Control of Paraffin Deposition in Production Operation by Using Ethylene–TetraFluoroEthylene (ETFE)

Mombekov Bagdat and Rashidi Masoud

Abstract The physiochemical characteristics of the crude and deposited wax are two main issues associated to the flow assurance. They can provide useful estimates of the parameters and behavior required for operational engineering process developments and/or physical modifications to the processing of crude oils where the main objectives are to reduce costs of production and transportation. This study will attempt to determine and explain the new and effective way of eliminating paraffin depositions by utilizing a novel polymer which is called Ethylene–TetraFluoroEthylene (ETFE) with IUPAC name poly(ethylene-co-tetrafluoroethylene). Furthermore, this paper compares the known characteristics of three types of pipes—ETFE internal plastic pipe coating and rigid PVC plastic pipe coating and steel pipe. The paraffin deposition decreases as the effect of temperature increases from 5 to 25 °C and the flow rate increases from laminar to turbulent. The deposition reaches its peak at a fluid velocity value around 2.4 ft/s. The surface roughness of the three pipes steel, rigid PVC, and ETFE plastic pipe coated on paraffin deposition was evaluated. The ETFE plastic pipe with the least roughness recorded an appreciably good deposition (15 g/4 h) than the other two pipes. This study results show that ETFE internal plastic pipe coating is the most appropriate solution for paraffin deposition in the pipelines.

Keywords Cloud point · Ethylene–tetrafluoroethylene (ETFE) · Polyvinyl chloride (PVC) · Paraffin deposition · Precipitation

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1 Introduction

Paraffin deposition problems have been recognized as one of the main challenge in oil and gas industry during production and transportation of crude oil. Petroleum industry loses hundreds of millions of dollars yearly for controlling these problems. Paraffin wax has been defined as the organic compounds found in crude oil. Paraffin molecules are very complex with relatively high molecular weight, and it mainly contains carbon and hydrogen atoms. They are usually found in between the hydrocarbon chain of $C_{18}H_{38}$ and $C_{78}H_{142}$ with highest melting point [1]. In the oil industry, paraffin deposits are frequently a trouble for assured flow of oil from production site toward processing facilities and refineries. Paraffin could be deposited anywhere along the production system, from near the wellbore region to production tubing, flow lines, pipeline, and processing facilities such as separators and leading to the reduced production and transportation rate, equipment damage, and production shut down [2]. Hence, several methods such as mechanical, thermal, and chemical have been used to remove and prevent the formation of paraffin deposits. However, no perfect solution has been found to overcome this initial problem yet.

Steel pipe and rigid polyvinyl chloride (PVC) have been used in several oil and gas fields, and it has lots of advantages and disadvantages which still need to be improved for this reason Ethylene–TetraFluoroEthylene (ETFE) can be a better solution to overcome this problem.

ETFE is fluorine-based plastic which melts at high temperature (250–280 °C), and it was synthesized in order to be highly resistant to corrosion, high temperatures, and water absorption as well as excellent weather durability and resistance to oxidation. Moreover, it is considered as material with exceptional electrical and chemical properties, which is also resistant to high energy radiation [3–5]. The application of internal coating can be an efficient solution for mitigating the precipitation and paraffin deposition as well as corrosion and pressure drop.

The use of ETFE plastic pipe coating for solving and preventing paraffin deposition is going to be novel mitigation study in EOR production state.

1.1 Mechanism of Paraffin Wax Crystallization, Precipitation, and Deposition

Paraffin is completely dissolved in crude oil in equilibrium condition [6]. Changes in temperature and pressure disturb this equilibrium, which might result in paraffin precipitation and crystallization. It is known that the solubility of the paraffin wax is very sensitive to temperature changes [7]. For instance, if the temperature of pipe's surface is below the Cloud Point (The Cloud Point is the temperature at which paraffin starts to crystallize in the solution [1, 8]) of the oil, high molecular weight paraffin waxes are deposited. When crude oil temperature is lowered below the Cloud Point, paraffin wax crystals precipitate and adhere by colliding with surface and deposits [6, 7, 10]. Besides, a mechanism such as shear dispersion, Brown diffusion, gravity, thermophoresis, and turbophoresis helps to drive the wax molecule particle to deposit on the pipeline wall [9, 11, 12].

There are three main factors that affect paraffin wax deposition in flow systems, which are flow rate, temperature deferential, and cooling rate, as well as surface properties [13].

2 Experimental Section

2.1 Characterization of Malaysian (Tapis) Crude Oil

Characterizations of crude oil were performed based on several ASTM methods. It should be carried out in order to determine the physiochemical properties of crude oil. The density of crude oil was determined by using DMA 35 N Standard Test Method, and the viscosity of crude oil was performed using an electromagnetic viscometer, EV 1000, by Vinci Technologies. Pour point measurement was carried out using ISL's CPP 5Gs Pour Point Analyzer, and the Carl Zeiss microscope equipped with Olympus BX51 camera was used to measure the WAT of crude oil. The Gas Chromatography Mass Spectrometer was used to determine carbon number distribution of crude oil. Surface roughness of the steel pipe, rigid PVC, and ETFE plastic coated pipe was measured by the Hommel T 1000®.

Experiments were carried out to characterize the crude oil sample studied in this paper. Rheological study results are reported in Table 1.

The result of compositionally characterized crude oil is shown in Fig. 1. The carbon number chain length of the n-alkane peaks is labeled in the chromatogram. The gas chromatogram indicates that the crude oil consists of mainly C14–C25 where the highest peak is at C14.

Table 1 Physical properties of the Tapis crude oil

Properties	Unit	ASTM method	Tapis crude oil
Density	g/m^3	DMA 35 N	0.82
Pour point	°C	D 97	18
Wax appearance temperature (cloud point)	°C	Cross polarized microscopy	27
Viscosity	cp	Electromagnetic viscometer	4.012
Carbon number distribution		GCMS	Refer Fig. 3

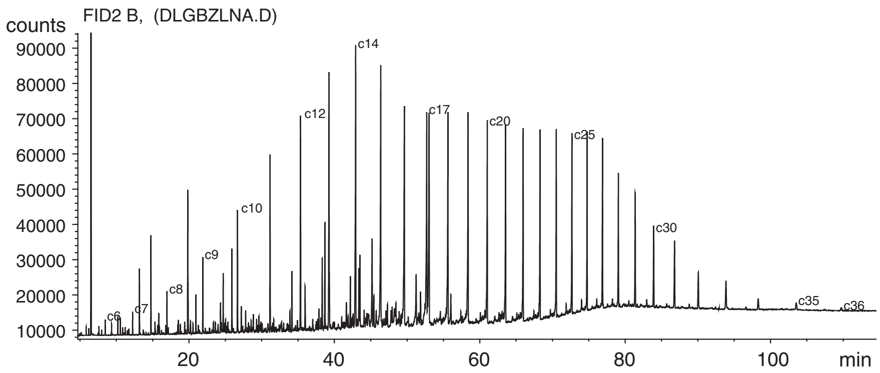

Fig. 1 Carbon number distribution of Tapis crude oil

2.2 Experimental Facility

The steel, rigid PVC plastic coated, and ETFE plastic coated pipes nominal diameter 2 in. and 12 m in length were used to determine the effect of velocity, temperature, and surface roughness on rates of deposition. The schematic diagram of the test device is shown in Fig. 2.

Paraffin deposition apparatus consisted of 4 major sections:

- Cooling section
- Heating section

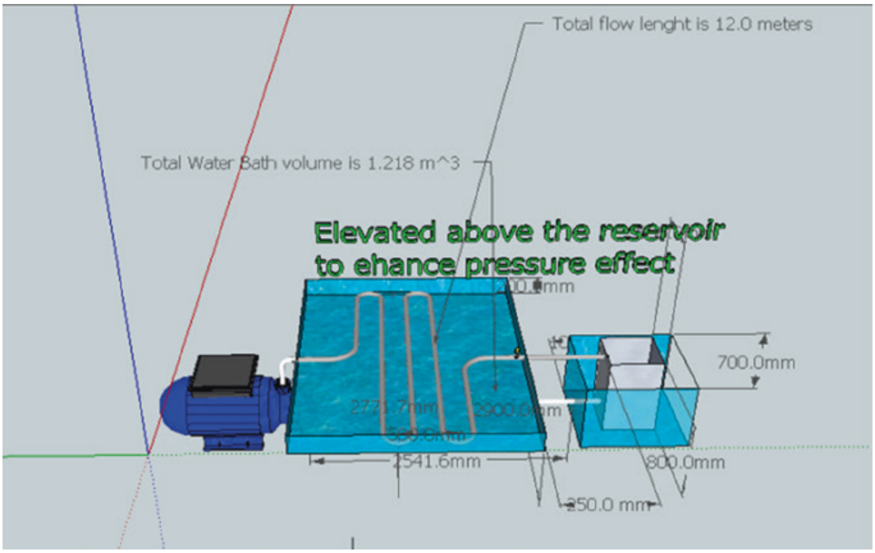

Fig. 2 Paraffin deposition apparatus

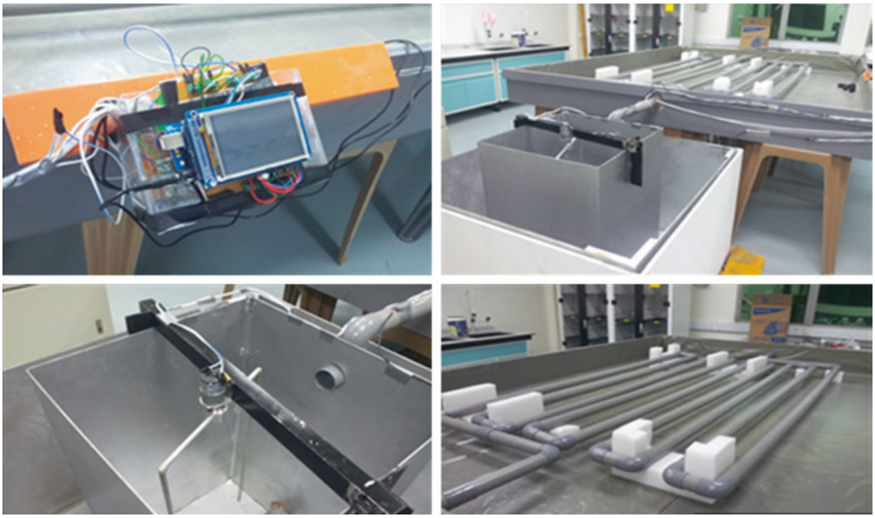

Fig. 3 Paraffin deposition apparatus

- Control and fluid flow section
- Stirring section

For the cooling section, a cold water bath of dimension 2.9 m × 2.1 m × 0.2 m was designed to house a piping system that stretched 12 m long. This cold water bath causes deposition and precipitation of the paraffin wax on the test pipes' surface when the temperature is below the cloud point of the crude oil.

For the heating system, there are two parts, namely the hot water bath and the oil reservoir. The hot water bath has a dimension of 1.0 m × 1.0 m × 0.7 m, and the reservoir on the other hand has a dimension of 0.5 m × 0.5 m × 0.8 m. As it can be seen from Fig. 3, the hot water bath was equipped with electro heater, and a thermo regulator is used to maintain the temperature of the oil. The oil reservoir is to be place in the hot water bath.

For the control and fluid flow section, the first design element is the valve in between the hydrocarbon pump and the heating system. This valve is to allow the crude to be properly heated above its cloud point before actually flowing into the cooling system via pump. As it can be seen from Fig. 3, the cold water bath is elevated to a level higher than that of the hydrocarbon pump and also the heating system. This is to allow pressure to stabilize and facilitate the flow of crude from the cooling system to the heating system.

For the stirring section, the stirring system is placed in the oil reservoir to mix up the crude oil in order to avoid early stage of precipitation of crude oil. As it can be seen from Fig. 3.

2.3 Experimental Procedure

Paraffin deposition apparatus was used in order to investigate the paraffin wax formation mechanisms. Detailed experimental procedures as well as parameters are shown below.

2.4 Effect of Lowering Temperature on Paraffin Deposition

Effect of lowering temperature on the rate of paraffin deposition has been studied by performing experiments with various temperatures. The lowering temperature shall be tested at three different points which are 25, 15, and 5 °C. The crude oil temperature has been kept constant at 55 °C, which is above its cloud point. Firstly, test pipes have been submerged in a cold water bath in order to reduce the crude oil temperature below its cloud point. The gear pump was used to circulate the oil through the system, and the flow rate was controlled by valves A. Typically, one cycle of the experiment takes 4 h, and after this, the test pipe must be removed in order to clean it from paraffin deposits. This operation can be carried out by pushing a rod scraper through the pipes several times. The scraped paraffin is mixed with normal pentane in the beaker into standard ASTM 100-ml centrifuge tubes. It was centrifuged at 1,500 rpm for 20 min. As a result, it is expected that the solid precipitation will take place and it is considered as paraffin deposition at the bottom of the beaker. Inside and outside of the test pipes were totally cleaned by wiping with kerosene—saturated rag then dried with a clean, waterless cloth for the next run.

2.5 Effect of Velocity on Paraffin Deposition

This section will follow the experimental procedure performed in the above section. However, this part is concerned on changing of velocity of the flowing fluid in the pipe which is crude oil in this case. The velocity shall be varied gradually, and the quantity of wax deposit will be determined for each variation. The change of velocity will be performed so that it can change the flow characteristic from laminar to turbulence. The crude oil temperature and all the surfaces properties shall be maintained at fixed value.

2.6 Effect of Surface Roughness on Paraffin Deposition

Similar experimental procedure will be performed as discussed in the previous section with no change on coolant temperature and crude oil velocity. The roughness parameters of steel, PVC, and ETFE pipes were measured, and effect of wax deposition on their surfaces will be determined.

3 Results and Discussions

Malaysian (Tapis) crude oil has been used in performing experiments to obtain the effect of velocity, temperature, and surface roughness on rate of paraffin deposition.

Experiments have been conducted to investigate the effect of temperature on paraffin deposition by lowering temperature between 25 and 5 °C while oil temperature was set to 55 °C, which is above its cloud point at the constant velocity. The study concluded that the paraffin deposit was indeed increased as the temperature decrease. The data obtained from these experiments are illustrated in Fig. 4.

It can be seen from the experiment above that when temperature decreases more heat will be dissipated from the deposit reducing the temperature of the crude oil. As a consequence, solubility of wax in the crude oil was reduced and thus forming a network of solid wax. The growth of these paraffin deposits increases simultaneously with increasing temperature difference between the temperature of the pipe surface and temperature of the crude oil.

The rate of paraffin deposition increased gradually with increase in velocity whereas the maximum rate was obtained when flow changed from laminar to turbulent flow. At higher velocities, the rate of deposition decreases rapidly. Results of flow test are illustrated in Fig. 5.

This investigation results show that the rate of paraffin deposition on steel pipe also was higher than rigid PVC and ETFE plastic pipe coated. It can be explained by the longer residence time of the oil in the tubing, which leads to more heat loss and decreases the temperature of the oil, which results in paraffin deposition.

The least amount of paraffin accumulation was found in the surface of the ETFE plastic pipe coated due to its smooth surface rather than rigid PVC plastic pipe coated and steel pipe. The result of this investigation is shown in Table 2.

ETFE plastic pipe coating is distinguished by its ability to improve the surface smoothness and reduce surface energy which leads to a reduction in the adhesive ability of paraffin—crystals on the material's surface with its excellent insulation properties and a low dielectric constant. These properties make ETFE plastic pipe coating an outstanding choice for using in oil production to solve and prevent paraffin deposition.

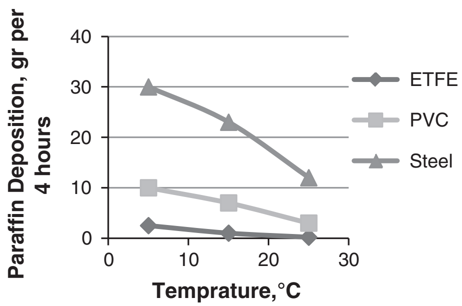

Fig. 4 The effect of temperature on rate of paraffin deposition

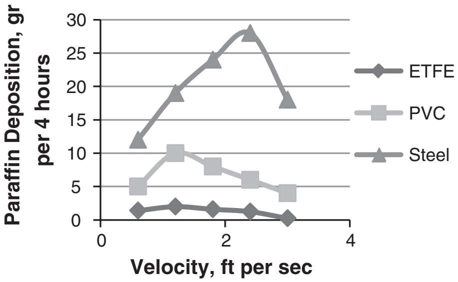

Fig. 5 The effect of velocity on rate of paraffin deposition

Table 2 The effect of surface roughness on paraffin deposition

Type of pipe	Surface roughness R_a (microns)	Paraffin deposition gram per 4 h
Steel	5.06	110
Rigid PVC	2.01	62
ETFE	0.10	15

4 Conclusions

The all experiment results show that the rate of paraffin deposition at all temperatures, velocity, and on the surface of the pipe was greatest in steel pipe but significant paraffin accumulation was found in rigid PVC plastic coated pipe. The lowest amount of paraffin deposition was observed in the ETFE plastic coated pipe.

It has been proven that the usage of ETFE plastic pipe coatings in a typical crude oil can potentially reduce down the paraffin deposition inside the pipelines, hence improving the whole system thoroughly.

The use of ETFE plastic pipe coating for solving and preventing paraffin deposition has proved to be an economically and technically feasible method.

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