Study on Wax Deposition Law in Daqing Gulong Shale Oil

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Abstract. Daqing Gulong shale oil exhibits elevated wax content, a high wax precipitation point, and a high freezing point. However, its oil density and viscosity are relatively low, making it susceptible to wax crystal precipitation. The risk of pipeline clogging is heightened in lower ambient temperatures, posing a hazard to the safe production of shale oil. This study focuses on testing the fundamental physical properties of crude oil. The wax deposition flow loop was employed to replicate wax deposition in extracted fluids under actual high-flow gas-liquid conditions within a pipeline. The deposition patterns were determined based on the experimental findings. The results indicate that, irrespective of whether in single-phase, gas-liquid two-phase, or oil-gas-water three-phase conditions, the deposition mass rises with decreasing oil temperature. Furthermore, the deposition mass rises with an increased temperature difference between the oil and the pipeline wall. Conversely, the deposition mass declines with an increased gas-liquid ratio, and the deposition thickness declines with elevated water content. The observed deposition patterns highlight the significant influence of molecular diffusion and the impact of gas phase shear. These experimental findings offer valuable references and insights for the transportation of Daqing shale oil through pipelines.

1. Introduction

Pipeline transportation plays a crucial role in the conveyance of oil and natural gas, serving as an economically and environmentally friendly method with substantial conveying capacity [1]. However, challenges arise in the pipeline transportation of crude oil containing wax. When the temperature of the pipe wall falls below both the oil temperature and the wax precipitation point, wax molecules within the oil stream gradually precipitate. This leads to the formation of deposits on the pipe wall, causing an increase in friction coefficient, pressure drop, and a reduction in circulation area, among other issues [2]. Ultimately, these challenges contribute to the occurrence of pipe clogging, presenting significant risks to the safe production of oil. Addressing this issue has become a prominent research focus in the field of flow assurance.

Numerous scholars have delved into the exploration of diverse factors influencing wax deposition, contributing to a more comprehensive understanding of the characteristics of wax deposition under various conditions. Fan and Ehsani used a cold finger device for wax deposition experiments to study the wax deposition phenomena[3-4]. M. Lashkarbolooki conducted single-phase wax deposition experiments on crude oil from the Kershman field using a loop channel. This research experimentally investigated the impacts of oil temperature, wall temperature, and the temperature difference between the oil and the wall on wax deposition [5]. Rainer and Lene explored the influence of flow rate on wax deposition through experiments using a loop channel with condensate from the North Sea [6]. Singh scrutinized the effect of deposition time on wax deposition through microscopic observation and gas chromatography [7]. At the University of Calgary, Kasumu conducted experiments on wax deposition in a water-in-oil (W/O) emulsion loop channel, varying water contents, flow rates, and temperatures using wax-containing simulated oil and tap water [8]. Similarly, Ekarit, from the University of Tulsa, performed experiments on wax deposition from a water-in-oil (W/O) type emulsion annulus under different conditions of water content, flow rate, and deposition time, utilizing South Pelto crude oil [9]. Matzain and Nilufer individually investigated wax deposition under gas-liquid two-phase flow conditions using crude oils with varying wax contents [10-11].

While the aforementioned experimental research results offer valuable insights for actual pipeline transportation, their applicability to cases involving highly waxy oil may be limited. Crude oils in China typically exhibit high wax content, often exceeding 20%. Consequently, the wax deposition characteristics of high wax content oils in China may differ significantly due to the diverse properties of different oils. Daqing Gulong shale oil, being a representative crude oil with both high wax content and a high wax precipitation point, experiences extremely easy wax precipitation.

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Given these unique characteristics, it becomes imperative to conduct specific research on the wax deposition patterns and control methods for Daqing Gulong shale oil. This research aims to elucidate the wax deposition behavior of Gulong shale oil and formulate an economically and logically sound wax deposition control program accordingly.

2. Experimental section

2.1. Experimental shale oil properties

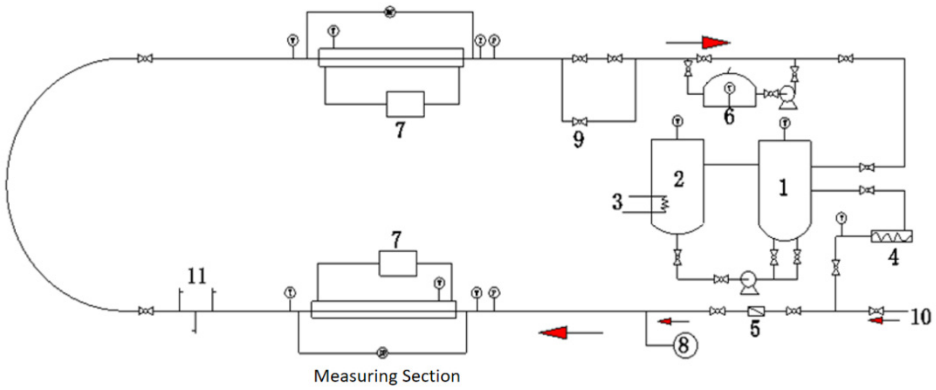
The physical properties of the shale oil used in the experiment are shown in Table 1, with a Pour point of 30 ℃, a wax appearance temperature of 50.86 ℃, and a wax content of 23.29 wt%.

Table 1. Physical properties of the shale oil sample.

Density at 25°C(kg/m^3)	Pour point(°C)	WAT(°C)	wax (wt.%)
812.4	30	50.86	23.29

2.2. Wax Deposition Flow Loop

The schematic representation of the wax deposition test is illustrated in Figure 1, depicting the wax deposition flow loop. The experimental setup predominantly includes an oil storage tank, a transfer pump, a water supply system, a gas supply system, a hot bath temperature control system, a cold bath temperature control system, a measuring section, a measurement system, and a data acquisition system.



1-oil tank ; 2-circulating water tank ; 3 - water tank heating coil ; 4 - screw pump ; 5-liquid mass flowmeter ; 6 - gas-liquid separator ; 7 - temperature controlled water bath ; 8-gas injection section ; 9-fast closing pipe section ; 10 - Air purge ; 11 - Local Sampler
Figure 1. Schematic diagram of the flow loop apparatus for wax deposition.

The entire loop spans a total length of 25 meters and is subject to temperature control achieved by circulating pure water through a water bath temperature control system, ensuring compliance with experimental temperature requirements. Within this setup, the test section, responsible for wax deposition, features a diameter of 25.4mm and extends over a length of 2 meters. It is temperature-controlled through a dedicated thermostatic water bath. The oil storage tank, acting as the source for the oil supply system, boasts a volume of 120 liters. Surrounding this tank is a heat bath responsible for elevating the oil temperature to the desired level. To ensure uniform heating of the crude oil, a stirring paddle is employed within the tank. A screw pump facilitates the conveyance of the oil sample from the heated tank to the annulus and back to the tank. The flow rate is adjustable within a specified range, regulated by the pump, and monitored by a mass flow meter. The gas supply system has the capacity to provide gas for the entire loop, facilitating multi-phase mixed transport experiments. The measurement system and data acquisition system enable the transmission and recording of sensor data, including pressure, temperature, and flow rate, to a computer.

The wax deposition flow loop is designed to conduct wax deposition experiments under both single-phase and multiphase conditions. It is equipped to investigate the influence of key experimental factors, including fluid temperature, wall temperature, flow rate, deposition time, and gas-oil ratio, on the wax deposition characteristics.

2.3. Experimental Process

The experimental procedure involved initial preheating of shale oil to 70 ℃ for a duration of 6 hours, followed by injection into the annulus tank. To maintain the crude oil at the desired temperature, both the tank and the pipe were heated, with the test pipe section specifically held at the experimental temperature. Once the system temperature stabilized, the experiment commenced. The oil flowed inside the pipe, and the flow was halted when the designated deposition time was achieved. Subsequently, the air blowdown process was initiated, and after completion, the test section was disassembled. The thickness of the wax deposition layer was determined using the volumetric method. To ensure accuracy, the experiment was repeated several times, and the average value of the deposition thickness was calculated. The investigation into the wax deposition law under different experimental conditions involved modifying air volume, liquid volume, and water content while repeating the aforementioned experimental steps.

https://doi.org/10.1051/e3sconf/202452801017

Table 2. Experimental scheme.

No.	Oil Temp. (°C)	Coolant Temp. (°C)	Temp. difference (°C)	Gas-liquid ratio (%)	Water content
1	40	35	5	0	0
2	35	30	5	0	0
3	35	25	10	0	0
4	35	30	5	4:1	0
5	35	30	5	13:1	0
6	35	30	5	0	20
7	35	30	5	4:1	20
8	35	30	5	13:1	20
9	35	30	5	0	40
10	35	30	5	0	60

The experimental scheme is shown in Table 2. Throughout the experiment, a constant flow rate of 0.9 m/s was maintained, while the deposition time varied at intervals of 1hour, 2hour, 3hour, 4hour, and 5hour. The study involved a comparative analysis to investigate the impacts of experimental time, temperature, temperature difference, gas-liquid ratio, water content, and other influencing factors on the thickness of wax deposition.

3. Result and discussion

Figure 2 demonstrates the effect of time, temperature interval, and temperature gradient on the deposited thickness under single-phase conditions. It can be observed that the trend of the increase of the deposited thickness gradually slows down with the increase of time. This is due to the thermal resistance effect resulting from the formation of the wax deposition layer, which acts as an inhibitor to the diffusion of wax molecules. Fixing the temperature difference between the oil walls, there is a tendency to exacerbate the deposition in the low temperature range. At the beginning of wax deposition formation, an initial gel layer is first formed on the cold wall. Obviously, in the low-temperature interval, the further the dissolved wax molecules crystallize away from the wall, the further the highest temperature isotherm for gel formation is from the cold wall, resulting in a thicker initial gel layer. Therefore, the gel layer gradually grows into a thicker wax deposition layer in the low temperature interval. Fixing the oil temperature, there is a tendency to increase the temperature gradient to intensify the deposition. This is due to the enhancement of the deposition driving force due to the temperature gradient. All of the above behaviors are wax deposition effects triggered by molecular diffusion [12].

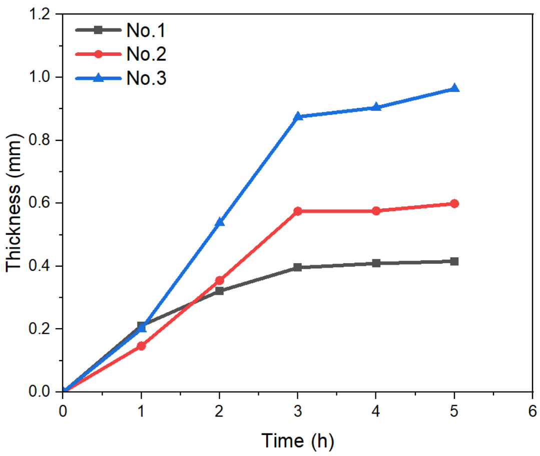


Figure 2. The effect of time and temperature difference on the thickness of wax deposition.

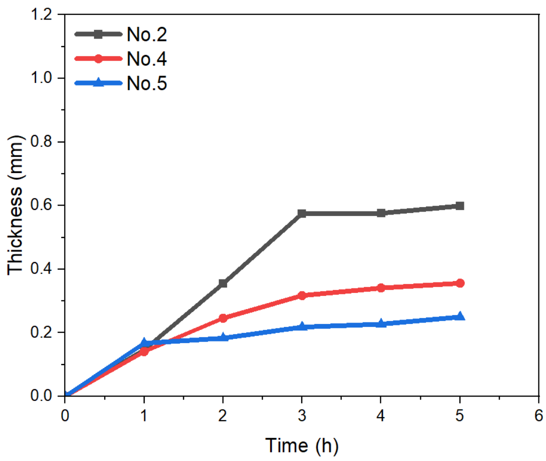


Figure 3. Effect of gas-liquid ratio and time on deposition thickness.

Figure 3 illustrates the influence of gas-liquid ratio and time on the deposition thickness in gas-oil two-phase conditions. Notably, the trend of deposition thickness growth exhibits a gradual slowdown with increasing time, mirroring observations in single-phase scenarios. Conversely, as the gas-liquid ratio rises, resulting in an augmented gas-phase velocity, the deposited layer undergoes the impact of gas shear, leading to a substantial reduction in the thickness of the deposited layer.

In Figure 4, the impact of gas-liquid ratio and time on deposition thickness is explored under oil-gas-water three-phase conditions with a constant 20% water content. Notably, the trend reveals a gradual deceleration in the increase of deposition thickness with extended time. Concurrently, a rise in the gas-liquid ratio corresponds to a reduction in deposition thickness, aligning with the observed behavior in gas-oil two-phase systems.

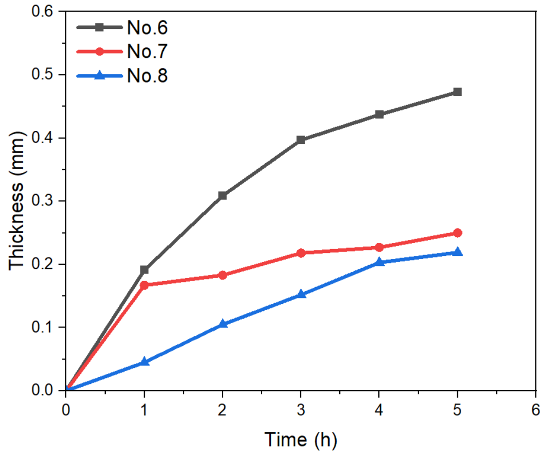


Figure 4. Effect of gas-liquid ratio and time on deposition thickness at 20% water content.

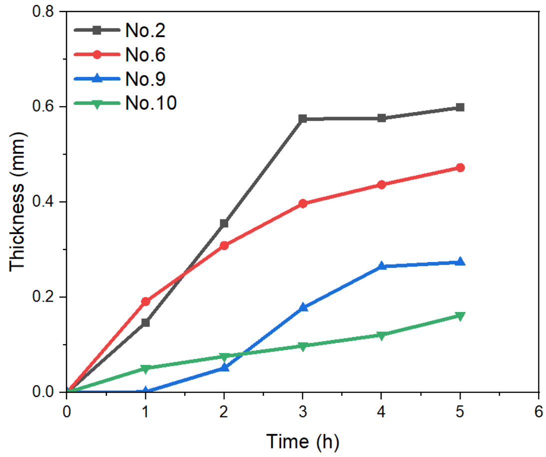


Figure 5. Effect of varying water content and time on sediment thickness.

In Figure 5, the influence of varying water content and time on sediment thickness in both oil and water phases is showcased. Notably, the trend indicates a gradual deceleration in the increase of deposited thickness with prolonged time. Furthermore, as the water content rises, there is an observed decrease in deposition thickness. This phenomenon is attributed to the potential inhibitory effect of water, which hinders the diffusion of wax molecules and serves as a barrier to deposition.

4. Conclusion

The experimental investigation of oil deposition in Daqing Gulong shale, conducted using a flow loop device, highlights the substantial impact of various factors on wax deposition thickness. Time, temperature difference, gas-liquid ratio, and water content emerge as key influencers in this study. Notably, as time progresses, there is a significant increase in wax deposition thickness, a phenomenon attributed to the diffusion of wax molecules. Furthermore, under consistent water content conditions, elevating both the gas-phase flow rate and water content correlates with a reduction in wax deposition thickness. This observed trend is linked to the inhibitory effects of gas-phase shear and water molecule diffusion, which collectively impede the diffusion of wax to the pipe surface. These findings contribute valuable insights and establish a solid foundation for optimizing the pipeline transportation of Daqing Gulong shale oil.

References

1. Diwen C , Ying X , Fangrui M ,et al.Research progress in wax deposition in oil-water two-phase flow[J].Petrochemical Technology, 2018.
2. Li, Bingfan, et al. A comprehensive review of wax deposition in crude oil systems: Mechanisms, influencing factors, prediction and inhibition techniques[J].Fuel,2024,357:129676.
3. Fan K , Li S , Li R .Development of wax molecular diffusivity correlation suitable for crude oil in wax deposition: Experiments with a cold-finger apparatus[J].Journal of Petroleum Science and Engineering, 2021, 205(7):108851.DOI:10.1016/j.petrol.2021.108851.
4. Ehsani S , Haj-Shafiei S , Mehrotra A K .Experiments and modeling for investigating the effect of suspended wax crystals on deposition from 'waxy' mixtures under cold flow conditions[J].Fuel, 2019, 243(MAY 1):610-621.DOI:10.1016/j.fuel.2019.01.089.
5. M. Lashkarbolooki, A. Seyfaee, F. Esmaeilzadeh, and D. Mowla. Experimental Investigation of Wax Deposition in Kermanshah Crude Oil through a Monitored Flow Loop Apparatus. Energy Fuels 2010, 24, 1234–1241
6. Mason S L , Meyer J C , Needham D J .The Development of a Wax Layer on the Interior Wall of a Circular Pipe Transporting Heated Oil -- The Effects of Temperature Dependent Wax Conductivity[J]. 2021.DOI:10.1007/s10665-021-10171-x.
7. Fan K F, Li S, Huang Q Y, et al. Research progress on radial properties of wax deposits in crude oil pipelines[J]. Chemical Industry and Engineering Progress, 2020, 2020: 1-19.
8. KASUMU A S, MEHROTRA A K. Solids Deposition from Wax–Solvent–Water “Waxy” Mixtures Using a Cold Finger Apparatus[J]. Energy & Fuels, 2015,29(2):501-511.
9. Ekarit Panacharoensawad. Wax deposition under two-phase oil-water flowing conditions [D]. Tulsa, Oklahoma, University of Tulsa, 2012.
10. Liu H S , Duan J M , Li J ,et al.Wax deposition modeling in oil-water stratified pipe flow[J]. Petroleum Science, 2023, 20(1):526-539.
11. Nilufer.K.Multiphase paraffin deposition behavior of a Garden Banks Condensate:(Doctoral Dissertaiton).Tusla:University of Tusla.2003.
12. Aiyejina A , Chakrabarti D P , Pilgrim A ,et al.Wax formation in oil pipelines: A critical review[J].International Journal of Multiphase Flow, 2011, 37(7):671-694. DOI:10.1016/j.ijmultiphaseflow.2011.02.007.