Heavy Oil Transportation as a Solid-Liquid Dispersion

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Abstract Traditionally, heavy oil pipelines are designed to handle liquids with effective viscosity below 0.5 Pa s at the pump outlet, in order to minimize the frictional pressure gradient and obtain a pipeline size and economically optimum pumping requirements. Asphaltenes and resins are the components of crude oil which have the highest molecular weights and are, also, the more polar ones. It has been determined that the characteristics of the asphaltenes play an important role in the high viscosity of heavy oils of the Orinoco Oil Belt. This chapter presents an experimental investigation of the behaviour of a potential transport method for heavy oils based on precipitation and conditioning of asphaltenes, followed by an ulterior reincorporation into the de-asphalted oil to obtain a solid-liquid dispersion (slurry) with a lower effective viscosity than the one of the original crude oil. The study comprises two steps: an analysis under static conditions to identify the rheological behaviour of the

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slurry for different solid contents, from 0 to 12 % (weight basis), and a fluid dynamic study to characterize the effectiveness of the solid–liquid dispersion method in a laminar flow regimen in a 1 inch horizontal pipeline, for mixture velocities between 0.2 and 2.3 m/s, corresponding to Reynolds Number values <1,400. A maximum effective viscosity of 0.15 Pa s @ 20 °C was measured 24 h after conducting the dynamic test, which implies a significant reduction compared to a typical viscosity range of 100–1,000 Pa s @20 °C for an original crude oil of similar API density and SARA composition. As expected, dispersion viscosity increases with time as asphaltenes are progressively reabsorbed into the de-asphalted oil as a colloidal suspension. The investigated transport method can be implemented together with a low pressure–low temperature de-asphalting process to improve transport properties of the heavy oils of Orinoco Oil Belt.

1 Introduction

Heavy oil production and transportation are particularly difficult processes due to the high viscosities of the heavy oil and the complexity of the multiphase flow involved. Most heavy oil transport methods are focused on reducing the liquid—wall shear stress. To achieve this, some methods as core annular flow and oil in water emulsions induce the water phase to be in contact with the wall, as water viscosity is several orders of magnitude lower than heavy oil viscosity. Other methods as, for example, partial or total upgrading and slurry transportation focus on reducing the viscosity of heavy oil itself, by removing or modifying the nature of the crude compounds, which are the main cause of the high viscosity.

Venezuela has 296,500 million barrels of heavy and extra heavy oil certified reserves, located in the Orinoco Oil Belt. It is expected that several of the new joint ventures established to exploit the heavy and extra heavy oil from the Orinoco Oil Belt include as a transportation method an integration of dilution and upgrading of the oil in order to convert extra heavy crude oil of approximately 8° API into synthetic crude of 42° API. This upgraded oil will be mixed with an original virgin heavy oil to obtain a final crude oil of 22° API to be transported to the Punta Araya terminal for export (Petróleos de Venezuela 2011; Brito and Trujillo 2011). The main strategy to be developed for the Orinoco Oil Belt is a combination of dilution and upgrading of the extra heavy oil. However, in order to make feasible all the developments, it is necessary to explore other alternatives for heavy oil transportation. This chapter presents a study of a potential transportation method based on transforming the heavy oil into a solid–liquid suspension with lower effective viscosity than the original crude oil. A simple alternative to the heavy oil transportation method was developed by Argillier et al. (2006). They presented a solid-liquid dispersion (slurry), where the asphaltenes are precipitated by n-alkanes as n-heptanes and reincorporated to the oil to obtain a slurry or suspension of non-colloidal particles with relatively low viscosity compared to the original extra heavy oil (Martínez-Palou et al. 2011).

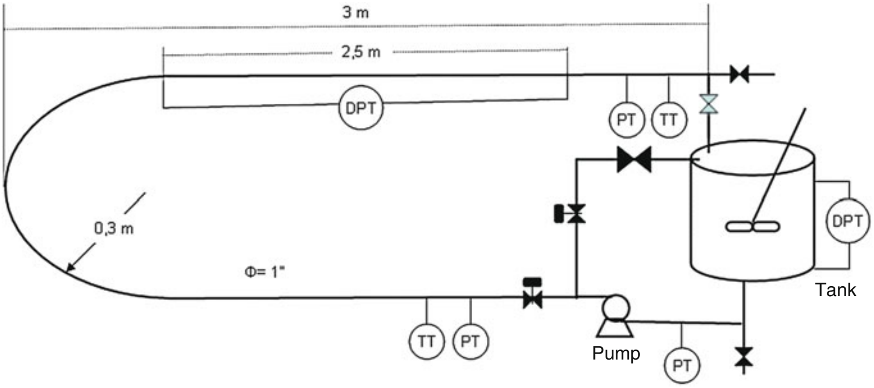


Fig. 1 Experimental test loop diagram

One of the main characteristics of heavy oil is its large content of asphaltenes that contribute to its high viscosity. For instance, Sanière et al. (2004) found that the slurry exhibits approximately 75 % less viscosity than the original crude oil. However, they observed the slurry during 146 days and observed that with time the suspension returns progressively to a colloidal stage. This transformation is quite slow and gives rise to a correlated increase of viscosity (at 20 °C) that can be accelerated at higher temperatures (40 °C). They also report that there is a critical concentration for asphaltenes (around 12 %): under this critical concentration the asphaltenes behave like colloidal particles dispersed in oil as a semi-dilute domain, while above this value the particles of asphaltenes are overlapped and the viscosity increases dramatically.

2 Experimental Test

Experiments were carried out in an Ø0.025 m test loop facility at PDVSA INTEVEP. Figure 1 show the experimental facility diagram, the total length of the loop is 6 m of carbon steel pipeline and is composed of two sections: the first one is a 3.5 m length section for flow development; the second one is the test section, which is 2.5 m long and equipped with transmitters for measurements of pressure, temperature, and differential pressure. Differential pressure transducers are used to measure the pressure drop between pressure taps. Downstream to the test section, the dispersion returns to the tank in which the slurry is continuously agitated. The slurry is pumped using a gear pump with a variable speed control to regulate the flow rate, the maximum dispersion flow rate is approximately 3.6 m^3/hr and it is measured by deviating the flow to a small tank with a level transmitter.

The slurry is prepared with de-asphalted oil (also known as maltenes) as the liquid phase and the asphaltic residue as the solid phase, with both phases being obtained from a proprietary de-asphalting process at relatively low pressure and temperature.

The solid phase, composed mainly of asphaltenes and resins, is prepared and sieved with a special procedure in which the particle size is kept up to 500 μm, then the solids are incorporated in the liquid under a mechanical stirring for 20 min. Dispersion properties are analyzed for each solid concentration and mixture velocities between 0.2–2.3 m/s at three stages, i.e., before starting the dynamic test (initial stage), just after running the dynamic test (middle stage), and 24 h after finalizing it. The dispersion morphology is analyzed using optical microscopy. The viscosity of the dispersion is assessed using a viscometre Anton Paar model MCR 301 according to the ASTM D 7,483 standard test method. Finally, the dispersion density is quantified using a densitometre Anton Paar DMA 4,500 according to the ASTM D 4,052 standard test method.

3 Experimental Results

Figures 2 and 3 show that the precipitated asphaltenes become progressively colloidal with time due to the viscosity and opacity of the samples, increasing both with time and solid concentration in agreement with the findings of Sanière et al. (2004). This evolution is probably due to the fact that the thermodynamic equilibrium state promotes the colloidal state rather than the precipitated one.

Similarly to the results obtained by Sanière et al. (2004), the slurry sample remains Newtonian and does not exhibit yield strength, which is quite unusual for slurry products. During the dynamic tests, it was observed that the viscosity and density of the fluid increase with the solid concentration, as expected, and decrease as the flow rate is increased, as is shown in Figs. 4 and 5. This last phenomenon is believed to be due to the significant viscous dissipation of energy inside the pump and pipes, which promotes an increase of the temperature.

As mentioned above, the temperature rises in the system because of the increasing viscous dissipation accompanying the higher flow rates. For a given concentration, the higher viscosities correspond to the lower flow rates and accordingly, the lower viscosities correspond to the higher flow rates (Fig. 5). As expected, the pressure drop in the pipeline increases with mixture velocity and solid concentration in the slurry (see Fig. 6).

The dispersion viscosity was measured at 20 and 26 °C. When comparing the results obtained during the initial, middle, and final stages, small differences in the viscosity are found for the solid concentrations, which are below 12 %. However, for a 12 % solid concentration, the viscosity differences with time are clearly noticeable. This could be explained by a re-dissolution of asphaltenes into the maltenes, thus returning to their colloidal state. The 12 % threshold seems to coincide with the findings of Sanière et al. (2004) for the critical asphaltene concentration in the Orinoco Belt heavy oils.

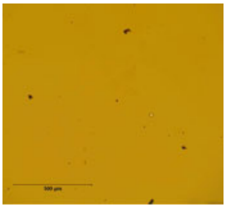
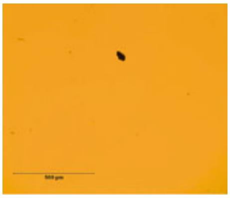
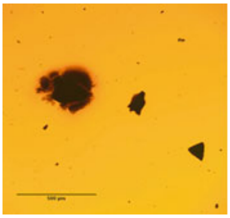
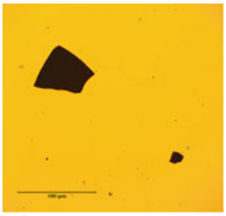
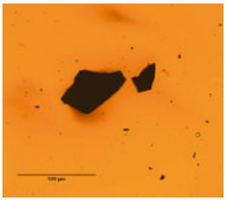
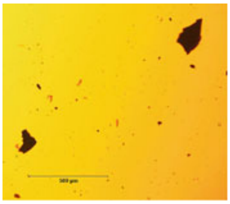
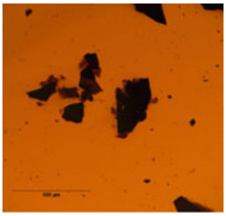
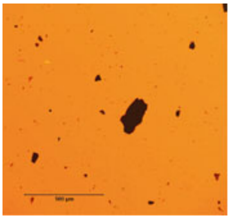
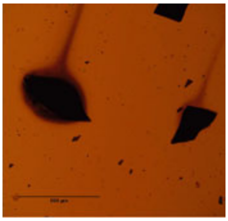
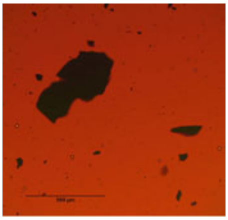
Concentration (% w/w)	Initial	Final
1		
3		
6		
8		
12		

Fig. 2 Evolution with time of the morphology of the slurry sample

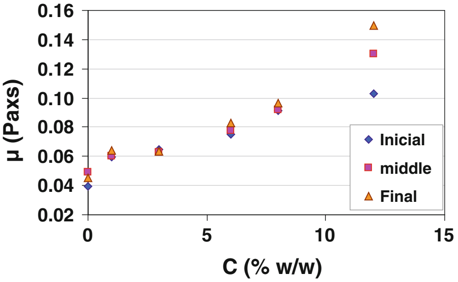


Fig. 3 Viscosity of the slurry as a function of the solid concentration at 20 °C

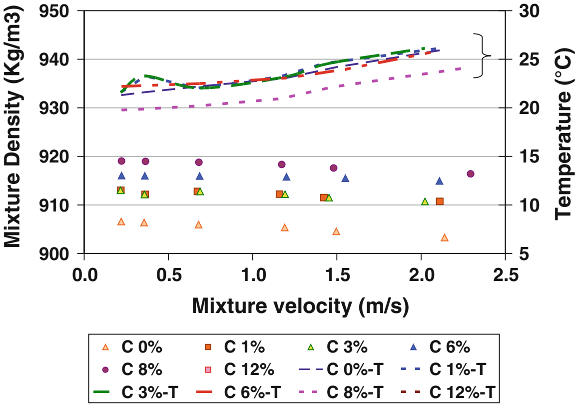


Fig. 4 Density of the slurry and temperature of the system as a function of the mixture velocity

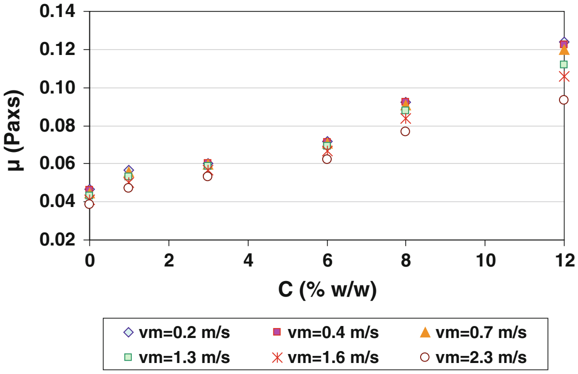


Fig. 5 Slurry viscosity as a function of the solid concentration in the slurry for different mixture velocities

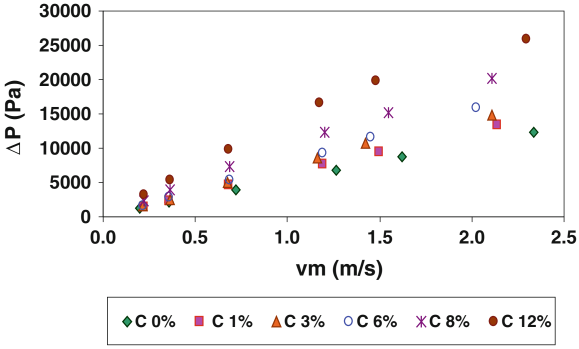


Fig. 6 Pressure drop in the horizontal pipeline as a function of the mixture velocity and solid concentration in the slurry

4 Conclusions

- The morphology and viscosity of the slurry are time-dependent. The solid asphaltenes obtained from a proprietary de-asphalting process are reincorporated as a solid into the maltenes and tend to return to a colloidal state, increasing the viscosity of the slurry with time.
- The viscosity of the slurry is at least three orders of magnitude lower than the typical viscosity of the heavy oil of the Orinoco Oil Belt.
- This transportation method could be implemented downstream of a de-asphalting process, in order to obtain the components needed to prepare the dispersion.
- Additional residue processing is necessary depending on the de-asphalting method used for obtaining the residue as a solid phase, which must be easy to handle and sieve in order to be reincorporated into the de-asphalted oil to prepare the dispersion.
- This transportation method could be used not only for the transport of heavy oils. It could be applied to transport other solid residues of hydrocarbon processes as is the case of coke, either in water or in synthetic oil.

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