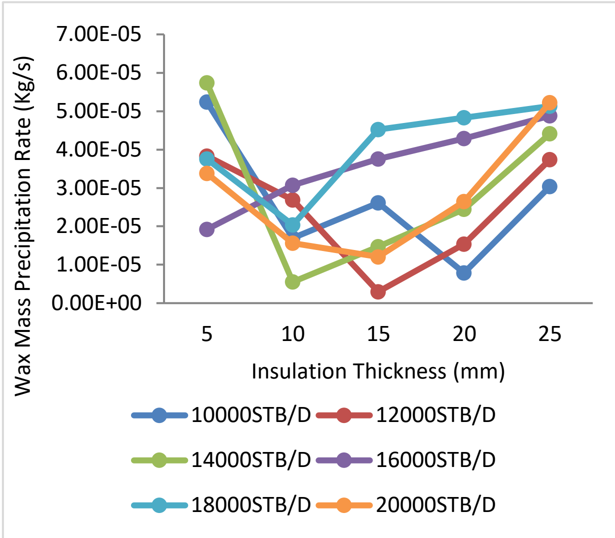

Figure 22. WMPR versus Insulation Thickness – Crude Sample 2, 12-in flow line

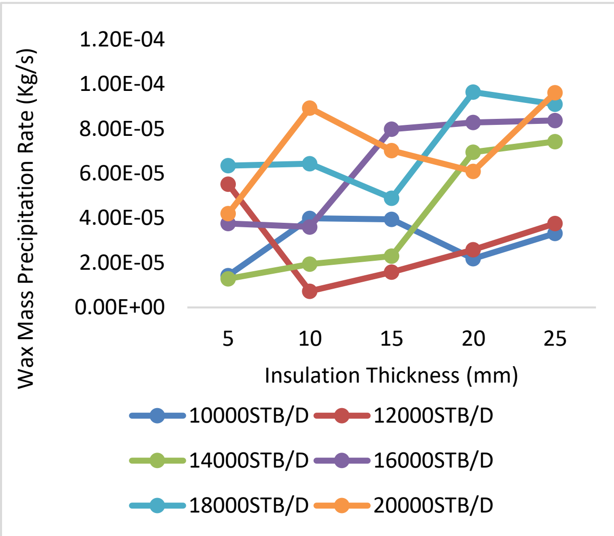

Figure 23. WMPR versus Insulation Thickness – Crude Sample 1, 14-in flow line

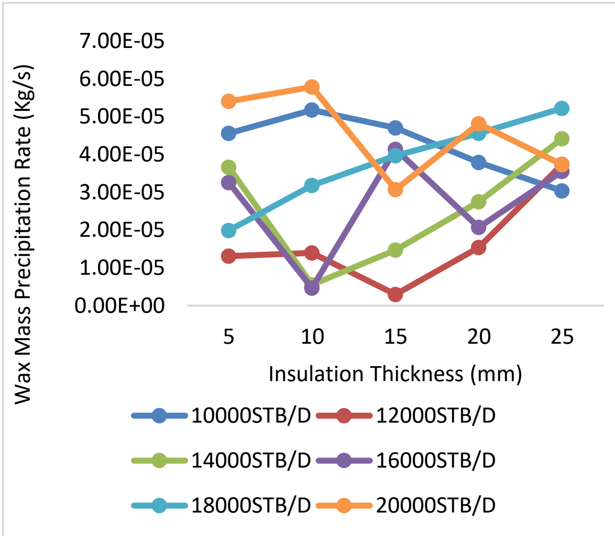

Figure 24. WMPR versus Insulation Thickness – Crude Sample 2, 14-in flow line

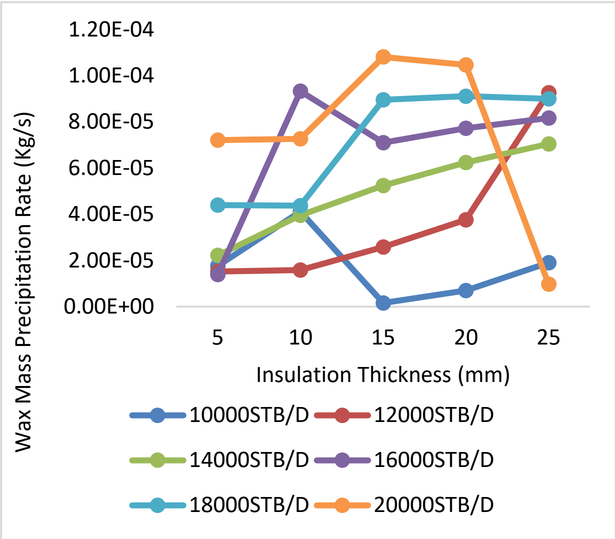

Figure 25. WMPR versus Insulation Thickness – Crude Sample 1, 16-in flow line

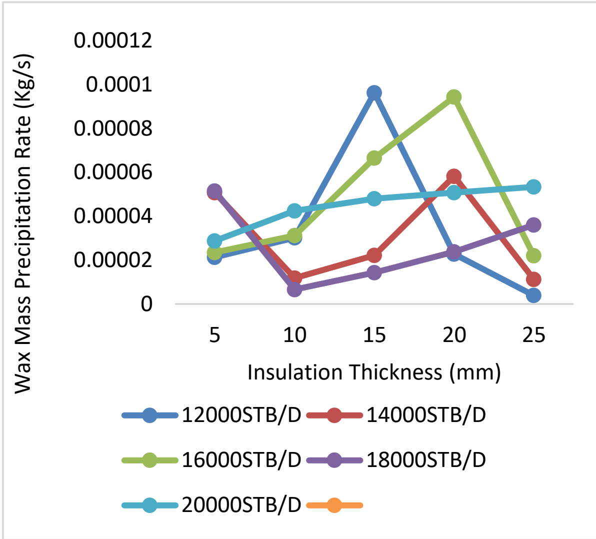

Figure 26. WMPR versus Insulation Thickness – Crude Sample 2, 16-in flow line

4. Conclusion

This study has evaluated the significance of insulation thickness as an underlying factor on wax precipitation and deposition tendencies in flow lines. An OLGA model was constructed using both field data and synthetic production scenarios of known two crude oil samples. The entire pipe segments were tracked from the wellhead to the reference terminal using the FT-WAT match criteria. From the results, the following conclusions were reached:

- Crude sample 2 showed more wax precipitation and deposition tendencies than crude sample 1 due to its higher value of wax content and cloud point. Hence, the waxier a crude oil sample has earlier WPP and WDT development.
- As production rate and insulation thickness increase, there is general increment in the WPP results for both samples.
- The use of thicker insulation materials facilitated the development of thinner WDT.
- The wax mass deposition rate does not show any consistent trend at each of the analyzed insulation thickness and production rates.

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