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# EXPERIMENTAL EVALUATION OF FLOW START-UP OF A MODEL WAXY OIL IN A PIPELINE

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## Abstract
The rise in offshore production led to an increase in waxy oil extraction. During oil transportation from the reservoirs to the seashore, the oil losses heat to the ocean floor due to the temperature difference. In this situation, the increase of the solubility and precipitation of paraffin crystals occurs, which may lead to oil gelation during any shutdowns. The gelled oil exhibits several non-Newtonian fluid characteristics, such as elasticity, viscoplasticity, time dependence, thermal and shear dependence. Understanding the influence of these variables on the restart pressure is a difficult task due to the oil complexity. Therefore, the objective of this paper is to investigate how thermal dependence affects the pressures and restart time. To do so, flow start-up tests under different temperature and operation conditions were performed. The fluid used was a model waxy oil (5% wt.), which was studied on a laboratory-scale flow loop (long helical pipe) with thermal control. The results showed that the pressures and the restart times were influenced by temperature, cooling rate and pressurization during cooling. Furthermore, it was verified that the model waxy oil was gradually pressurized during the transient regime of start-up flow due to the formation of voids in the pipeline.

## Keywords
Flow loop; flow start-up; model waxy oil.

## Introduction
Exploitation of highly waxy crude oil in offshore conditions are challenging and it has a high cost. The transportation of these waxy crude oils is one of the main flow assurance problems due to its composition with high molecular weight paraffins such as n-paraffin of straight chain and iso-paraffin of branched-chain [1].
When the oil is in the reservoir, the wax molecules are soluble as a consequence of the high temperature and pressure. However, during transportation the temperature of oil may decrease below the wax appearance temperature (WAT) due to the heat loss to the seabed. In this condition, the wax starts to precitate and deposit along the pipeline. If the transportation is stopped for any cause (planned maintenance or an emergency situation) for a period of time, the oil may turn in to a gelled state. This gelled oil cannot flow with the normal operating pressure [2].
Waxy crude oils has several non-Newtonian characteristics, such as viscoplasticity, elasticity, time dependence and dependence of thermal and shear histories [3]. These characteristics added to different thermal operating conditions influence the complexity of the behavior of the material during the flow restart.
Therefore, this paper studies the influence of the thermal effect over the fluid start-up behavior. In order to achieve the objective, a laboratory-scale flow loop (long helical pipeline) placed inside a thermal insulated chamber was used to conduct the flow restart of a model waxy oil.

## Methodology
The tests were performed with a model waxy oil. The formulated fluid was tested in a laboratory-scale flow loop that is composed of two syringe pumps, a long helical pipe, a fluid reservoir, four pneumatic valves and four pressure transducers. All the components are placed inside a temperature-controlled chamber.

### Working fluid
A model waxy oil was used to perform the experiments since it behaves similarly to waxy crude oils below the crystallization temperature [4]. The oil was formulated by adding 5 wt% of a wax paraffin (Sigma Aldrich) in 11 L of mineral oil (Sigma Aldrich). To dissolve the paraffin, it was necessary to keep the mineral oil stirred and heated to approximately 80 °C throughout the preparation.

### Experimental Setup
The main components of the flow loop are the reservoir and the two syringe pumps that are connected to a helical pipeline of 50 m. Figure 1 shows a schematic diagram of the experimental apparatus, where four pressure transducers (P1 to

P4) and ten uniformly distributed thermocouples (T) are distribuited along the pipeline. The flow loop was placed inside a thermally insulated chamber to control the temperature during the tests.

To improve the fluid temperature control, an external tank was installed in the reservoir to maintain the temperature of the fluid at the initial temperature of the test. It was also installed a thermal bath connected to the pumps to maintain the temperature of the fluid at the same temperature of the test.

The flow loop (Fig. (1)) was operated with two syringe pumps that provide constant flow rate. The working fluid were pumped through the helical pipeline, and returned to the reservoir. In these experiments the bypass line wasn't used, so valve V5 was permanently closed. The flow direction along the circuit is represented by the arrows in Fig. (1).

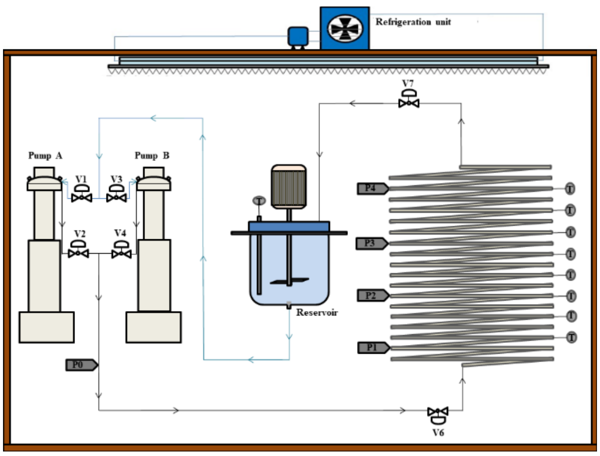


Figure 1. Schematic diagram of the laboratory-scale flow loop.

**Start-up flow experimental procedure**

Before any experiment, it was necessary to conduct pre-test to maintain the same initial condition of the tests. The pre-test consists in heating the entire flow loop to 40°C, and then the fluid was pumped for 30 min at the maximum flow rate of 193.2 ml/min. Following, the flow loop was cooled to the final test temperature, which was 15°C, with a cooling rate of approximately 0.8 °C/min. Independently of the cooling process, the fluid inside both the reservoir and the pumps were maintained in the desired test temperature - a different temperature of the final test temperature.

After the pre-test, a constant flow rate is set in the pump controller. Then, the pressure evolution profile was recorded until it reached the equilibrium condition. The selected flow rate was 64.4L. It is highlighted that for a Newtonian fluid, these flow rates values correspond to shear rates of 10 $s^{-1}$.

The objective of start-up test was to assess the influence of the thermal effect over the material behavior and the overshoot pressure. So, the main focus of this experiment was on the transient region of pressure evolution.

**Results and Discussion**

This section presents a preliminary result of the flow start-up with different final test temperature to evaluate the pressure evolution for the two material conditions: a waxy soluble phase condition and a gelled state.

The start-up flow tests for the model waxy oil at the final test temperature of 15ºC is shown in Fig. (2). It is observed at the pump start-up time (at 10s in the graph), the pressure at the first transducer (P1) starts to increase, after 5 s it is followed by the pressure at P2, after more 3 s by pressure at P3 and then after more 3 s by pressure at P4. There is a 12 s delay until all transducers reached overshoot pressure in approximately 22 s. In this test, there is an interesting behavior in the transient regime, indicated by the appearance of pressure oscillations, which is a consequence of the voids formed during the gelation in the cooling process. Pressure oscillations appeared as the gelled material was pressurized and filled the voids formed in the helical pipeline before the flow restart occurred.

It is important to highlight that these pressure oscillations in the transient regime was not seen in the start-up test for less complex fluids such as Newtonian (glycerin), viscoplastic (carbopol) and thixotropic (laponite solution).

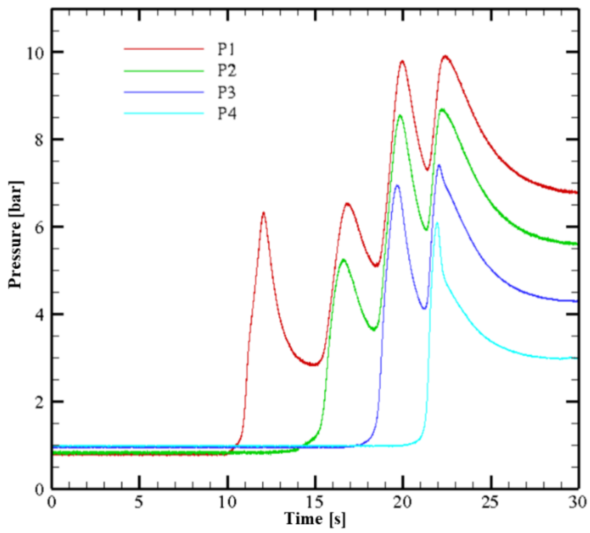


Figure 2. Flow restart of the gelled model waxy oil at a flow rate of 64.4 ml/min with 10 s of rest time and at a temperature of 15 ºC.

Considering the model waxy oil is thermal history dependent, the influence of the temperature in the flow restart was evaluated by carrying out a test with two different final test temperatures: 40 and 25 ºC. The results for these temperatures are shown in Fig. 3a and b, respectively. In Fig. 3a the fluid has a homogenous liquid phase and the restart curve is similar to a viscoplastic fluid, while in Fig. 3b, the material has already started the gelation process, and the test has a overshoot pressure indicating the thixotropic characteristic of the material due to the start of the parrafin precipitation. The Wax Appearance Temperature (WAT) of the model waxy oil is 27.11 ºC, and it was determined by the differential scanning calorimetry test, therefore, at the temperature of 25 ºC in which the test was performed, it is expected that the material has precipitated paraffin in the material, which justifies the thixotropic behavior.

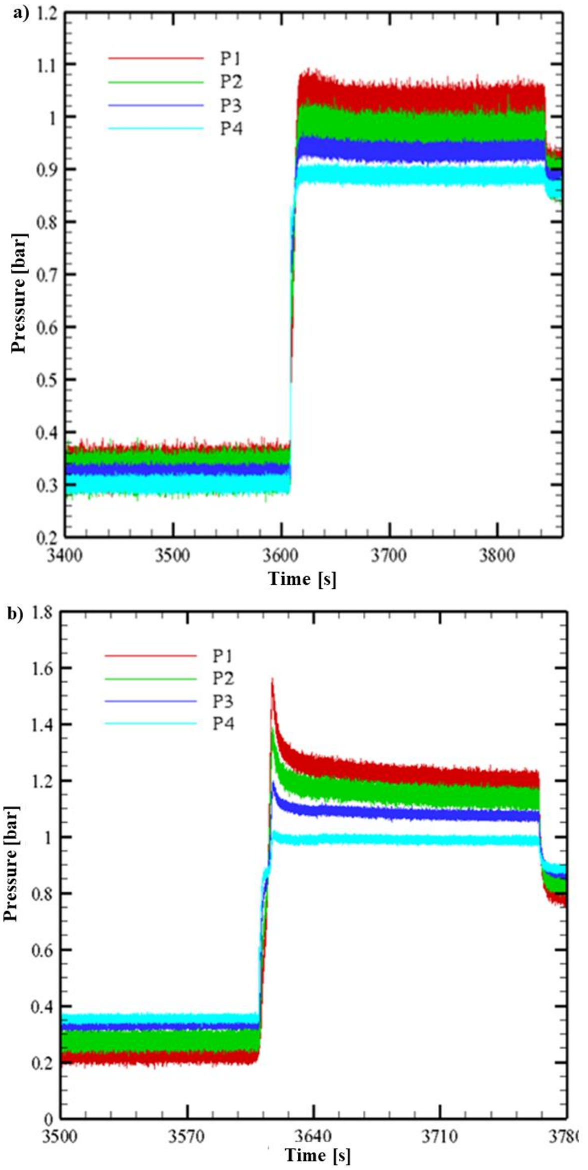

Figure 3. Flow restart of the model waxy oil with flow rate of 64.4 ml/min and a temperature of: a) 40 °C and b) 25 °C.

## Conclusions

Waxy crude oil exhibits a variety of uncommon characteristics during flow due to its complex rheological behavior. In the flow restart process, the characterization of these properties is even more problematic due to the coexistence of such characteristics with different operational conditions. To understand the thermal effect on the behavior of waxy oils, this paper used an experimental apparatus to study the start-up flow of a model waxy oil (5% wt).

The preliminary results of the start-up tests showed that the waxy oil has different restart behavior under different final test temperatures. At the temperature of 15 ºC, the gelled oil was gradually pressurized during the transient regime of start-up flow due to the formation of voids in the pipeline.


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## Responsibility Notice

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