Australian Journal of Science and Technology

ISSN Number (2208-6404)
Volume 8; Issue 3; September 2024

ORIGINAL ARTICLE

Model selection for rheological characterization of an environmentally friendly synthetic-based mud formulated Using tiger nut oil

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ABSTRACT

Complex rheological behavior is a characteristic of most drilling fluids. Due to strict environmental regulations, efforts are on to formulate more environmentally friendly drilling muds. There is need for comprehensive rheological characterization of these proposed mud formulations to ensure their suitability for use, and the conditions for such use. This work examines the rheological behavior of an environmentally friendly synthetic-based mud derived from Tiger Nut Oil over temperatures of 86°F, 120°F, and 150°F. Herschel-Bulkley Rheological model (HBRM) performed best in five cases while the Casson Rheological model performed best in four cases. However, the Casson model had the least cumulative error (0.7263) compared to the HBRM (0.8771). This shows that the Casson model had the least overall deviation from the measured shear stress. The choice of rheological model for a given drilling fluid must be evaluated on temperature basis.

Keywords: Model, rheology, shear rate, shear stress, temperature

Submitted: 26-08-2024, Accepted: 11-09-2024, Published: 30-09-2024

INTRODUCTION

The reliance of human activities on different energy sources cannot be overemphasized. With crude oil being one of such energy sources, it has been a focus of the attention of industry experts and researchers for decades. The fact that it is a non-renewable energy source justifies the efforts. The reality of depleted reserves, coupled with the prominence of crude oil due to its relatively low cost and availability, has forced production operations into very harsh terrains. However, the strict requirements of keeping to environmental regulations make cost-effective, yet environmentally friendly operations a major concern due to high costs. Drilling fluid is a major contributor to drilling costs and is also a major factor when considering compliance with environmental regulations. In times past, diesel oil was used as the base for mud formulations but given its negative impact on the environment, and the current trend of strict environmental regulations aimed at preserving the environment, research is ongoing to obtain environmentally friendly substitutes for diesel oil as base fluid for drilling fluids.

Complex rheological behavior is a characteristic of most drilling fluids.[1] This is because drilling fluids are designed to perform multiple functions under different operating conditions.[1,2] This results in frequent changes in the composition and properties of the drilling fluid. For this reason, close monitoring of downhole rheological properties is key to successful drilling operations.[3,4] This close monitoring is partly achieved with rheological models. The use of rheological models to describe the behavior of drilling fluid has played a major role in the drilling industry. Therefore, as research is ongoing to formulate substitutes for environmentally harmful muds, there must be a comprehensive rheological examination of the proposed samples using industry models and standards. This will ensure the suitability and universal acceptability of these newly proposed mud formulations. To date, no work has been done to characterize the rheological behavior of a Tiger

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Nut Oil-derived drilling mud. This paper therefore fills this gap by examining the rheological behavior of an environmentally friendly synthetic based mud derived from Tiger Nut Oil.

LITERATURE REVIEW

The need for a comprehensive characterization of drilling fluids stems from the fact that drilling fluids behave differently over time when subjected to changes in temperature, chemical composition, or stress.[2] The behavior of drilling fluids at regions of high shear rate is of importance, as well as their behavior in regions of low shear rate. Low shear rate data help to predict stability of drilling fluid (which is needed when there is no active drilling) while high shear data help to predict behavior of the drilling fluid at the drill string.[5] For this reason, different models have been proposed to describe a wide range of probable behavior that can be observed from drilling fluids.

Common rheological properties of a drilling fluid include viscosity (plastic and apparent viscosity), yield point (YP), and gel strength.[6] These properties are responsible for cuttings removal, and influence the drilling progress in general. Unsatisfactory performance can lead to serious problems such as reduced penetration rate, hole enlargement, stuck pipe, filling the bottom of the hole with drill cuttings, lost circulation, or even blow-out.

To obtain flow properties, dial readings are read from viscometers at different speeds (shear rates). Common viscometers have eight speed readings, R_{600}, R_{300}, R_{200}, R_{100}, R_{60}, R_{30}, R_6, and R_3. The dial readings indicate the shear stress in lb/100ft^2. One division marked on the dial is equivalent to a stress of 1.0065 lb/100ft^2. For corrected readings, a conversion factor of 0.48 is multiplied to the dial reading to convert from lb/100ft^2 to Pa; while for uncorrected readings, a conversion factor of 0.51 is multiplied to the dial reading to convert from lb/100ft^2 to Pa. To convert shear rate from units of revolutions per minute (RPM) to per second (s^{-1}), the RPM value is multiplied by 1.703.[7] A plot of shear stress on the vertical axis against shear rate on the horizontal axis (called a rheogram). The dial readings are also converted to YP, plastic viscosity (PV) using equations (1)–(2).[2,4] PV is in cp, YP is in lb/100ft, AV is in cp, R_{600} is the viscometer reading at 600 revolution per minute, and R_{300} is the viscometer reading at 300 revolution per minute.

$$PV = R_{600} - R_{300} \tag{1}$$

$$YP = R_{300} - PV \tag{2}$$

The dial readings are also used in mathematical models to understand and predict the behavior of the drilling fluid. Common models include Power-law, Herschel-Bulkley, Bingham plastic, and Casson models. From the shear stress-shear rate plot, the fluid can be categorized as a Bingham fluid, a Power Law fluid, a Herschel-Bulkley fluid, or a Casson fluid. The four models are given in equations (3)-(6) where: τ is the shear stress; γ is the shear rate; K is the consistency coefficient; and n is the flow behavior index; τ_y is the symbol for yield stress; η is used to represent plastic viscosit; τ_c is the YP in Pa, γ is the symbol for shear rate, μ_∞ is the extreme high coefficient.[2,3,8,9] Power law model describes the shear thinning characteristic of some drilling fluid. A drilling fluid is said to be shear thinning if it experiences a reduction in its viscosity as shear rate increases. For such fluids, the Power law index, n, is less than one. Some fluids also exist that require a minimum amount of stress to be overcome before flow is initiated; they are commonly described using the Bingham plastic model. Herschel–Bulkley model incorporates both Power law and Bingham plastic terms; it reduces to Bingham model when n is equal to 1, and reduces to Power law model when yield stress is equal to 0.[10]

$$\tau = K\gamma^n \tag{3}$$

$$\tau = \tau_y + K\gamma^n \tag{4}$$

$$\tau = \tau_y + \eta\gamma \tag{5}$$

$$\tau 0.5 = \tau 0.5 + K 0.5(5\ c\ c\ \gamma 0) \tag{6}$$

Power and Zamora[1] studied over 48,000 mud reports to determine the optimum strategy for determining the Herchel–Bulkley yield stress. Six different options for determining the yield stress was considered in the study, including Fann R_3, Fann R_6, low-shear YP (LSYP=2R_3-R_6), "Zero" gel strength, that is no time delay gel strength, initial (10-s delay) gel strength, 10-min gel strength. The Low-shear YP gave the best results. Okon and Udoh[8] studied the pressure drop profile of two types of mud formulated locally using Power law and Bingham plastic models only. This work uses four rheological models.

MATERIALS AND METHODS

The materials and methods for this study are as given in Ehwarieme and Akintola.[11] Three different mud samples were formulated using Transesterified Tiger Nut Oil as base oil. The different samples were obtained by varying the oil-water-ratio. Sample A, B, C had oil-to-water ratios of 70:30, 75:25, and 80:20, respectively. All samples had a mud weight of 10 ppg.

All samples were subjected to varying temperatures (86°F, 120°F, and 150°F) and their rheological properties were monitored and measured across these temperatures. Industry-accepted rheological models were used to characterize the different samples. Error metrics including mean absolute error and root mean square error were used to ascertain the performance of the different rheological models on the drilling fluid samples. The best models that described the behavior of the sample (typically, models with the smallest errors) were selected and reported.

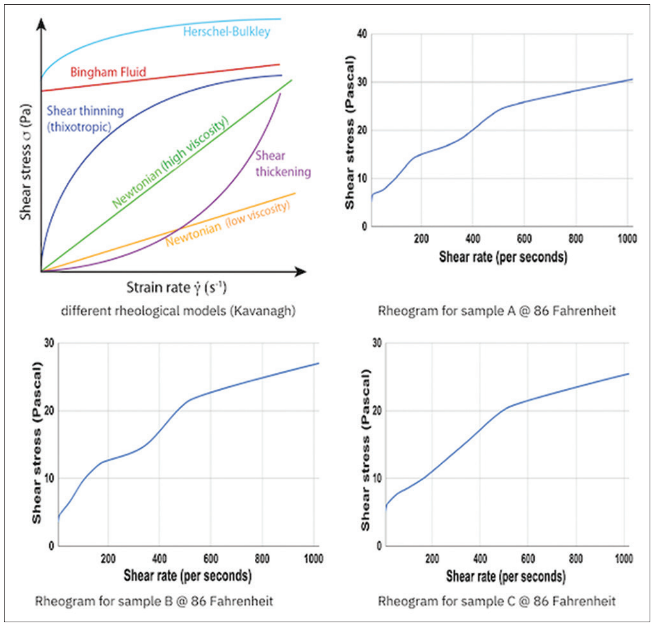

Figure 1: Comparison of (a) standard rheogram with samples A, B and C at 86°F

In this study, the Fann R_3 and the low-shear YP methods were compared and the method of choice was the low-shear YP method as it gave values of shear stress closer to the measured shear stress (MSS) than the Fann R3 method when used in the Herschel–Bulkley model. This agrees with Power and Zamora.[1]

RESULTS AND DISCUSSION

A plot of the MSS in Pascal (Pa) against the shear rate in per second (s^{-1}) for samples A, B, and C at a temperature of 86°F is given in Figure 1. It can be seen from the chart that the rheogram for samples A, B, and C, approximate that of the Herschel–Bulkley model.

In Figure 2, the MSS in units of Pascal (Pa) is plotted and compared with rheological models such as Power law rheological model, Bingham plastic rheological model, Herschel–Bulkley rheological model (HBRM), and Casson rheological model (CRM) for each of the formulated mud samples. It can be observed that as temperature increased, the shear stress recorded in all the samples reduced accordingly. This is due to reduced viscosity due to increase in temperature. Herschel–Bulkley model gave the best description of sample A at 86°F, 120°F, and 150°F, respectively. The model gave mean absolute errors of 0.993; 0.6688; and 0.4166 (Root mean

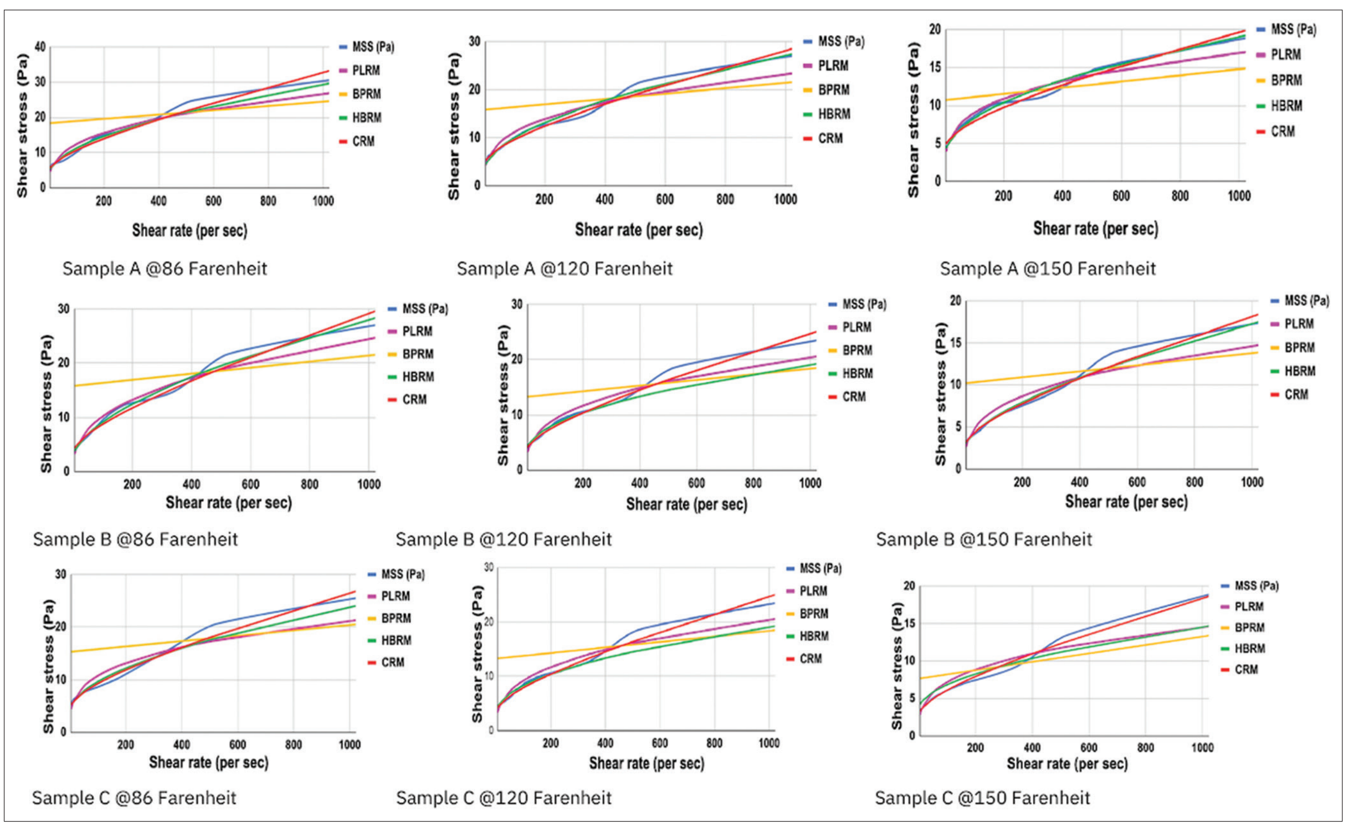

Figure 2: Plot of shear stress versus shear rate for different mud samples

square errors of 1.2667, 0.9283, and 0.5459), respectively, which proved to be the lowest for all the models used at these temperatures for sample A. For sample B, the result was different. At a temperature of 86°F, Herschel–Bulkley model gave the best behavior prediction with mean absolute error of 0.9495 (Root mean square errors of 0.9473), but at 150°F, the CRM gave the best behavior prediction with mean absolute error of 0.7613 (Root mean square errors of 0.9543), while the Herschel–Bulkley model gave the best prediction at 150°F with mean absolute error of 0.3554 (Root mean square errors of 0.5808). CRM gave the best description for sample C at 86°F, 120°F, and 150°F, respectively. The model gave mean absolute errors of 0.7576; 0.4632; and 0.3406 (Root mean square errors of 1.0111, 0.6106, and 0.4683) respectively, which proved to be the lowest for all the models used at these temperatures. Details of the error analyses of the performance of the rheological models on the three mud samples can be seen in Figure 3. At 86^{o}F, the cumulative predictive performance of all the models was highest for sample C and lowest for sample A. This indicates that at 86°F, rheological models would perform better on sample C compared to samples B, and A. The same trend was noticed at 120°F, the average performance of all the models was highest for sample C, followed by sample B, and sample A had the least performance. There was a sharp change in trend at 150°F. The average performance of all the models was highest for sample A, followed by sample C, and sample B had the least performance. All the models had their least error margin at 150°F. The yield stress to YP ratio for sample A was slightly below the expected value given by Power and Zamora at temperature of 150°F; but it was within the expected range for samples B at temperature of 150°F; and it was within the expected range for sample C at temperatures of 120°F and 150°F.

HBRM performed best in five cases (sample A, sample B at 86°F and 150°F), while the CRM performed best in four cases

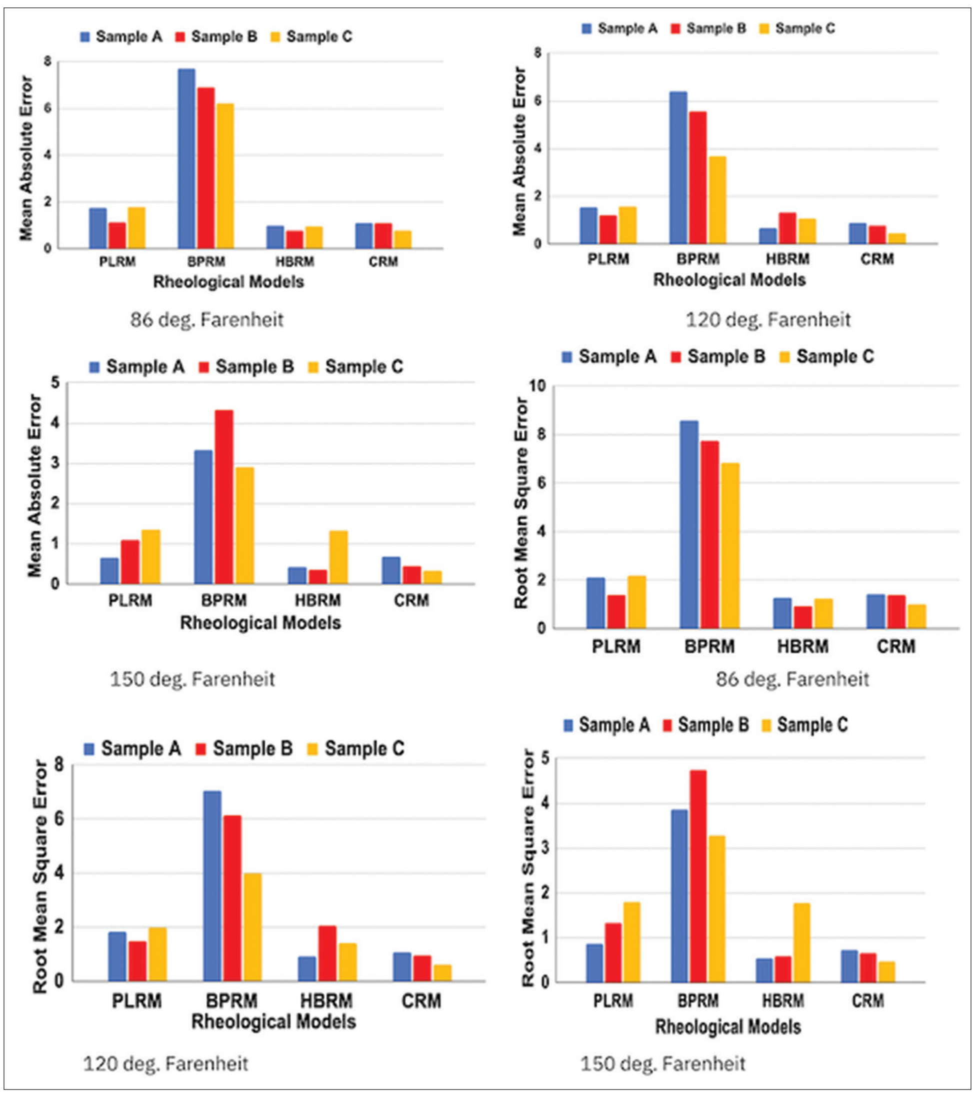

Figure 3: Mean absolute error and root mean square error of rheological models

(sample C, and sample B at 120°F). However, it is worth noting that when the cumulative average of the mean absolute errors for all cases was taken, the Casson model had the least error (0.7263) compared to the HBRM (0.8771). This shows that the Casson model had the least overall deviation from the MSS.

CONCLUSION

The choice of a rheological model for studying the behavior of a drilling fluid should be subjected to the range of temperatures within which the fluid was previously tested because a model that performed best at a given temperature can fail to do so at a different temperature. The low-shear YP method for determining the Herschel–Bulkley stress gave the best results for the mud samples in this study compared to the R_3 method.

HBRM showed the best performance for sample A at the three temperatures and CRM showed the best performance for sample C at the three temperatures. The HBRM had a higher frequency of best performance; however, a close look at the overall mean absolute error for all cases showed that the CRM had the least deviation from the MSS.

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