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Study of the effect of temperature and gas condensate addition on the viscosity of heavy oils

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ABSTRACT

Heavy and extra heavy oils have been the focus of attention since the conventional oil reserves are becoming more scarce in the world. To explore and process these oils is a challenging task because of their high viscosity and high density, which can lead to many problems during their flow and processing. In this study, the effect of temperature and gas condensate addition over the dynamic viscosity of four Brazilian heavy oils was analyzed with API density varying from 13.7 to 21.6. In addition, the effect of gas condensate addition over the densities of these samples was studied. The elevation of temperature around 20 °C led to levels from 70 to 77% of oil dynamic viscosity reduction. Condensate addition significantly reduced oil viscosities by as much as 98% (in comparison to the crude oil viscosities) in the concentration of 32% (v/v) of condensate. At a condensate concentration of 14% (v/v) the percent viscosity reduction was about 90% for the studied oils, meaning that condensate addition over this value may be unnecessary to reach the desirable objective of reducing the oil viscosity. Additionally, models that represent the influence of temperature and condensate addition over the studied oils were built.

1. Introduction

With the increase in world demand for energy and the decrease in the conventional oil reserves, oils classified as heavy oils represent important hydrocarbon resources for the future (Abdurahman et al., 2012; Shokrlu and Babadagli, 2014; Barrufet and Setiadarma, 2003; Ashrafizadeh et al., 2012). According to estimates from the International Energy Agency (IEA), heavy oils represent at least half of the world's recoverable oil resources (Martínez-Palou et al., 2011; Kelesoglu et al., 2012; Ghannam et al., 2012). According to the world heavy oil conference, the heavy oils are those whose API gravity is below 22.3 (Trevisan et al., 2006).

Oil transportation is a complex and highly technical operation, and one of the major difficulties in pipeline transportation is the high viscous fluids that require efficient and economical ways to transport the heavy oil (Ashrafizadeh et al., 2012; Kelesoglu et al., 2012; Hasan et al., 2010; Meriem-Benziane et al., 2012). So, the production from these reservoirs is challenging and reducing the in-situ viscosity of the oil is considered the main objective of this process (Shokrlu and Babadagli, 2014; Barrufet and Setiadarma, 2003; Gonçalves et al., 2011).

Heavy oils are more viscous than conventional petroleum and have a low mobility in the reservoir but can be recovered through a well from the reservoir by the application of enhanced methods for recovery (Kelesoglu et al., 2012; Speight, 2002; Zhao et al., 2013). Different methods are employed in order to reduce the viscosity of heavy oils and to allow their transportation through the production chain. Some of the more common methods applied for this purpose are: heating, dilution and the use of surfactants to stabilize emulsions. Blending of heavy oils with lighter oils, hydrocarbons gases or alcohols is also another alternative to reduce the viscosity of heavy oils (Ashrafizadeh et al., 2012; Martínez-Palou et al., 2011; Hasan et al., 2010; Gao and Li, 2012).

Dilution is one of the methods widely used for reduction of oil viscosity, and it consists in the addition to the heavy oil of lighter liquid hydrocarbons, typically condensates from natural gas production (Martínez-Palou et al., 2011). The dilution method is especially applicable if cheap and large amounts of lighter hydrocarbon are available. Dependent on the site of an oil field, gas condensate recovered from a petroleum gas could be employed for

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the dilution of a heavy crude oil (Shigemoto et al., 2006). Gas condensate is composed mostly of pentane, hexane and heptane. It is also called natural gasoline and it is used for blending with refinery gasoline (Speight, 2002). If considering that the gas condensate is abundantly produced on its own producer field, its use to reduce the heavy oils viscosity becomes a viable and low operational cost practice. The heavy oils have the characteristic of having greater asphaltenes content than the medium or light oils. So, it is important to highlight that the addition of light paraffins, such as condensate, to these oils could lead to asphaltenes precipitation, what may cause problems during the oil production (Shigemoto et al., 2006; Speight, 2004).

Determination of heavy oil mixtures viscosity is very important in the petroleum industry to evaluate fluid flow either in the reservoir or for pipeline transportation (Barrufet and Setiadarma, 2003; Kelesoglu et al., 2012; Werner et al., 1998). And to know the effect of the solvent over the oil viscosity is important to decide how much solvent should be added to it (Gao and Li, 2012). In this sense, the present work consists on evaluating the effect of temperature and gas condensate addition over the dynamic viscosity of heavy oils. The effect of condensate addition over the asphaltenes precipitation has not been studied in the present work but it is something that the industry needs to keep in mind when blending this solvent with a heavy oil.

2. Material and methods

2.1. Treatment of crude oils and condensate sample

In this study, four heavy crude oil samples (A, B, C and D) were selected from production fields located in the sedimentary basin of the Brazilian coast. The main characteristics of the oils and of the gas condensate sample are shown in Table 1. The samples were transferred for testing according to the ASTM D5854 procedure (ASTM Standard D 5854, 2005). This standard method covers the handling, mixing and conditioning procedures that are required to ensure that a representative sample of the liquid petroleum or petroleum product is delivered from the primary sample container/receiver into the analytical test apparatus. During the oil treatment process, the free water (non-emulsified water) was first separated from the crude, and the water content analysis (ASTM D4377, 2011) was determined in the water-in-oil emulsions according to ASTM D4377 using a Metrohm KF titrator (model 836 Titrando) equipped with a double-platinum electrode. Those oils which presented water content in excess of 2% (v/v) were dehydrated by the use of 200 μL of a concentrated commercial demulsifier (composed of surfactants containing isoprene and glycol propylene oligomer species) at 60 °C and centrifuged at 1600 rpm for 15 min (Barbosa et al., 2013; Perini et al., 2011). After the demulsification, the water content was determined again to verify if it was below 0.5% (v/v) for all oils. These oils were called "dehydrated oil". The characterization properties were then determined (Table 1) for the dehydrated crude oils, according to each standard ASTM method.

2.2. Experimental techniques applied for crude oils and condensate characterization

The physicochemical properties of the oils and condensate are given in Table 1. Density was determined in compliance with ISO 12185 (International Organization for Standardization, 1996) by injecting the sample into the digital automatic analyzer Stabinger SVM 3000 (Anton Paar). API density was also reported in compliance with ASTM D1250 (2008). Total acid number measurements followed the ASTM D664 (2011) by potentiometric titration (Metrohm 836 automatic titrator) of the sample with an alcoholic solution of potassium hydroxide. Total sulfur content was determined according to ASTM D4294 (2008) by energy-dispersive X-ray fluorescence spectrometry using the automatic analyzer HORIBA, model SFLA-2800. Elemental analysis for the oil samples was obtained on a LECO CHN-1000 analyzer. SARA content of each oil was obtained by chromatographic analysis following the ASTM D2549 (2012). The chromatographic profile of the gas condensate (Table 2) was obtained by chromatography with a GC–MS 5050 Shimadzu.

2.3. Dynamic viscosity

Dynamic viscosity tests were conducted by using a rotational rheometer by Anton Paar (model RheolabQC), with a coaxial cylindrical measurement system. The chosen temperature for the tests was 50 °C, by estimating a medium temperature for the oil processing along the production chain. This test consists on transferring the oil to a measuring cup until it reaches a predefined mark designed inside the cup, then this cup containing the sample is inserted to a temperature jacket that is fixed to a measuring head with a cylindrical spindle connected. The spindle rotates inside the measuring cup with the oil and the rheological information is monitored by the measuring head. A total of 100

Table 1
Physicochemical properties of the dehydrated oils and condensate used in this study.

Properties	A	B	C	D	Gas condensate
Water content (% v/v)	0.050 (0.002)	0.050 (0.001)	0.050 (0.002)	0.301 (0.003)	0.050 (0.002)
Density at 20 °C (g cm^{-3})	0.920 (0.002) (21.6° API)	0.938 (0.003) (18.7° API)	0.951 (0.002) (16.8° API)	0.970 (0.003) (13.7° API)	0.6734 (0.005)
Total acid number (mg of $KOHg^{-1}$)	0.840 (0.008)	1.871 (0.010)	3.350 (0.020)	0.800 (0.030)	< 0.010
Dynamic viscosity at 50 °C (Pa s)	0.0820 (0.0023)	0.1055 (0.0030)	0.3195 (0.0040)	2.7319 (0.0080)	0.0010 (0.0005)
SARA content (wt%)					
Saturates	57.20 (0.06)	49.00 (0.03)	45.02 (0.05)	36.02 (0.03)	88.7 (0.04)
Aromatics	26.90 (0.02)	31.10 (0.05)	31.02 (0.04)	25.04 (0.03)	11.1 (0.02)
Resins	12.86 (0.02)	19.03 (0.01)	22.02 (0.03)	32.01 (0.01)	0.10 (0.010)
Asphaltenes	3.14 (0.02)	0.98 (0.01)	2.10 (0.02)	7.10 (0.03)	< 0.05
Element analysis (wt%)					
C	86.0 (0.4)	85.8 (0.3)	86.7 (0.2)	87.0 (0.3)	87.9 (0.4)
H	13.6 (0.1)	13.5 (0.1)	12.5 (0.3)	12.5 (0.2)	12.1 (0.4)
N	0.17 (0.02)	0.25 (0.04)	0.27 (0.04)	0.24 (0.02)	< 0.0001
S	0.3200 (0.0020)	0.5103 (0.0010)	0.6012 (0.0040)	0.3566 (0.0020)	0.0016 (0.0003)