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FACILITATING MUD DESIGN, CEMENTING JOB DESIGN AND THE ENTIRE DRILLING OPERATIONS BY MODELLING THE RHEOLOGICAL PROPERTIES OF WATER-BASED MUD AND OIL-BASED MUD WITH TEMPERATURE

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ABSTRACT

The increasing rental cost of a drilling Rig and the associated painful cost of downtime when drilling oil & gas wells, are some of the major concerns of Oil & Gas Companies. Improper rheological properties of drilling mud may cause a variety of problems including insufficient cuttings transport, limited solids suspension, poor hole-cleaning and excess filtrate loss into the formation. Facilitating mud design, cementing job design and the entire drilling operation will save Rig time and associated cost and prompt management of Oil & Gas Companies to devote more of their useful time and resources to other significant aspects of their operations. The aforesaid prompted this work, on developing mathematical models representing the rheological parameters of drilling mud (water-based mud and oil-based mud) to enable prediction of the rheological properties in emergency situations where and when Laboratory services are not immediately available. The methods applied include Laboratory testing and mathematical modeling. Results revealed that mathematical models can be confidently applied to predict variation of the Plastic viscosity and Yield stress of water-based mud and oil-based mud with temperature as the correlation coefficient (R-squared value) obtained for each of the aforesaid rheological properties was higher than 95%. Therefore, as the rheological properties of water-based mud and oil-based mud also depend on their composition, chemical properties and other physical properties, mathematical models representing the variation of Plastic viscosity and Yield stress with temperature, should be proactively developed for every mud in hole to enable their prediction in emergency situations especially when and where laboratory services are not immediately available.

Keywords: Drilling Operations, Oil & Gas Wells, Well Control, Rheology, Mathematical Models, Plastic Viscosity

1. INTRODUCTION

The rheological properties of drilling mud depend on its composition, chemical properties, and physical properties. The flow behaviors of water-based mud and oil-based mud change with temperature. The importance of water-based mud and oil-based mud to the oil & gas industry cannot be over-emphasized. There have been emergency situations when bidding for contracts, conducting pilot mud design and pilot cementing job design that require tentative input of rheological parameters of drilling mud at higher or lower temperature than the temperature of a previous design or original design, pending the outcome of Laboratory tests. There have been situations involving writing a mud programme that required tentative input of rheological parameters of drilling mud, pending the outcome of Laboratory testing. There have also been emergency situations that involved sudden change in bottomhole temperature of an oil & gas well during drilling.

The aforesaid prompted this work to invent a method for modelling the rheological properties of water-based mud and oil-based mud with temperature in order to predict their rheological properties at different temperatures, whenever the need arises, especially where and when Laboratory services are not immediately available. Mathematical models proactively derived for the rheological parameters of oil-based mud and water based mud will help mud engineers to predict the rheological properties ahead of target depth and make required changes to the mud composition to suit the higher temperature anticipated. Such mathematical models will help mud engineers and cementing engineers to do pilot designs for target depths pending when Laboratory data become available. The consequences of improper mud rheological properties include low rate of penetration (/ROP), reduced drilling rate, well insecurity, wellbore instability and reduced life of bit. Nelson and Guillot (1990) stated that it is customary to circulate drilling mud through the well and around the drill bit during drilling operations. Ahmad and Ganat (2022) stated that improper rheological properties of drilling mud may cause a variety of problems such as insufficient cuttings transport, limited solids suspension, poor hole-cleaning and excess filtrate loss into the formation. Vryzas et al. (2017) stated that temperature has significant effect on water-based Bentonite mud and that the Bingham plastic viscosity decreased with temperature while the Bingham yield stress increased with temperature.

The variation of the viscosity of water-based mud with temperature should be thoroughly investigated for each particular sample as the rheology of water-based mud depends on many variables. Sound understanding of the rheological behavior of drilling mud will enhance drilling performance and increase drilling rate. Vryzas et al. (2017) stated that the degree of the influence of temperature on the rheological properties of water-based mud should be investigated with good accuracy because a number of variables are involved and the behavior of Bentonite mud at high temperatures is unpredictable and not fully understood.

Schlumberger (2023) stated that the functions of drilling mud include, controlling formation pressures, removing cuttings from the wellbore, sealing permeable formations encountered during drilling operations, cooling and lubricating the bit, transmitting hydraulic energy to downhole tools and the bit and maintaining wellbore stability and well control. Petrowiki (2023) stated that the functions of drilling mud include transporting cuttings to the surface, well-control and wellbore stability, minimizing formation damage, cooling and lubricating the drill string and providing information about the wellbore.

Drilling Manual (2022) stated that the main target of drilling mud design is to resolve or minimize drilling problems. Taugbol et al. (2005) reported that oil-based mud exhibit better temperature stability when drilling at high temperatures compared to water-based mud; providing better drilling performance, better lubricity, lower coefficient of friction and better hole-stability than water-based mud. Abduo et al. (2016) wrote that oil-based mud is not always applicable because of environmental concerns and cost especially when it involves mineral or synthetic fluids and that kick detection is more problematic when using oil-based mud compared to water based mud due to high gas solubility in oil-based mud.

2. MATERIALS AND METHODS

Methods applied include Laboratory testing and mathematical modelling using Microsoft Excel. The water-based mud and oil-based mud used in this work were supplied by an oilfield services company. The water-based mud was conditioned at each test temperature for 20 minutes in an Atmospheric Consistometer that has been preheated to the respective test temperatures of 30°C, 40°C, 50°C, 60°C and 70°C.

The rheology was conducted using Chan-35 Rheometer and the Plastic viscosity and Yield stress calculated for the water based mud and oil-based mud at each test temperature and separately plotted against temperature using Microsoft Excel. Regression analysis was performed using the "Add trend-line" option of Microsoft Excel and clicking on the "display Equation on chart" and the "R-squared value on chart" options on the "Add trend-line drop down menu for each graph. The polynomial model gave the best R-squared value.

3. RESULTS AND DISCUSSION

The plastic viscosity of the water-based mud decreased with rise in temperature while the yield stress increased with rise in temperature as evidenced by Figure 1 and Figure 2 respectively.

Figure 1

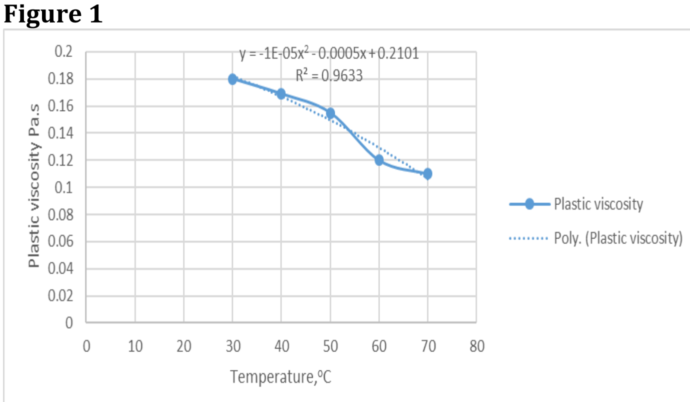

Figure 1 Variation of the Plastic Viscosity of Water-Based Mud with Temperature (Where y=Plastic Viscosity in Pa.s and x = Temperature in °C)

Figure 2

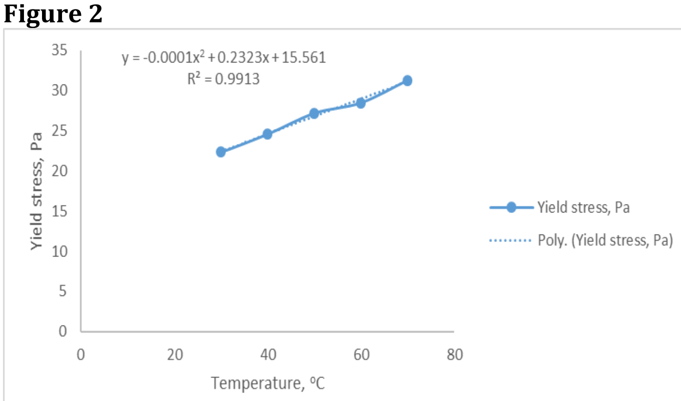

Figure 2 Variation of the Yield Stress of Water-Based Mud with Temperature (Where y=Yield Stress in Pa and x = Temperature in °C)

Vryzas et al. (2017) reported that water-based muds that use bentonite for rheology control are greatly and negatively affected by temperature due to the large number of variables that affect the behavior of water-based bentonite mud. Makinde et al. (2011) stated that the plastic viscosity and yield point of water-based mud decreased with increase in aging time. Allawi et al. (2019) stated that higher viscosities and higher yield stress at higher temperatures can be ascribed to the flocculation of the Bentonite.

The plastic viscosity and yield stress of the oil-based mud decreased with rise in temperature as evidenced by Figure 3 and Figure 4 respectively.

Figure 3

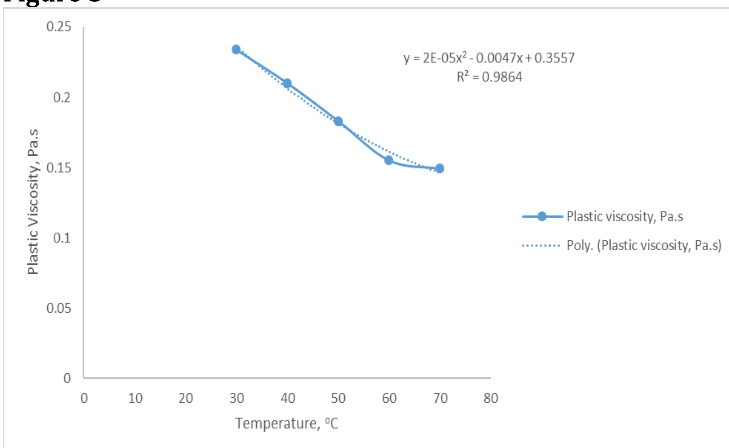

Figure 3 Variation of the Plastic Viscosity of Oil-Based Mud with Temperature (Where y=Plastic Viscosity in Pa.s and x = Temperature in °C)

Figure 4

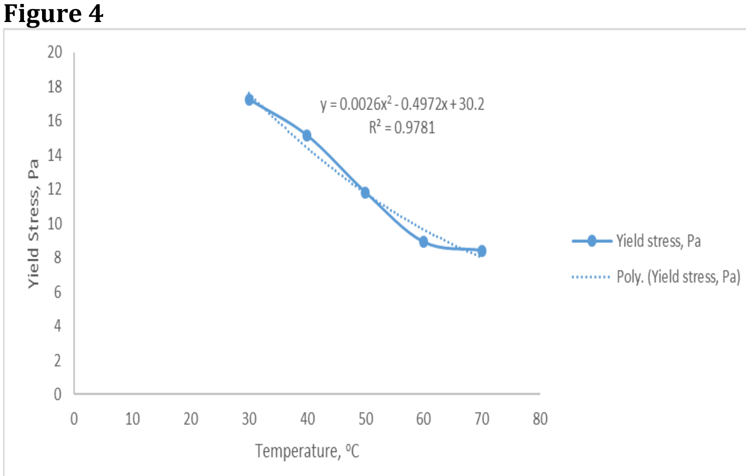

Figure 4 Variation of the Yield Stress of Oil-Based Mud with Temperature (Where y=Yield Stress in Pa and x = Temperature in °C)

Abduo et al. (2016) stated that oil-based mud can be designed to withstand high temperatures over long periods of time but water-based mud can break down leading to loss of viscosity and fluid loss control while other advantages of oil-based mud include shale stability, faster penetration rates and providing better gauge hole.

The very high regression coefficient (R-squared value) obtained with the mathematical models derived for the rheological properties (Plastic viscosity &

Yield stress) of the water-based mud is more than 95% in each case. Similarly, the regression coefficient (R-squared value) obtained with the mathematical models for the rheological properties (Plastic viscosity and Yield stress) of the oil-based mud is also very high, more than 95% in each case. This trend shows that the respective mathematical models can be confidently applied to predict the plastic viscosity and the yield stress of the water-based mud and the oil-based mud respectively in emergency situations where Laboratory services are not immediately available. The mathematical models can also be applied by drilling engineers, mud engineers and cementing engineers during pilot designs and training programmes for trainee mud engineers, trainee cementing engineers, trainee drilling engineers and other drilling personnel. The mathematical models will enable drilling engineers and mud engineers to proactively predict the rheological parameters required for target depths and also prompt quick prediction of mud rheological parameters when bottomhole temperature changes suddenly during the drilling of oil & gas wells. The mathematical models will enable cementing engineers to predict the rheological properties of mud when doing pilot cementing designs or when bottomhole temperature changes abruptly, where and when Laboratory services are not immediately available.

The significance of this work to the oil & gas industry cannot be over-emphasized. The limitations encountered in this work are equipment and funding.

4. CONCLUSION

The regression coefficient (R-squared value) obtained for the rheological parameters of the water based mud and the oil based mud with the respective mathematical models as displayed on Figure 1, Figure 2, Figure 3 and Figure 4 are very high (above 95%) signifying that the mathematic models can be used very confidently to predict the Plastic viscosity and Yield stress of the water based mud and oil-based mud resppectively, especially where and when Laboratory services are not immediately available.

Therefore, mathematical models representing the Plastic viscosity and Yield stress of drilling mud should be proactively generated for every mud in hole to enable proactive prediction of rheological parameters required for target depth or when bottomhole temperature changes suddenly during drilling and in other emergency situations where and when laboratory services are not immediately available e.g., if the only Rheometer (Viscometer) on the Rig suddenly becomes non-functional.

The proactive development of mathematical models for the rheological properties of every mud in hole will facilitate mud design, cementing job design and the entire drilling operations and increase the productivity of mud engineers, cementing engineers and drilling engineers and other drilling personnel alongside saving Rig time and cost for oil & gas companies.

CONFLICT OF INTERESTS

None.

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