Rheology of Brazilian Crude Oils: Viscous Testing and Shear Effects
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Introduction
Rheology, the study of the flow of matter, is an important area of experimentation for substances such as petroleum that possess both solid and fluid characteristics. Furthermore, these substances are comprised of complex molecular structures whose flow cannot be defined by a set value of viscosity. Rather, the viscosity will vary with different factors such as temperature, shear rate, and even time.1

Recently discovered oil reserves in Brazil have great economic and commercial potential, but the heavy and extra-heavy oils they contain have challenged the oil industry in terms of production methods. This production is directly tied to the rheological behavior of the petroleum. Thus, Brazilian heavy oils were studied to observe the effects of temperature and other treatments on viscosity and shear moduli.

Experimental Methods
Initially, heavy oils from two oil fields (OF1 and OF2) were untreated and tested at different temperatures to observe its effect on the relationship between shear rate and shear stress.

Approximately 1 mL of oil was used as a sample. Samples were placed in a rheometer between two disks 35 mm in diameter and 1 mm apart. Sample temperature was controlled by a water bath was initially set at 25°C. A ceramic cover was placed over the disks to prevent evaporation. When the test was run, the upper disk, free to rotate, increased the shear rate from 0 to 100 s⁻¹ over 300 seconds. Variables (beside temperature) were all monitored by the rheometer itself and relayed to a computer, which recorded measurements every second.

Temperature was then increased in increments of 10°C up to a final temperature of 85°C, testing at each increment. It was then lowered again by the same increment, and the tests were run in descending order. The same sample was used the entire time to keep mass constant. Once all tests were run on OF1, the same procedure was carried out on a same volume sample from OF2.

Using more 1 mL samples from OF1, oscillatory experiments, in which frequency of disk oscillation was increased rather than shear rate, were also run at the same temperature increments. In these experiments, the storage modulus, $G'$, and loss modulus, $G''$, were measured with respect to frequencies from 0 to 100 Hz over 300 seconds.

Finally, OF1 samples were prepared and treated with 1wt% of an organic additive, still keeping sample volume at 1 mL. Additives included toluene, heptane, and nitrobenzene. These samples, and an untreated sample, were each tested under the increasing shear rate parameters described above, at a temperature of 55°C, and viscosity was noted with respect to shear rate.

Results and Discussion
The relationship between shear rate and shear stress of the heavy oils tested is heavily temperature dependent. The only difference in the oils is asphaltene content: OF1 contains 12wt% while OF2 contains 20wt%. Due to this, while at low temperatures OF2 is more likely to experience non-Newtonian behavior (a non-linear relationship between shear rate and stress) than OF1. As temperature increases, however, both oils behave fairly Newtonian, as seen in Figure 1.

Concerning storage and loss modulii, certain trends can be observed, as seen in Figure 2.

Summary and Conclusions
Petroleum oils from two different Brazilian oil fields were tested in a parallel plate rheometer at various temperatures to observe the effects on shear rate and stress relationships. It was seen that regardless of the oil and its molecular makeup, behavior becomes less Newtonian at higher shear rates, but more Newtonian at higher temperatures. A higher level of asphaltene also results in less Newtonian performance. Oscillatory tests were also used to observe trends in the storage and loss modulii of the oils. In these tests, $G'$ was almost always less than $G''$, except in the peculiar case of a high temperature, high frequency situation. Finally, the oils were combined with various organic additives and tested to observe viscosity changes. A viscosity decrease was seen for all additives at all shear rates. Whether or not these will be used in the final commercial production of the oils remains the decision of the production company, Petrobras.

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References