START-UP OF WAXY CRUDE OILS IN SUBSEA PIPELINES

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Abstract. *One of the main problems in the operation of subsea pipelines that convey paraffin oils is the startup flow after long stoppages. Along the path from the reservoir to the platform, the oil experiences significant heat losses, especially to the low-temperature water at the bottom sea. When there is no flow, the oil may reach very low temperatures. The cooling induces wax precipitation and hence gelification of the oil, which may cause blockage of the pipeline. Under these circumstances, pressures much higher than the usual ones may be needed the restart flow. The knowledge of the minimum pressure level that causes flow after prolonged stoppages is an important piece of information. In this work we analyzed the flow startup using a viscoplastic fluid, waxy crude oil.*

Keywords: *start-up, Waxy crude oil, Rheology*

1. INTRODUCTION

Under the hot reservoir conditions, waxy crudes behave like Newtonian fluids but once they experience very low temperatures in deep seawaters, the heavy paraffin begins to precipitate from the solution imparting non-Newtonian flow behavior to the crude, and often depositing on the pipe wall. If the transportation in a pipeline is shut down due to a planned maintenance or an emergency situation, the temperature and solubility of wax further decrease and wax molecules precipitate out of liquid phase in a static condition. If the crude oil in the pipelines is trapped for a certain period of time below the pour point temperature, it becomes a wax oil gel because of the interlocking of solid wax crystals. This gel cannot be broken with the original steady state flow operating pressure applied before gelation.

Predicting the restart of waxy crude oil flows in pipelines is a difficult issue because of the complex rheological behavior of the gelled oil. Indeed, below the wax appearance temperature (WAT), the gelled oil exhibits viscoplastic, thixotropic, temperature-dependent, and compressible properties due to the interlocking gel-like structure formed by the crystallized paraffin compounds and the thermal shrinkage of the oil.

The main objective of this work is to understand the influence of the governing parameters on the minimal pressure required to restart the flow, in the other words, determine the relationship between the rheology of the fluid, the geometry of the pipe and the pressure required for the resumption of the flow. This knowledge allows the reduction of production costs, risks of blockages of the line and enables the development of an improved design of pipelines and pumps.

Smith and Ramsden studied the importance of simulating the full scale treatment in the laboratory testing and emphasised to experience in full scale start-up trials. They described how the likelihood of gelling is assessed and calculated the pressure needed to start-up the flow in a gelled line. They concluded that procedures for predicting oil gelation, cooling rates and pipeline start up have now been tested enough by full scale application to give confidence in their use.

Hans Petter Ronningsen and Brit Bjorndal made a series of experimental work about the wax precipitation in North Sea crude oils. This series led a better thermodynamic model to predict the wax formation. In the first work of the series, three different methods for determination of wax precipitation temperature (WPT) were discussed and the results are compared: polarization microscopy, differential scanning calorimetry (DSC) and viscometry. WPTs determined by microscopy were in general about 10^o C higher than DSC and viscometry values, except for most waxy oils. WPTs from microscopy probably are the most relevant for predicting initial onset of wax deposition in equipment production equipment, flow lines etc. Transition from Newtonian to non-Newtonian rheological behavior generally occurred a few degrees below the DSC and viscometric WPTs.

Many other researchers studied about this subject. The literature is quite large when it comes of restart flow. But still has many things on this subject that needs to be studied, because the findings are not conclusive.

2. EXPERIMENTAL ANALYSIS

The purpose of this study is to determine the relationship between the rheology of the fluid, the geometry of the pipe and the pressure required for the restart-up the flow. The Figure 1 illustrates the experimental apparatus and the Figure 2 shows the coil schematic.

Figure 1. Experimental apparatus.

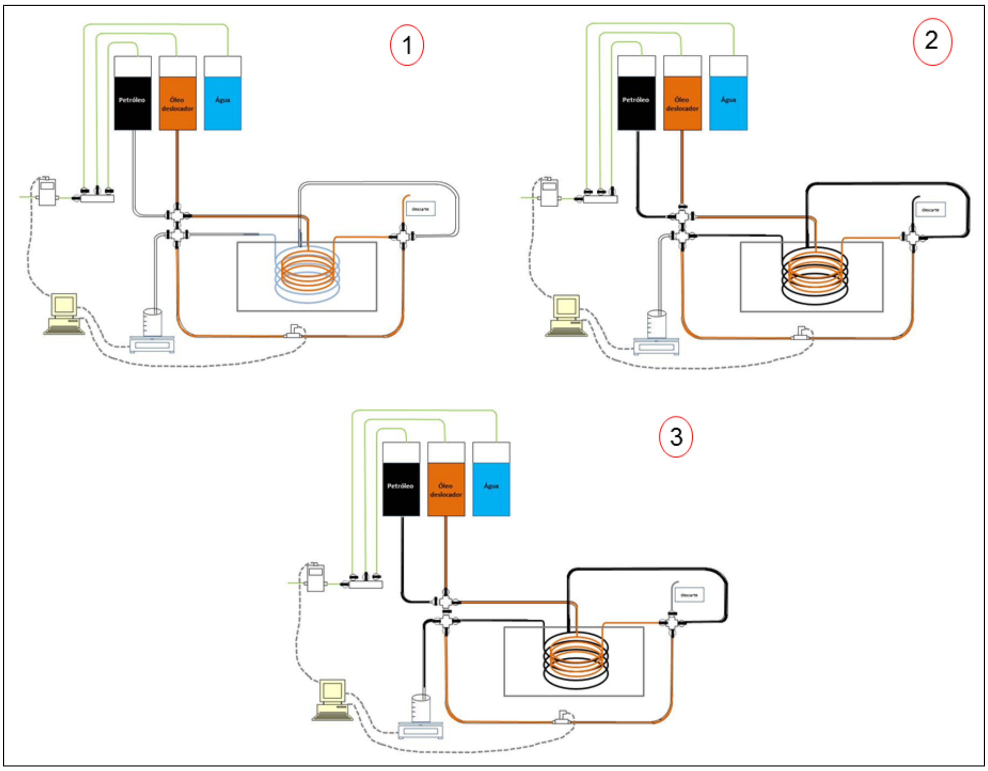

Figure 2. Coil schematic.

In the testing bench there are one ITV valve, four resevoir (water, wax crude oil, mineral oil and discard), two serpentines (coiled heat exchanger), one refrigerated circulated, one precision balance, one three-way ball valve and one computer (Easy Sensor software and LabView).

Calibrations were performed in the refrigerated circulator in order to control the cooling rate and heating rate for it can be reproduced in the rheometers (Figure 3). The calibration curve was approximated by four straight because the rheometer only works with linear systems, and the refrigerated circulated doesn't have options to control the cooling rate (this is a fixed parameter on the apparatus).

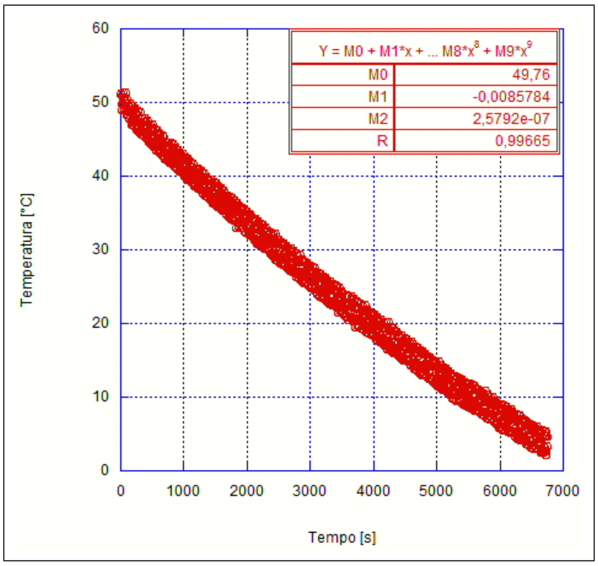

Figure 3. Refrigerated circulator calibration.

The tests will be performed with a Newtonian fluid displacing the wax crude oil. The pretreatment used for the rheological characterization will be reproduced. Firstly, the oil will be heated to 50^oC to dissolve the crystals and then will be performed a cooling at a constant rate to 4^oC.

After the controlled formation of wax cristais and consequently the fluid gelification will be applied a pressure step for check if there is the restart or not of the flow. The next step is to perform tests to validate the testing bench by Hagen-Poiseuille equation. After the validation, tests will be performed with the same oil in both testing bench and in rheometers to verify the repeatability of the minimum pressure calculus required to initiate the flow (yield stress).

3. PRELIMINARY RESULTS

3.1 VALIDATION EXPERIMENTS

The validation test consists in displacing of mineral oil and oil Morlina for the serpentine through obtaining data of mass and pressure drop along the duct. Thus, the validation was performed by comparing the radius calculated using the two Newtonian fluids in the equation of Hagen Poiseuille1. The proprietary of oils were obtained in Cannon Feske viscometer.

$$\Delta P = \frac{8\mu LQ}{\pi R^4} \tag{1}$$

Where:

- ΔP is pressure difference;
- L is tube length;
- μ is viscosity;
- Q is volumetric flow rate;
- R is radius.

Serpentine 1 (250 mm)				
soya oil		Morlina oil		
Viscosity [Pa.s]	0,05635	Viscosity [Pa.s]	0,022113	
length [m]	9,42	length [m]	9,42	Mistake
radius [m]	1,939E-03	radius [m]	1,977E-03	1,91%
Density [kg/m³]	916,3	Density [kg/m³]	889,8	
Serpentine 2 (230 mm)				
soya oil		Morlina oil		
Viscosity [Pa.s]	0,05635	Viscosity [Pa.s]	0,022113	
length [m]	7,95	length [m]	7,95	Mistake
radius [m]	1,926E-03	radius [m]	1,959E-03	1,69%
Density [kg/m³]	916,3	Density [kg/m³]	889,8	

Figure 4. Validation of the experimental bench.

3.2 RHEOLOGICAL CHARACTERIZATION

Rheological tests were performed for the purpose of know basic characteristics of the petroleum used in the experiment. Were made temperature ramps varying the cooling conditions, such as Shear Rate during the cooling ($\dot{\gamma}_h$) and cooling rate ($\dot{T}_h$). Will be performed constant strain tests (creep), for the purpose of determine the yield stress for a given cooling history. As can be seen in figure 1.

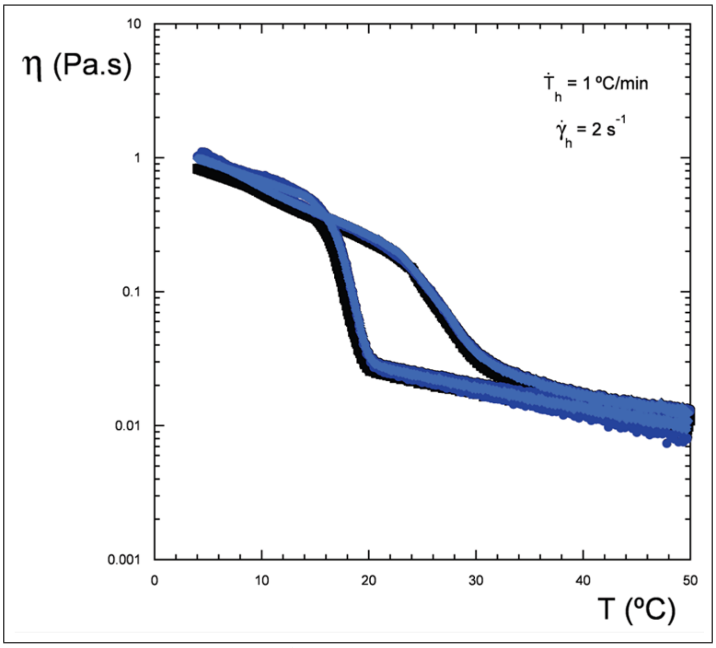

Figure 5. Temperature ramp.

4. ACKNOWLEDGEMENTS

The authors are indebted to Petrobras S.A., CNPq, CAPES, FAPERJ, FINEP, for the financial support to the Group of Rheology at PUC-Rio.

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