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# Effect of Pressure on the Rheological Properties of Maya Crude Oil

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*Supporting Information*

**ABSTRACT:** At atmospheric pressure, hydrocarbon resources, such as bitumen and Maya and other heavy oils, have been shown to exhibit non-Newtonian behavior at or below typical ambient temperatures. This work is devoted to investigating the effect of pressure on the non-Newtonian rheological properties of Maya crude oil (a commercial heavy oil blend from Mexico). Measurements were performed from 258 to 333 K, using a stress-controlled rheometer, at pressures up to 150 bar and over a broad range of shear rates. Maya crude oil was shown to be a shear-thinning fluid below 313 K exhibiting thixotropy below 293 K, at atmospheric pressure, in a prior work. At fixed temperature, the magnitude of the non-Newtonian behaviors of Maya crude oil appears to increase with increasing pressure, and shear thinning is shown to persist to higher pressures below 313 K. Boundaries of the non-Newtonian region with respect to temperature, pressure, and viscosity are identified and discussed. The thixotropic behavior of Maya crude oil is also shown to persist at higher pressure, and the recovery of the moduli at rest appears to be faster at elevated pressures than at atmospheric pressure.

## 1. INTRODUCTION

Heavy oil and bitumen reserves, which are found in many countries such as Canada and Venezuela, are comparable to global conventional oil resources, assuming that 15% for heavy oil and bitumen and 33% for conventional oil[1] can be produced. New exploitation and production techniques are making these heavier hydrocarbon reserves easier to exploit, but their high viscosities and complex rheological properties, among other characteristics, present challenges for their production, transport, and processing. There is ongoing research on their transport properties and, more specifically, on their rheological properties to facilitate the design, operation, and optimization of production, transport, storage, blending, and refining processes. Rheological properties of heavy oil and bitumen are affected by composition, temperature, and pressure as well as sample shear and thermal histories and shear conditions during measurements. Although many researchers provide information about the viscosity of heavy oil and bitumen at different temperatures and/or pressures,[2−7] most have not considered and have not reported sample shear histories and shear conditions prior to and during measurements. These temporal factors[8−11] affect the reported viscosity values for heavy hydrocarbon resources, and consequently these resources must be categorized as non-Newtonian fluids. Ignoring their non-Newtonian behavior has introduced unnecessary uncertainties in the "viscosity" data available in the literature. This is particularly evident at higher pressures.[12−14] There are a number of studies in which heavy oil and bitumen viscosity is measured or correlated at higher pressures.[3,7,15−19] However, there are few papers that consider impacts of shear conditions during measurement and that also consider or provide sample shear history.

Maya crude oil is a thixotropic non-Newtonian fluid.[11] Thixotropy, explained elsewhere in detail,[20,21] leads to time-dependent apparent viscosities at fixed shear rate that arise from the breakage or growth of coherent structures within a fluid. Thixotropy can be responsible for order of magnitude changes in reported viscosity values. The impacts of thixotropic behavior are particularly evident during restart operations following flow disruption in a pipeline and during blending and mixing operations[22−24] and tend to become more significant at low temperatures.[11] Although one can anticipate that the impact of increasing pressure is equivalent to the impact of decreasing temperature, there do not appear to be extant studies that report the effect of pressure on thixotropic properties of fluids, in general, or within the context of heavy oil and bitumen, in particular.

In this study, the effect of pressure on the rheological properties of Maya crude oil over a range of temperatures is investigated. Care is taken to avoid artifacts by adopting the same experimental procedure for all of the measurements, providing well-defined initial shear conditions and clear shear histories. The effect of pressure on the viscosity at constant temperature and shear rate as well as shear rate dependence of the viscosity values at different pressures and at the same temperature are presented. The effect of the phase behavior of the maltene fraction of Maya crude oil on the onset of non-Newtonian behavior is discussed. Boundaries between the Newtonian and the non-Newtonian region with respect to temperature, pressure and viscosity are identified and the effect of pressure on the magnitude of non-Newtonian behavior is illustrated using a non-Newtonian Index. The way pressure affects thixotropic behavior of heavy oil is studied for the first time. These data are expected to provide a benchmark for heavy oil rheological model development and evaluation at higher pressures as well as a better understanding of the interrelation between rheological properties and the phase behavior of their constituting compounds such as asphaltenes and maltenes. This study is also expected to reduce the uncertainty of heavy oil and bitumen rheological properties reported in the literature

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