Measuring the Yielding of Waxy Crude Oils Considering its Time-dependency and Apparent-yield-stress Nature

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Abstract:
Production in reservoirs located in deep and ultra-deep water that contain waxy crude oils faces a huge obstacle imposed by the low temperatures of the environment. When the waxy crude oil is subjected to a temperature below the Gelation Temperature, as in the case investigated in the present work, it exhibits a variety of non-Newtonian features: elasticity, plasticity, viscous effects, and time-dependency, which renders to this material a highly complex behavior. A crucial feature that is frequently ignored when the determination of the yield stress is being carried out, is the time-dependency nature of these materials. We demonstrate how significantly different values of yield stress can be obtained if this character of the material is neglected. We use the asphaltenes properties as inhibitors of wax formation and propose a protocol to capture yield-stress parameters. One important conclusion is that waxy crude oils can be classified as apparent-yield-stress fluids, and not (true-) yield-stress materials, with the presence of a dynamic and a static yield-stresses.

Zusammenfassung:
Die Produktion in Reservoiren, die im Bereich von tiefem und ultratiefem Wasser liegen und wachsartige Rohöle beinhalten, wird durch ein großes Hindernis aufgrund der niedrigen Umgebungstemperaturen erschwert. Wenn wachsartige Rohöle Temperaturen, die niedriger als die Gelierungstemperatur sind, ausgesetzt werden, wie es in dieser Arbeit untersucht wird, treten eine Vielzahl nicht-Newtonscher Erscheinungen auf: Elastizität, Plastizität, viskose Effekte und zeitabhängige Phänomene, die hochkomplex sind. Eine bedeutende Erscheinung, die häufig bei der Bestimmung der Fließspannung ignoriert wird, ist das zeitabhängige Verhalten dieser Materialien. Wir zeigen, wie bedeutend unterschiedliche Werte der Fließspannung erhalten werden können, wenn diese Materialeigenschaft vernachlässigt wird. Wir verwenden asphaltartige Eigenschaften als Inhibitoren der Wachsbildung und schlagen ein Protokoll vor, um die Fließspannungsparameter zu bestimmen. Eine bedeutende Schlussfolgerung ist, dass wachsartige Rohöle klassifiziert werden können als scheinbare Fließspannungsfluide und „falsche" Fließspannungsmaterialien mit dynamischen und statischen Fließspannnungswerten.

Résumé:
La production de pétrole brut cireux dans des réservoirs localisés dans les eaux profondes et ultra profondes fait face à un énorme obstacle : les basses températures imposées par l'environnement. Lorsque le pétrole brut cireux est assujetti à une température inférieure à la température de gélification, comme dans le cas de la présente étude, il présente une variété de propriétés non Newtoniennes : élasticité, plasticité, effets visqueux et dépendance temporelle, qui donnent à ce matériau un comportement très complexe. Un aspect crucial qui est fréquemment ignoré lors de la détermination de la contrainte seuil, est la nature transitoire de ces matériaux. Nous démontrons que des valeurs de contrainte seuil significativement différentes peuvent être obtenues si cet aspect du matériau est négligé. Nous utilisons les propriétés inhibitrices des asphaltènes pour la formation de la cire, et nous proposons un protocole pour mesurer la contrainte seuil. Une conclusion importante est que les bruts de pétrole cireux peuvent être classifiés comme des fluides à contraintes seuils apparentes, et non comme des matériaux possédant de vraies contraintes seuils, avec la présence de contraintes seuils dynamiques et statiques.

Key words: waxy crude oils; re-start problem; yield stress measurement; time-dependent material; wax formation inhibitors

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As the literature also reports, our results strongly suggest that asphaltenes and resins play a significant role on the paraffin crystal formation. However, the real effect of asphaltenes and resins on the yield stress needs to be measured considering the time dependency nature of the waxy crude oil. A protocol that does not take this time dependency into account can lead to very different values for the yield stress and, consequently the measured quantity will not represent the real influence of the asphaltenes and resins as wax inhibitors from the rheological perspective. Since the yield stress is a crucial parameter on the determination of the re-start pressure and, consequently, on the pumping project, the accuracy of its measurement is something that the oil industry must pursue.

5 CONCLUSION

We analyzed the rheology of a waxy crude oil at the temperature of 4 °C in a process of constant cooling rate that started from 60 °C, and null shear rate, simulating the shut down conditions obtained in ultra-deep oil reservoirs, where a restart of the production is necessary. The main conclusion of the present analysis concerns the necessity of taking into account the time-dependency nature of the material at these low temperatures. In particular we found that for the Brazilian oil tested, the differences in the dynamic yield stress can achieve more than 300 %. These differences can make an enormous impact on the prediction of the re-start pressure and can be a reason for the known fact that laboratory characterization overestimates the yield stress and consequently the re-start pressure.

We used the known property of the asphaltenes as inhibitors of wax formation to quantify its effects from the rheology perspective. To this end we added different amounts of two types of flocculants: n-pentane and n-heptane in order to precipitate asphaltenes and resins. When the virgin oil was characterized, its corresponding static yield stress was τ_y = 11 Pa. For a precipitation of ≈ 2.3 % of asphaltenes and resins and a further rheological test made this value rise to τ_y = 49 Pa; while the associated static yield stress value for a precipitation of 3 % of asphaltenes and resins was τ_y = 58.8 Pa.

We also found that the Brazilian waxy crude oil tested is an apparent-yield stress fluid and, therefore it flows at very low shear rates below the static yield stress. This feature combined with the presence of a dynamic and a static yield stress renders to the flow curve a non-monotonic behavior with a very particular character. In fact, a new flow curve fitting is proposed, adapted from a previous one proposed by [35]. This new curve fitting reveals a shear-thickening behavior for very low stress values, in the pre-yielding regime. The whole non-monotonic flow curve can only be obtained in a constant shear rate input, because a constant shear stress input leads to more than one value as a corresponding shear rate. Because of this, a part of the flow curve is considered not stable [36] and leads to the possibility of shear banding effects [37].

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