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Full Length Research Paper

Influencing factors governing paraffin wax deposition during crude production

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In this study, influencing factors controlling paraffin wax deposition from its reconstituted wax solution to the pipe wall surface will be presented. An experimental methodology constructed to simulate wax deposition process was employed to investigate these governing conditions. Series of test were designed to determine the effects of temperature differential, flow rate, residence time and wax concentration percentage weight in the deposit. Samples of the deposits were weighed and analyzed at the conclusion of each test for wax percentage weight in the deposit. Temperature differential between the waxy-fluid inlet temperature and a cold surface is a major influencing factor for wax deposition. The experimental result revealed that: wax deposition decreased with increasing temperature difference and flow rate, while the amount of paraffin wax deposited increased with time, attained a maximum value and gradually tails off. Wax concentration percentage weight, slightly varied with time as the temperature changes at a constant flow rate. However, this Study found that the integration of these conditions could have significant influence on wax deposition during crude production.

Key words: Wax deposition, influencing factors, risk.

INTRODUCTION

Paraffin wax depositions in production systems constitute a critical concern to crude exploration and production operations. 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 differential, flow rate, residence time 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. Although much progress has been made in the last decades to better the understanding of this complex process, yet the ability to accurately account for all the factors that affect wax deposition does not currently exist in the wax simulators used presently in industries. This study investigated the parameters influencing the deposition of paraffin wax; illustrated through results from flow-loop experiments, which is often used as a simple means to approximate the deposition process in production tubing / pipelines. The menace of paraffin wax problem would become more pronounced as oil exploration activities extend to offshore environments.

Hence, the urgency to understand the fundamental variables that effect or influence wax deposition is necessary for optimum crude productivity.

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FLOW LOOP EXPERIMENTAL DESIGN AND MATERIALS

To investigate the effect of the conditions under study on wax deposition, a paraffin wax-kerosene oil system was designed in the laboratory. The solution of paraffin wax - kerosene system was prepared by dissolving into kerosene solvent (a 3:1 mixture of refined paraffin wax and kerosene oil), as a reconstituted wax of average Malaysian crude oil. A laboratory flow-loop system was designed and constructed to simulate wax deposition of paraffin wax in heat exchanger. The flow-loop consist of a double-pipe heat exchanger, a temperature-regulated reservoir stainless steel tank (internal diameter = 360 mm; Height = 550 mm; tubular immersion heater rating = 240 V/ 3 KW), holding a 50 L reservoir with a hydromatic submersible pump, for recirculating the wax-solvent

Table 1. Experimental results for the effects of flow rate and time on wax deposition wt % deposit (kg) at 40℃.

Time (min)	Subsea temperature = 27℃				
	40℃				
	100 (ml/min)	200 (ml/min)	300 (ml/min)	400 (ml/min)	500 (ml/min)
3	0.32495	0.28496	0.26571	0.23897	0.20714
6	0.48134	0.38339	0.35362	0.30681	0.26317
9	0.50982	0.40777	0.35362	0.29593	0.24977
12	0.46845	0.39235	0.32628	0.26748	0.20573
15	0.42254	0.36481	0.28213	0.22197	0.16515
18	0.38012	0.32915	0.22729	0.16885	0.12084

Table 2. Experimental results for the effects of flow rate and time on wax deposition wt % deposit (kg) at 45℃.

Time (min)	Subsea temperature = 27℃				
	45℃				
	100 (ml/min)	200 (ml/min)	300 (ml/min)	400 (ml/min)	500 (ml/min)
3	0.24212	0.18207	0.18288	0.15614	0.14631
6	0.43299	0.33204	0.30765	0.26146	0.20782
9	0.47311	0.38896	0.32481	0.27812	0.21889
12	0.42723	0.35869	0.30604	0.23624	0.16149
15	0.36888	0.31815	0.24847	0.16519	0.10649
18	0.31159	0.2748	0.18994	0.09462	0.04149

mixture, a temperature-regulated refrigerated bath system. A centrifugal pump for circulating the coolant (water), a flow meter, a bypass valve for regulating the flow of wax-solvent mixture and thermocouples connected to a digital scanner data-logger. An insulated straight stainless steel tube (2.54 cm (internal diameter) x 3.8 cm (outer diameter) x 67 cm long) and stainless valve was used before the wax-solvent mixture entered the heat exchanger. The experimental program included variables considered to affect the deposition process, the composition of the wax-solvent mixture, the inlet temperature of the wax-solvent mixture, the inlet temperature of the coolant were measured and recorded. The range of the inlet temperature of the wax-solvent mixture was (40 - 55℃) Tables 1-4. While the inlet of the coolant temperature was maintained constantly at the Seabed temperature of Malaysia (27℃ to accommodate all seasonal variations). The flow rate of the wax-solvent mixtures was varied over 100 to 500 ml/min, while a constant coolant flow rate was used in all the experiments.

PROCEDURE FOR WAX DEPOSITION EXPERIMENTS

The flow loop was assembled and the 50 L reservoir was filled with wax-solvent mixture. After the desired heating and cooling bath temperatures were attained, the submersible pump turned on. The bypass valve was adjusted to achieve the desired flow rate. The deposition process was commenced by circulating the coolant (water) at a constant flow rate from the refrigerated bath, through the annular side of the heat exchanger. During each deposition experiment, the readings of inlet temperature of the wax-solvent mixture, the inlet coolant temperature, and the outlet coolant temperatures, as well as the wax-solvent mixture flow rate were recorded using digital data scanner. The deposition experiment was terminated by stopping the submersible pump. The coolant circulation was discontinued and the heat exchanger was dismantled to carefully recover the wax deposit in the deposition cell. The deposit was weighed on an electronic balance to obtain its mass. Sample of the deposit (wax-solvent mixture) were saved for analysis, and the remainder was recycled into the wax-solvent mixture reservoir for subsequent deposition experiments. This deposit recycling allowed for the composition of the wax-solvent mixture to not change significantly between runs (Figure 1).

RESULTS AND DISCUSSION

The paraffin wax deposition test were undertaken to enhance the understanding of the deposition process and for assessing the effect of any given wax-related operational conditions, with flow-loop test providing the best direct representation of oilfield production system.

Effect of temperature differential

Considerable of Flow-loop tests were performed under different operating conditions to evaluate the effects of temperature differential on wax deposition. In addition to the cooling rate, the temperature difference between the bulk of solution and a cold surface is major factor for wax

Table 3. Experimental results for the effects of flow rate and time on wax deposition wt % deposit (kg) at 50°C.

Subsea temperature = 27°C					
Time (min)	50°C				
	100 (ml/min)	200 (ml/min)	300 (ml/min)	400 (ml/min)	500 (ml/min)
3	0.1795	0.1462	0.1247	0.1145	0.09833
6	0.2884	0.25809	0.2345	0.19657	0.16336
9	0.30741	0.27165	0.24124	0.21098	0.14874
12	0.28471	0.2264	0.18741	0.15619	0.10867
15	0.24419	0.16098	0.12408	0.09525	0.04674
18	0.16639	0.08674	0.06438	0.04063	0.01638

Table 4. Experimental results for the effects of flow rate and time on wax deposition wt % deposit (kg) at 55°C.

Subsea temperature = 27°C					
Time (min)	55°C				
	100 (ml/min)	200 (ml/min)	300 (ml/min)	400 (ml/min)	500 (ml/min)
3	0.0828	0.06527	0.02188	0.01874	0.01561
6	0.14407	0.15021	0.08078	0.06165	0.04841
9	0.18622	0.14818	0.06804	0.04911	0.02758
12	0.20882	0.10638	0.04332	0.02828	0.01675
15	0.18337	0.06373	0.02852	0.01688	0.01284
18	0.12316	0.04036	0.01379	0.01253	0.00246

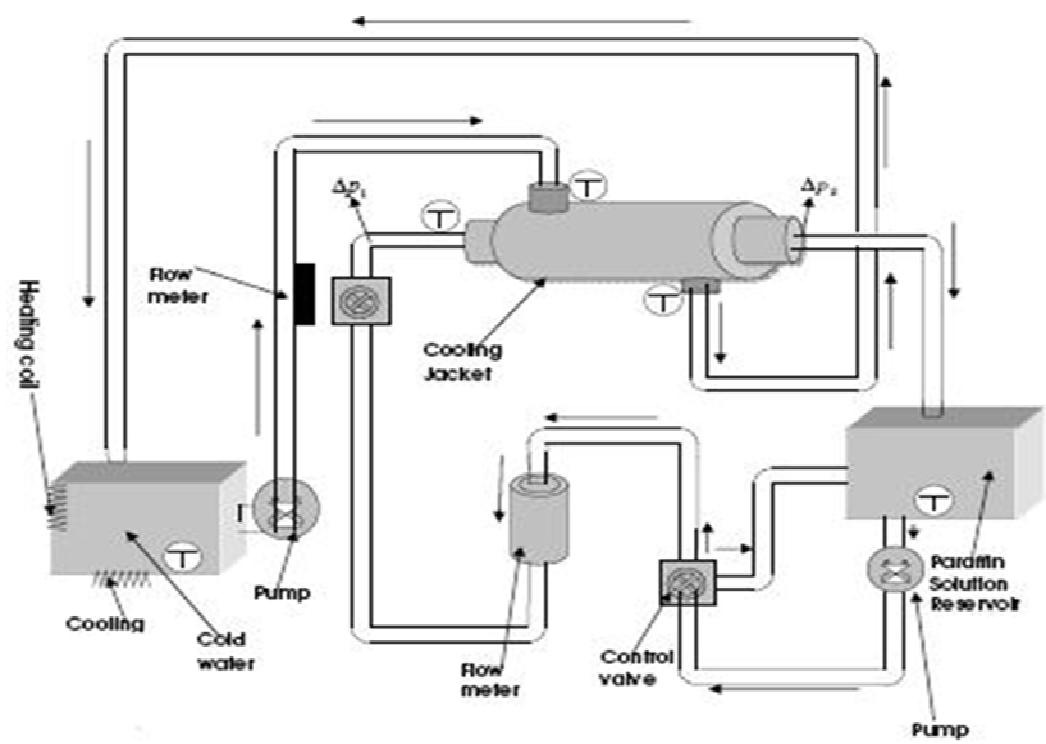

Figure 1. Schematic diagram of flow-loop heat exchanger for simulating wax deposition in the laboratory.

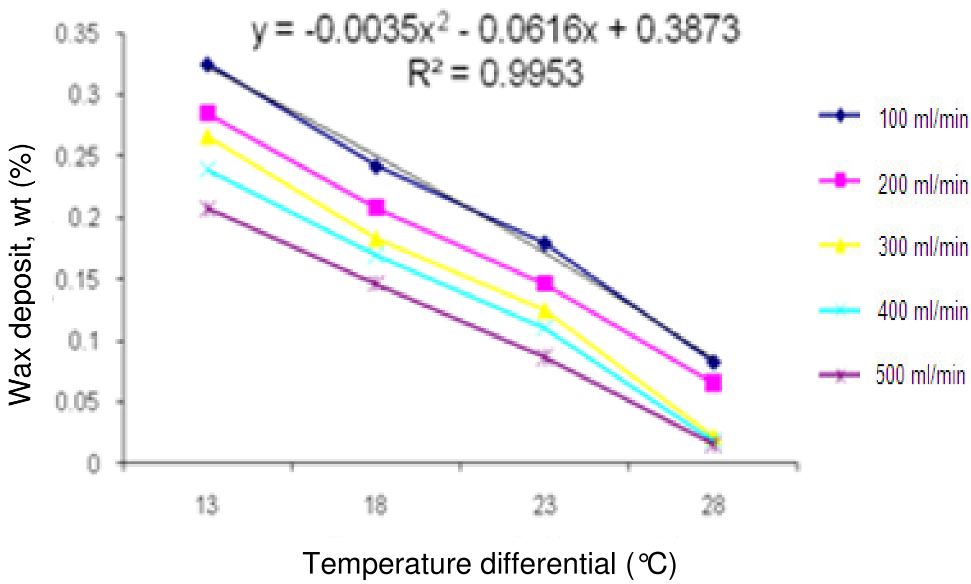

Figure 2. Effect of temperature differential on wax deposition at 3 min.

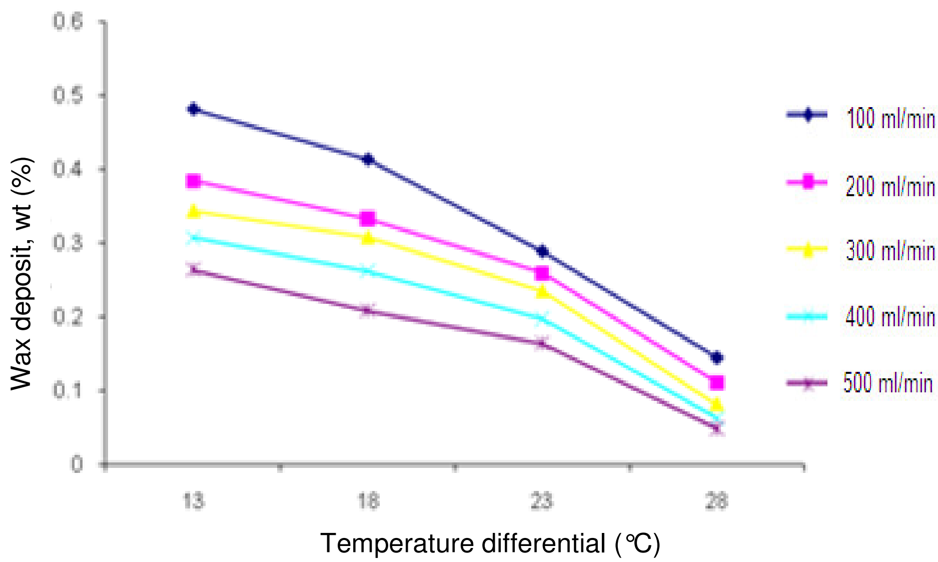

Figure 3. Effect of temperature differential on wax deposition at 6 min.

deposit. Wax deposit decreases with an increase in temperature difference.

The first target of the study was the effect of the temperature difference between the oil and the pipe wall. This was conveniently represented as the temperature difference of “waxy-solvent and the coolant” as they enter the flow-loop. As mentioned previously, for wax deposition to occur, a temperature differential (ΔT) must exist between the waxy fluid and the colder deposition surface. But however, as long as the operating temperature remains above the WAT, wax deposition will not occur. The laminar flow deposits were mostly found to be soft and marshy. These deposits had the consistency of gelation with embedded wax-crystals. But the deposit from the greatest temperature differential between the “coolant” and oil also give among the softest deposits.

Figures 2 - 7, shows the plotted graph of paraffin wax deposition per kilogram weight against various waxy-solution temperatures using same ratio of wax-solution. The temperature of the cooling water was constantly fixed at 27°C. The results showed that as the temperature difference increases, the paraffin wax

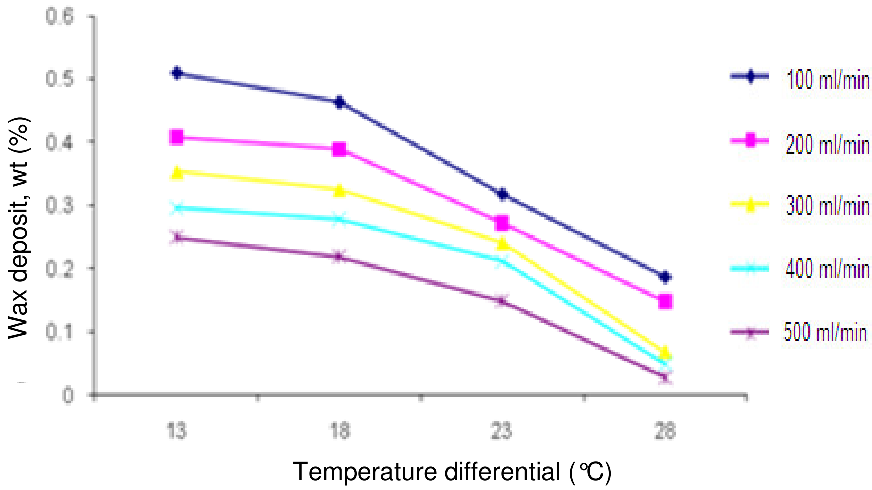

Figure 4. Effect of temperature differential on wax deposition at 9 min.

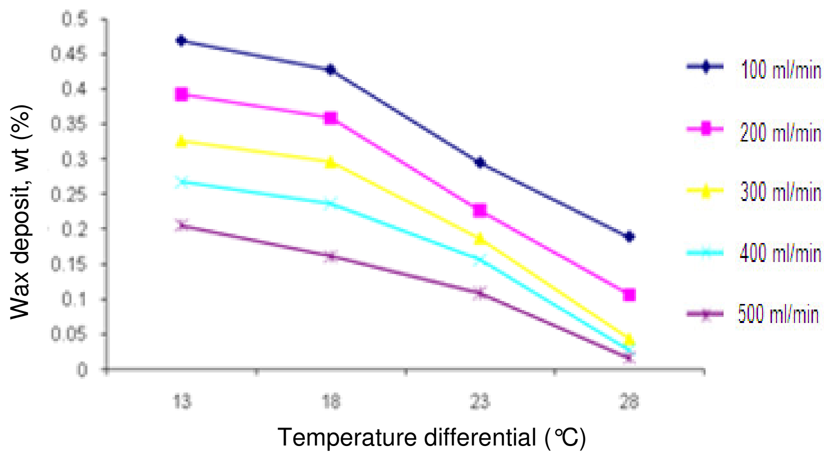

Figure 5. Effect of temperature differential on wax deposition at 12 min.

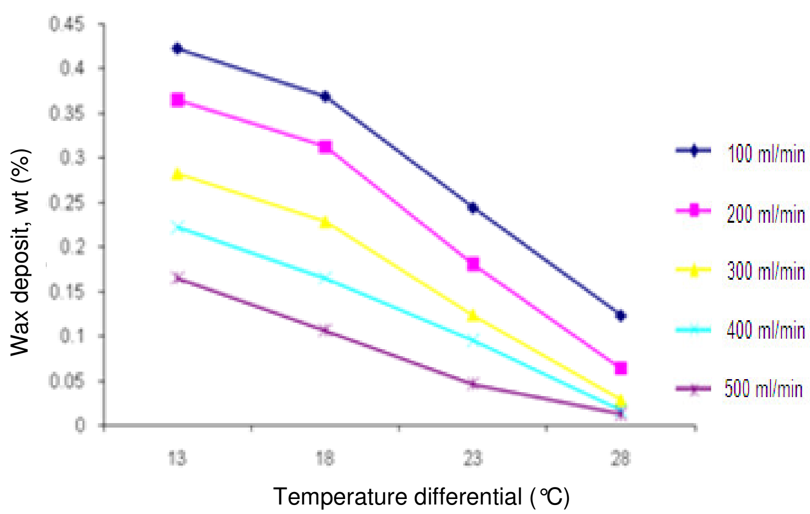

Figure 6. Effect of temperature differential on wax deposition at 15 min.

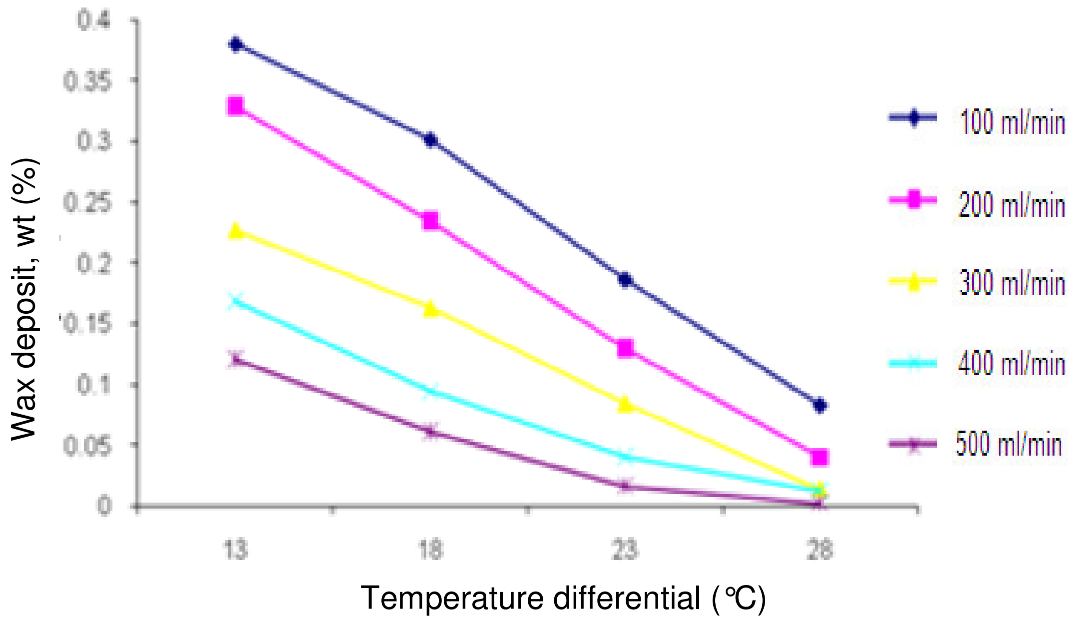

Figure 7. Effect of temperature differential on wax deposition at 18 min.

deposition consistently decreases. This result is in total agreement with previous studies conducted by Cole and Jossen (1960); Haq (1978) and Tang et al. (2002), but however, disagreed experimentally that wax deposition would increase by the increasing temperature difference between cold pipe wall temperature and feed temperature as reported by Nazar et al. (2001), and Jennings and Weispfennig (2005). This drop in wax deposition rate with increasing in temperature difference could be attributed to the extra heat gained or added in the solution, which would further move the solution away from its cloud point. Hence the process of crystal formation and their deposition is a function of temperature difference (Norman, 1989).

Effect of flow rate

The variation of flow rate as a function of time and different differential temperature are shown in Figures 8 to 13. These set of results dealt with the amount of wax deposition as a dependent of flow rate or its equivalent production rate. Mohammed (2007) hypothesized that a higher flow shear, which is a function of flow rate, leads to lesser but likely harder deposit build up. Thus wax deposition gradually decreases with increase in flow rate and turbulence. The wax that deposits at a higher flow rate is harder and more compact. In other words, only those wax crystals and crystal clusters capable of firm attachment to the surface, with good cohesion among themselves, will not be removed from the deposit. The effect of increasing flow rate, decreasing the amount of wax deposited or entrapped oil in the deposited, was also reported in two subsequent coaxial shear cell studies by Lee-Tuffnell (1996) and Dawson (1996).

The plotted graphs in Figures 8 to 13, illustrate flow rates and its contemporary effect on paraffin wax deposition. It’s obvious from the results that the wax deposited decreased with increasing flow rates; with apparent asymptotic behavior (within experiment precision) at the increasing flow rates that had been examined. This can be explained; that as the velocity of the stream increases the viscous drag, exerted by the moving stream tends to remove the accumulation as it exceeds the shear stresses within the deposited wax, thereby, providing the removal of deposition mechanism. It was also noticed that the paraffin wax deposited at higher flow rates was harder than deposited at lower flow rates. Low flow rates affect wax deposit mainly because of the longer residence time of the oil in the tubing. This results are in good agreement and can be correlated with previous investigations reported by Lund (1998) and Venkatesan (2004). However, this result is limited within the tenets of laminar flows.

Effect of residence time

Figures 14 to 18, shows the deposition of paraffin wax and total deposit build up (kilograms) as a function of residence time of the wax-solvent mixture for different flow rates and temperature differential into the thermal system. This residence time permits more heat loss and leads to a lower oil temperature, which in turn leads to wax precipitation and deposition. These plots serve as the basis to evaluate the effect of time on wax deposition

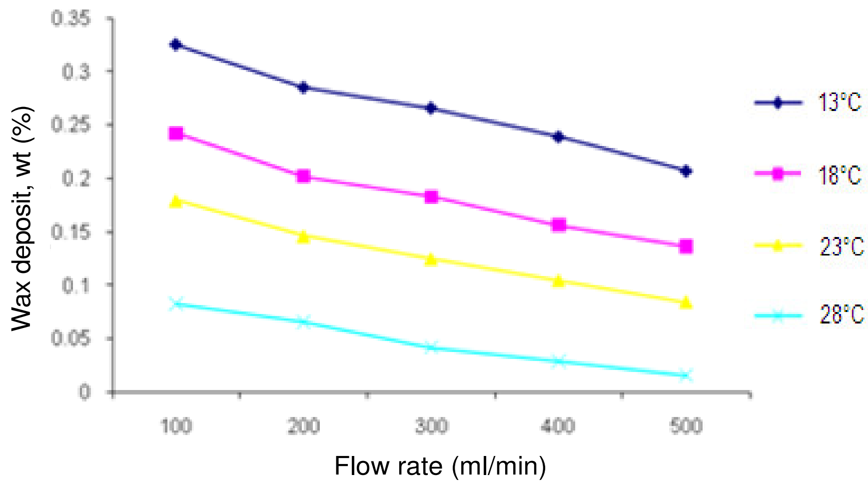

Figure 8. Effect of flow rate of the wax-solvent mixture on wax deposition at 3 min.

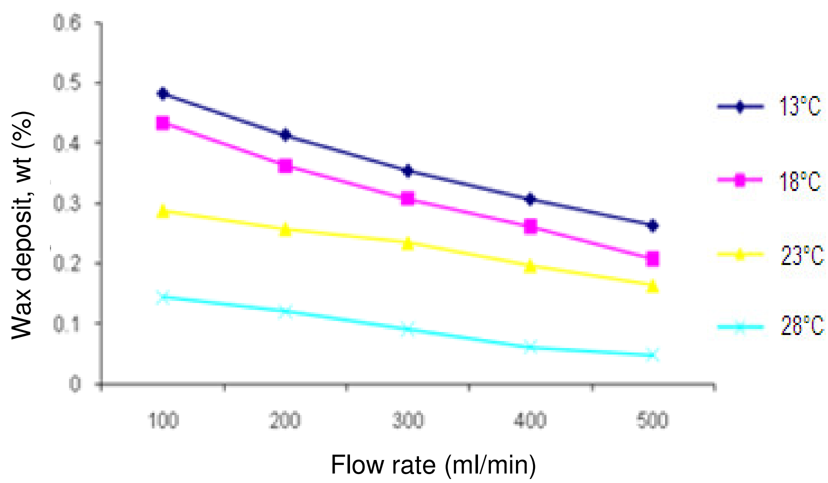

Figure 9. Effect of flow rate of the wax-solvent mixture on wax deposition at 6 min.

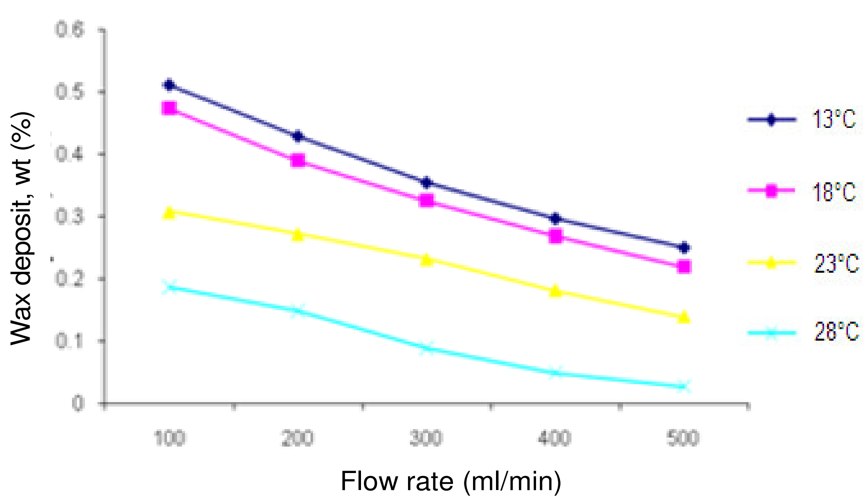

Figure 10. Effect of flow rate of the wax-solvent mixture on wax deposition at 9 min.

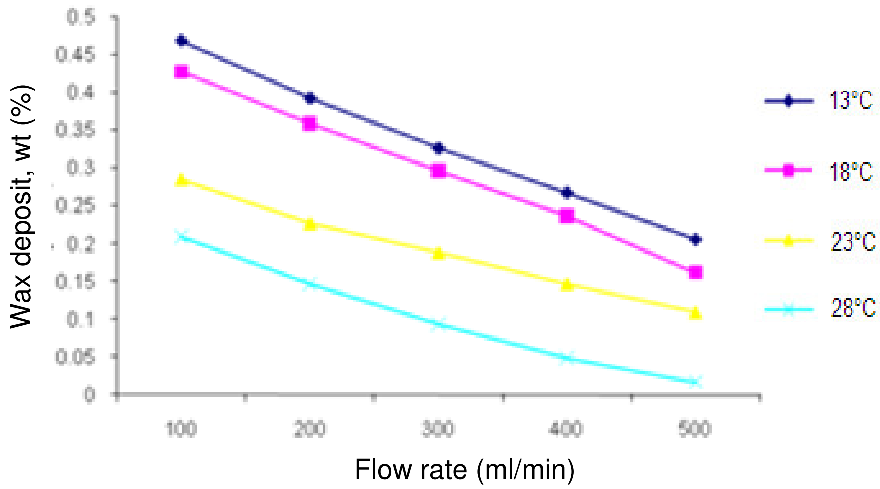

Figure 11. Effect of flow rate of the wax-solvent mixture on wax deposition at 12 min.

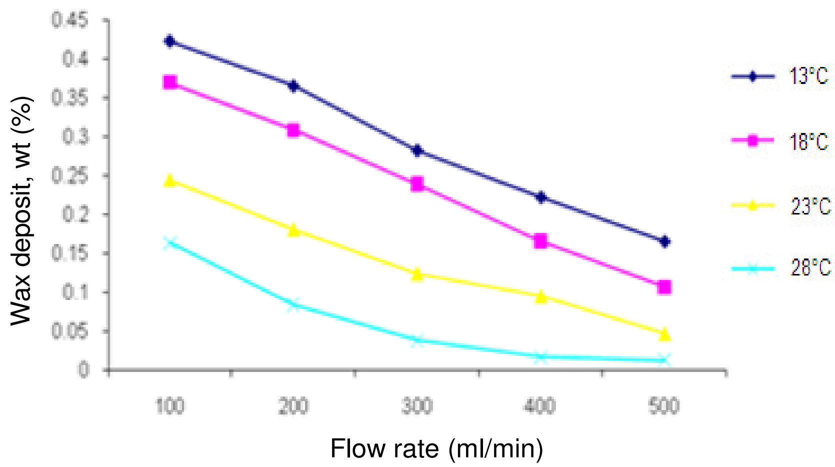

Figure 12. Effect of flow rate of the wax-solvent mixture on wax deposition at 15 min.

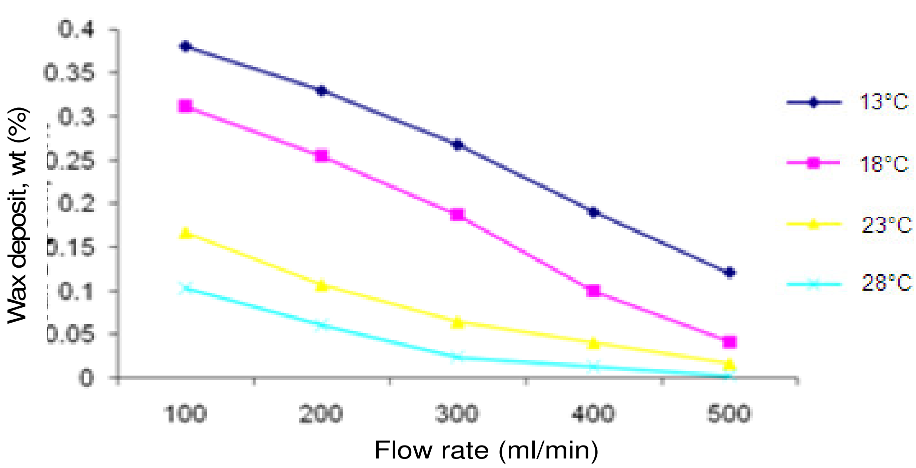

Figure 13. Effect of flow rate of the wax-solvent mixture on wax deposition at 18 min.

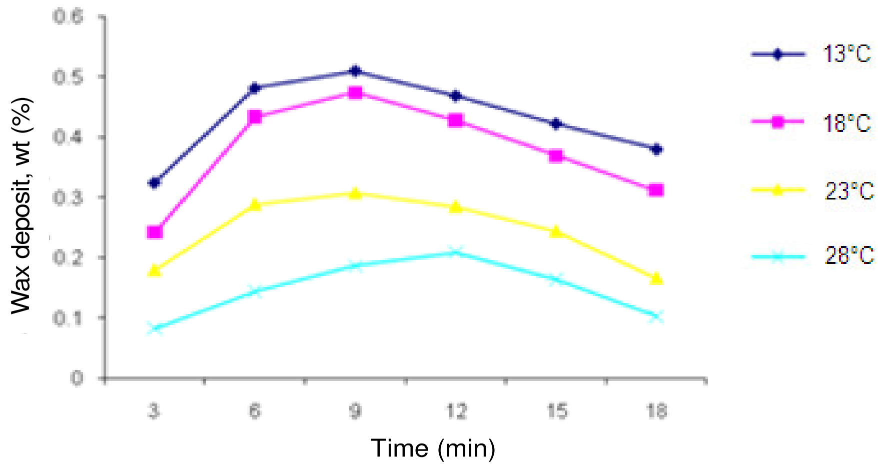

Figure 14. Effect of residence time on wax deposition at 100 ml / min.

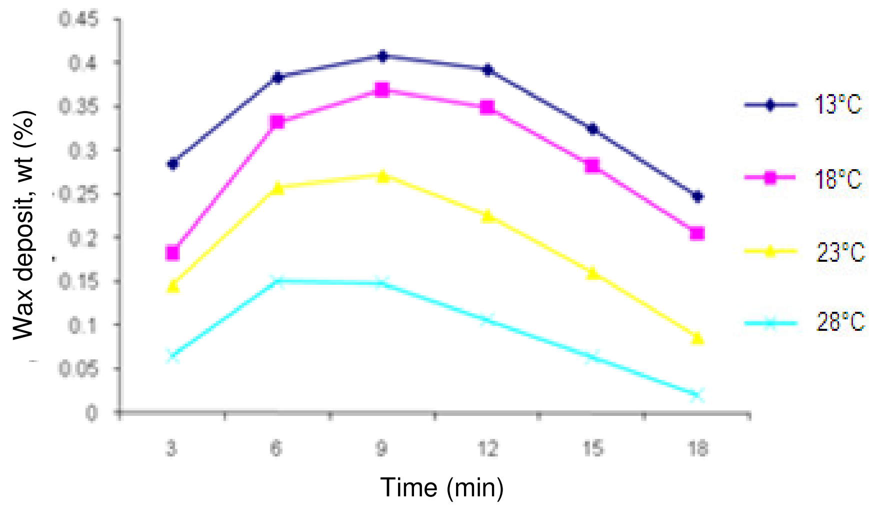

Figure 15. Effect of residence time on wax deposition at 200 ml / min.

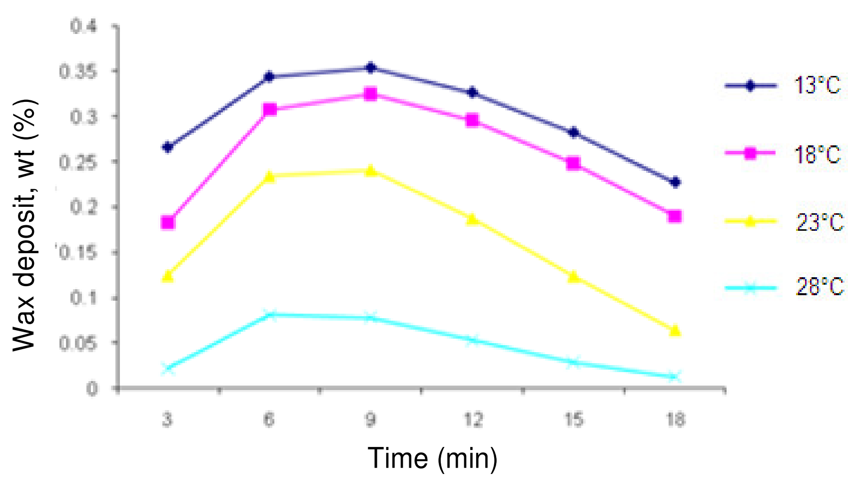

Figure 16. Effect of residence time on wax deposition at 300 ml / min.

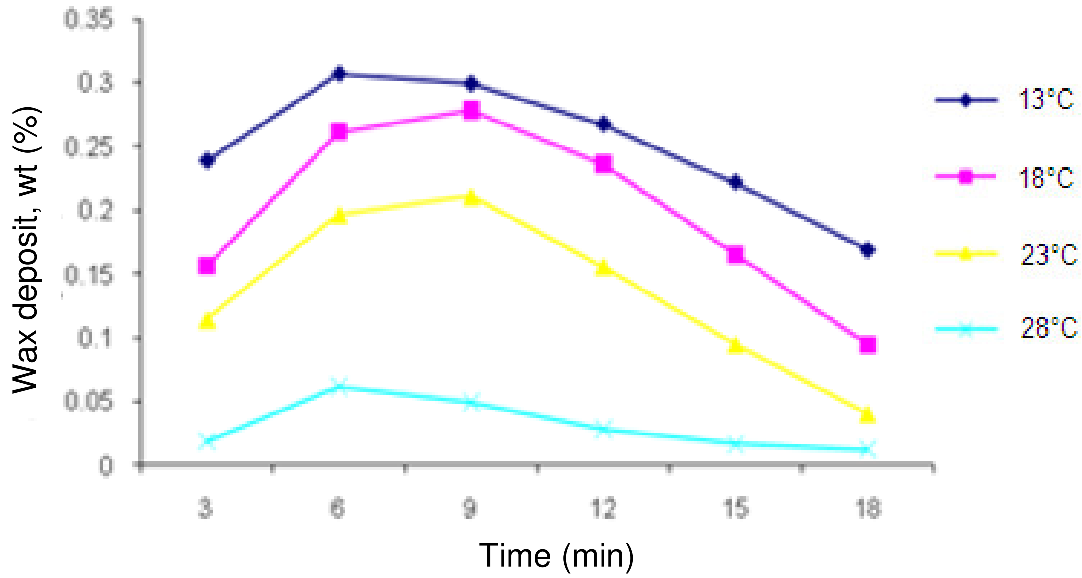

Figure 17. Effect of residence time on wax deposition at 400 ml / min.

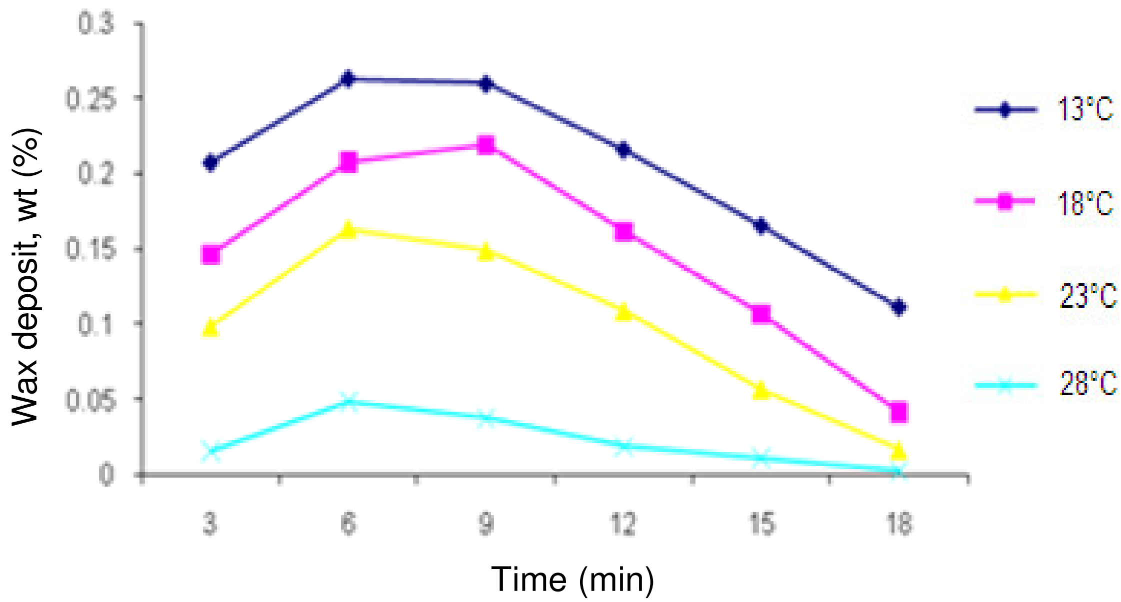

Figure 18. Effect of residence time on wax deposition at 500 ml / min.

as provided. Expectedly, the deposit trend is not linear, which is believed due in part to depletion effects. It's paramount to note that since the employed laboratory set up is a close-loop system, no fresh sample was supplied; therefore , precipitated or deposited wax depletion (or active wax reduction) due to deposition build up will occur (Mohammed, 2007). Although the scenario may not be same in a real oilfield pipeline, hence the presence of an unlimited supply of fresh crude oil from the reservoir provides enough precipitated wax and makes the resident time for the fluid small enough to minimize or mask the effect of depletion due to deposition.

A graphical plot of paraffin wax deposits by percentage weight against residence time is shown in Figures 14 - 18. Initially, the amount of wax deposition increased with increasing time, which approximately becomes constant, before gradually tailing off as the time increases to higher values. The drop in paraffin wax deposition weight (kilograms) at higher value of time could be attributed to the thermal insulation by the deposited wax layer and the

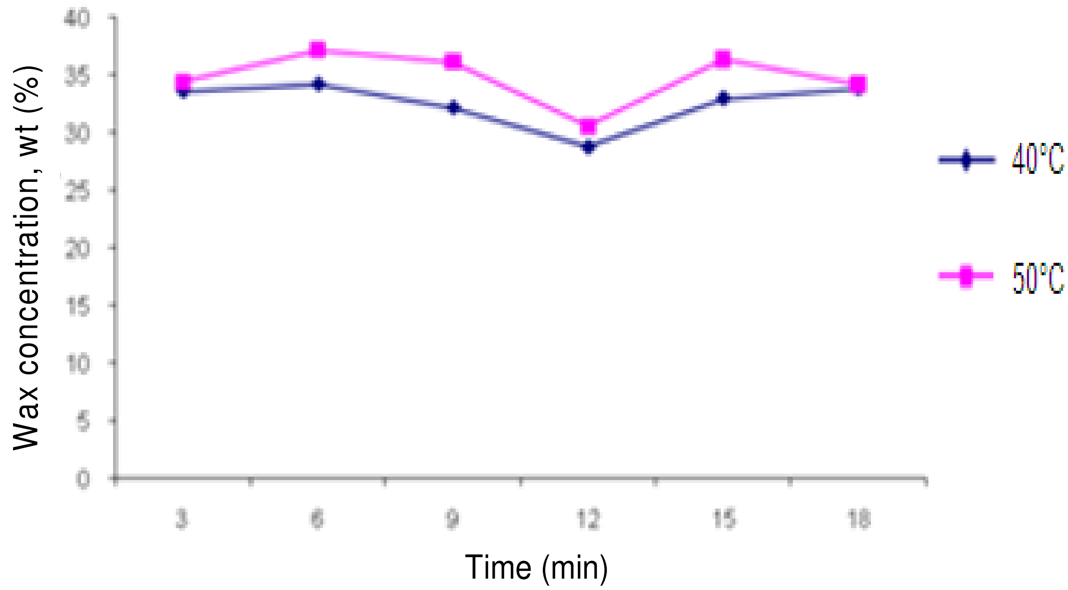

Figure 19. Effect of temperature and time on wax concentration percentage weight.

variation in the amount of paraffin wax particles available for deposition. This is in agreement with the findings of Cole and Jessen (1960), Bott and Gudmundsson (1977), Haq (1978), Towler and Rebbapragada (2004) and Mohammed Zougari (2007).

Effect of concentration

In Figure 19, paraffin wax concentration percentage weight was plotted against time, while varying the temperature of the waxy-fluid, while maintaining flow rate constant. This was primarily investigated to ascertain the effect of time at various temperatures on wax concentration during deposition. It could be found that wax concentration percentage weight slightly varied inconsistently with increasing time at different waxy-fluid temperatures. However, it is considered that when a certain critical thickness is reached, which will give rise to the fluctuating flow conditions (Haq, 1978) as production time increases with changes in temperature.

Conclusion

A detailed literature review of wax deposition problems was covered in this work. This effort culminates in a handy tool for new researchers to easily get acquainted with every aspect of wax deposition issues. Paraffin deposition flow-loop system was constructed, which simulates the paraffin deposition in the production tubing and flow lines. The amount (weight) of paraffin deposits were measured and plotted for each experiment, and results analyzed.

Experiments were conducted using a mixture of paraffin wax and kerosene oil in a laboratory flow-loop. The deposition was performed under a wide range of parameters including residence time, flow rate, temperature differential and wax concentration. The amount of paraffin wax deposited increased with time, attained a maximum value and then gradually tails off .The wax deposition decreased with increasing flow rates. The temperature difference between the waxy-fluid inlet temperatures and the subsea condition represented at the pipeline surface is considered important factor in controlling the paraffin wax deposition. The experimental study revealed reasonable functionality and relationship between wax deposition and the studied variables.

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