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# Investigation of Particle Size on Drilling Fluid Properties in Water-Based Drilling Fluid

IKEH LESOR[1], NDUBUISI, ELIZABETH[2], OSIGWE UCHE STANLEY[3]
[1,2,3] *University of Port Harcourt, Faculty of Engineering, Department of Petroleum and Gas Engineering, East-West Road, Choba, Port Harcourt, Nigeria.*

***Abstract—This study examines the influence of particle size on the properties of water-based drilling fluids, which are commonly utilized in oil and gas drilling operations. Drilling fluids, or muds, play a crucial role in lubricating the drill bit, controlling downhole pressure, and transporting cuttings to the surface. The performance of these fluids is primarily determined by their rheological properties, which are influenced by the composition and size distribution of the solid particles within the fluid. This research investigates how varying the particle size distribution of fine, medium, and coarse calcium carbonate impacts key properties, including plastic viscosity (PV), yield point (YP), and gel strength, at temperatures of 80°F, 120°F, and 150°F. A total of 1.67 grams of each particle size, fine, medium, and coarse calcium carbonate, was used to prepare a 5-gram mixture for each size. The effects of both individual and composite mixtures on the rheological properties of water-based drilling fluids were evaluated under the specified temperature conditions. The results indicated that variations in particle size did not significantly alter the PV, YP, or the flow curves obtained from shear stress versus shear rate plots. The fluid flow curves followed the typical behavior of drilling fluid models, with shear stress increasing proportionally to shear rate as temperature rose. Coarse carbonate particles exhibited the most significant improvement in viscosity as temperature increased. The composite mixture displayed optimal performance, with high YP suggesting that the drilling fluid may lose its rheological properties due to temperature fluctuations downhole. The medium particle size also performed well in terms of YP at elevated temperatures. Gel strength was maximized when a mixture of fine, medium, and coarse particles was incorporated into the drilling fluid. Overall, this work highlights the impact of carbonate particle size on the rheological properties of water-based drilling fluids and demonstrates that altering particle size can significantly influence gel strength, PV, and YP.***

***Keywords— plastic viscosity, yield point, gel strength, drilling fluid, rheological property, calcium carbonate***

## I. BACKGROUND TO THE STUDY

Drilling fluids, often called drilling muds, are crucial in the oil and gas industry for the drilling process. These fluids are vital for lubricating the drill bit, controlling downhole pressure, preventing wellbore collapse, and transporting rock cuttings from the well to the surface. The main role of drilling fluids is to maintain a stable environment around the drill bit, help remove debris, and enable the continuous circulation during of the drilling (Silliman, 2012). Various types of drilling fluidsare used in the industry, with water-based drilling fluids (WBDFs) being the most common due to lower cost, environmental safety,, and easy handling. Water-based systems mainly consist of water with added additives and solid particles, such as clays, salts, and carbonates, which alter the fluids rheological properties. Optimizing these properties, including plastic viscosity (PV), yield point (YP), and gel strength, is essential for efficient efficient and safe drilling operations (Akin et al., 2017).

The rheological properties of a drilling fluid directly influence its performance in the wellbore. These properties determine how well the fluid can carry cuttings, suspend and transport materials, and control pressures. The most important rheological properties of drilling fluids include: Plastic Viscosity (PV), which measures the fluid's resistance to flow, and its effect by the concentration and size of solid particles in the fluid (Spencer et al., 2011). A higher PV indicates increased friction within the fluid, which can help withfor cutting removal and wellbore pressure control. Yield Point (YP) reflects the fluid's ability to start flowing and is crucial for suspending cuttings when the pump is off. A High yield point helps keep cuttings suspended during auses in of circulation (Liu et al., 2015). Gel Strength refers to the fluids ability to maintain its viscosity when circulation stos. Gel strength is vital for maintaining wellbore stability and preventing from settling (Mohammad et al., 2020). The rheological properties of drilling fluids are mainly affected by interactions between solid particles and the base liquid (water), with the composition of these particles playing a key role in controlling these properties (Alvarez et al., 2014). Solid particles in water-based drilling fluids come from various sources, including base fluid additives (such as bentonite or barite) and formation cuttings. These particles interact with the water to form a stable suspension, which influences the viscosity and flow behavior of the drilling fluid. Key additives include calcium carbonate, clay, and weighting agents like barite. The size and distribution of these particles directly impact the overall rheology of the fluid (Stamford et al., 2013). Solid particles affect several properties particularly fine particles. These fine particles have a large surface area relative to their volume, which increase viscosity due to their high interaction with the water phase (Gupta et al., 2016). Fine particles can also enhance the fluid's yield point and gel strength, making it easier to suspend and transport cuttings. Conversely, coarse particles, have a smaller surface area and contribute less to viscosity but are critical for stabilizing the fluid's structure and ensuring effective suspension of cuttings in high-density environments (Ding et al., 2018).

The mixture of fine, medium, and coarse particles in the fluid must be carefully managed to achieve optimal rheological properties, which ultimately influence the performance of the drilling fluid regarding cuttings transport, pressure control, and wellbore stability (Quintero et al., 2017). Calcium carbonate ($CaCO_3$) is a common additive in water-based drilling fluids due to of its beneficial effects on viscosity and wellbore stability. Calcium carbonate helps improve the rheological properties of the fluid, by acting as a weighting agent and increasing the yield point and gel strength. Calcium carbonate particles can also control the pH of the fluid, preventing corrosion of the drilling equipment (Olayinka et al., 2016). In water-based systems, calcium carbonate is available in various particle sizes, ranging from fine to coarse. The particle size distribution of calcium carbonate directly impacsts the rheological behavior of the fluid. Fine calcium carbonate particles tend to enhance the fluid's viscosity by providing a larger surface area for interaction with the fluid. In contrast, coarse particles can improve the fluid's ability to suspend and transport cuttings. Therefore, an optimal mixture of particle sizes is necessary to ensure that the drilling fluid performs effectively under varying conditions (Ahmad et al., 2021). The particle size distribution of solids in a drilling fluid is a critical factor that influences the fluid's rheological properties. Particle size can affect how the solid particles interact with the base fluid and other additives, thereby impacting the fluid's flow behavior, its ability to transport cuttings, and its overall performance under different operational conditions (Frost et al., 2013). Small particles (fine and medium-sized) provide a higher surface area to the fluid, which increases the fluid's viscosity and helps suspend solid materials. Large particles (coarse particles) contribute less to the viscosity. Still, they can assist in transporting larger cuttings and prevent the formation of a mud cake that could inhibit circulation (Liu et al., 2016). The balance between fine, medium, and coarse particles is critical in maintaining an adequate drilling fluid. The size and concentration of these particles must be carefully adjusted to ensure the fluid can maintain an optimal viscosity while also providing sufficient cutting transport capacity and wellbore stability (Yuan et al., 2019). Temperature is another critical factor influencing the rheological properties of drilling fluids. As temperature increases, the viscosity of water-based drilling fluids typically decreases due to the thinning of the base liquid (Chen et al., 2014). However, the addition of solid particles, such as calcium carbonate, can mitigate the impact of temperature fluctuations by stabilizing the fluid's structure and maintaining its rheological properties. At high temperatures, the fluid's viscosity may decrease, which can lead to difficulties in suspending cuttings and maintaining effective pressure control in the wellbore. Some types of solid particles, such as coarse calcium carbonate, may help improve the fluid's ability to perform under high-temperature conditions by increasing the yield point and gel strength (Rocca et al., 2020). At low temperatures, the fluid's viscosity may increase, which can make it more challenging to circulate the fluid. This can be beneficial for certain aspects of wellbore stability and cutting transport, but it may require additional additives or adjustments to maintain fluid flow (Ali et al., 2017). Understanding how particle size interacts with temperature fluctuations is crucial for optimizing the performance of water-based drilling fluids, especially in wells with variable temperature profiles (Yilmaz et al., 2018).

## II. THE NANOFLUID THEORY

A nanofluid is a mixture of nanoparticles in a base fluid designed to improve the fluids thermal performance. It is a colloidal dispersion of a two-phase system where nanoparticles are in solid form and the base fluid is in liquid form. Similarly, It is a special type of heat transfer fluid that has higher thermal conductivity than traditional fluids like glycols, water, or engine oil. The nanofluid theory aims to understand how nanoparticles influence the behaviour of the fluid, especially how they change properties such as thermal conductivity and viscosity compared to the base fluid alone.

Many nanoparticles are studied to enhance the properties of drilling fluid in water-based drilling mud. Silica nanoparticles have been used to reduce water absorption into shale formations and to minimize problems such as pipe sticking, shale hydration and wellbore stability (Saboori R, et al, 2018; Rafati R, et al, 2018). CMC nanoparticles have been applied, to improve rheology, decrease filter cake thickness and control filtration (Huang X, et al, 2018; Villada Y, et al, 2017). $Fe_3O_4$ has been utilized to enhance of drilling fluid performance under high-pressure, high-temperature (HPHT) conditions, Ezeakacha CP, Salehi S (2018).The invasion of drilling fluid solids and water filtration into hydrocarbon-bearing formations can cause in many problems, Kalantariasl , 2014).

Water can alter near-wellbore wettability, impacting oil production. Different water chemistry may detach fine particles from the grain surface and reduce permeability, which is a serious problem that can delay production and may not always be fixable. Therefore, minimizing formation damage is important and that can be achieved with proper mud design and the right additive selection Civan, F, 2015).

Saboori R, Sabbaghi S, Barahoei M, Sahooli M (2017) measured the thermal conductivity and viscosity of three different water-based suspensions containing $Al_2O_3$, $TiO_2$, and $SiO_2$ nanoparticles (particles ranging from 1 to 100 nm). They reported that both thermal conductivity and viscosity of the water increase after adding nanoparticles. Consequently, Rafati R, Smith SR, Haddad AS, Novara R, Hamidi H (2018) designated the term "nanofluid" for a mixture of nanoparticles and a liquid. It is important to note that nanofluids are not simply made by adding nanoparticles to water or oil and stirring the mixture, like mixing sugar into tea. Creating a nanofluid requires specific physical and chemical processes to ensure a uniform and stable dispersion of particles for long-term use. Techniques such as using of surfactants (non-covalent functionalization), functionalizing nanoparticles, controlling pH, and sonication are some primary methods to improve nanofluid stability, as noted by Rafati R, Smith SR, Haddad AS, Novara R, Hamidi H, (2018).

## III.METHODS AND PROCEDURES

The materials used for this study were xanthan gum, barite, soda ash, caustic soda, calcium carbonate particles (fine, medium, and coarse), bentonite, soltex, and potassium chloride. The equipment used was a Low Pressure Low Temperature Filter (LPLT) press, scale, Fann Viscometer, and pH meter. Table 1 and Table 2 show the composition of the first and fourth drilling mud prepared.

Table 1. Composition of the first drilling mud.

| S/n | Additives | Quantity |
|---|---|---|
| 1 | Water | 276ml |
| 2 | Soda Ash | 0.2g |
| 3 | Bentonite | 15g |
| 4 | Caustic Soda | 0.3g |
| 5 | Xanthan Gum | 2g |
| 6 | Soltex | 1.5g |
| 7 | Barite | 25g |
| 8 | Potassium Chloride | 25g |
| 9 | Calcium Carbonate (fine) | 5g |

Table 2. Composition of the fourth drilling mud.

| S/n | Additives | Quantity |
|---|---|---|
| 1 | Water | 394.29ml |
| 2 | Soda Ash | 0.29g |
| 3 | Bentonite | 21.43g |
| 4 | Caustic Soda | 0.29g |
| 5 | Xanthan Gum | 2.9g |
| 6 | Soltex | 2.14g |
| 7 | Barite | 35.71g |
| 8 | Potassium Chloride | 35.71g |
| 9 | Calcium Carbonate | 1.67g |

3.1 Preparation of Mud Samples

The mud samples were prepared using 276ml of water. Other additives were weigh using a laboratory scale, and poured into the mud cup and stirred for 2 minutes. Bentonite was later added and stirr for 5 minutes with soda ash, Xanthan Gum. Similarly, soltex, caustic soda, chloride and calcium carbonate particle were added. Continuous stirring was done for five (5) minutes more. The mud weight readings of the drilling fluid was taken, pH reading of the drilling fluid was also recorded. The drilling fluid was heated in the thermocouple. This process was carried out using the selected additives of different particle sizes.

3.2 Determination of the Rheological Properties

The rheological properties were determined using the dial readings from the Fann Viscometer. Gel strength reading was also recorded. Filtration test was done using LPLT filter press to determine the flow loss and readings were taken. The filter cake thickness was measured and recorded

## IV. RESULTS ANALYSIS/DISCUSSION

4.1 Variation of shear stress with shear rates at different particles sizes.

The samples were prepared using calcium carbonate at different particle sizes and the rheological properties were determined, recorded and presented. The particle sizes of the additive (calcium carbonate) which were fine, medium, coarse, mixture of fine, medium and coarse were evaluate with respect to the relationship between the shear stress and shear rate and results were presented in Figure 1 to Figure 12 respectively.

The relationship of shear stress as a function of shear rate is use to determine the fluid flow model and the slope gives viscosity of the drilling fluid in consideration. In this study, the fluid flow property was examine at different carbonate particle sizes added to the drilling fluid. Figure 1 to Figure 3 show that addition of mixture of equal concentrations of different particle sizes (fine, medium and coarse) did not alter the fluid flow model of the drilling fluid at temperature different temperature. However, it was observe that the fluid flow model still showed typical drilling fluid model (Figure 1 – Figure 3).

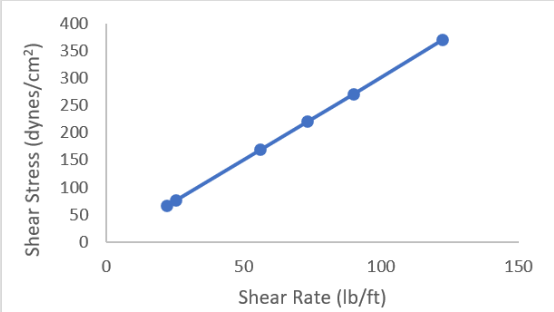


Fig. 1. Shear stress as a function of shear rate for mixture at 80ºF.

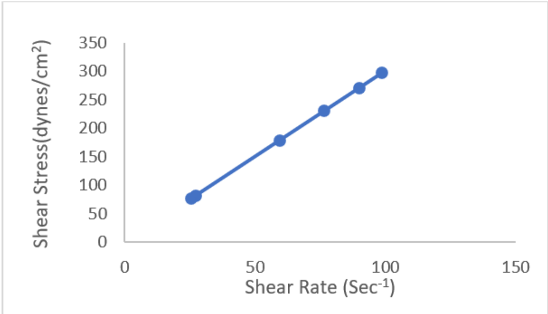


Fig. 2. Shear stress as a function of shear rate for mixture at 120ºF.

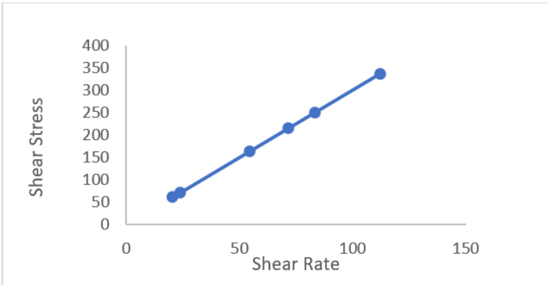


Fig. 3. Shear stress as a function of shear rate for mixture at 150ºF

The addition of fine carbonate samples to the drilling mud did not change the fluid flow property. As the shear stress increases, the shear rate (shear thinning) increases, which is typical of drilling fluid at different temperatures (Figures 4 - 6). The fine particle size did not change the fluid shearing trend. It was observed that the medium particle size added to the drilling fluid also followed a similar trend of the fluid flow at different temperatures (Figures 7 – 9).

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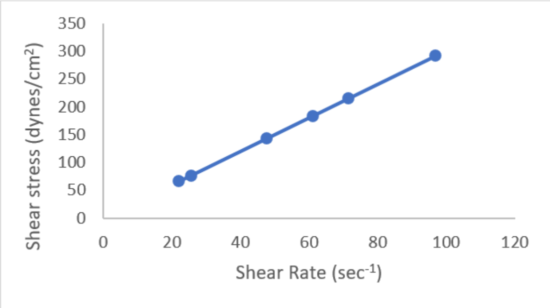


Fig. 4. Shear stress as a function of shear rate for the fine sample at 80°F

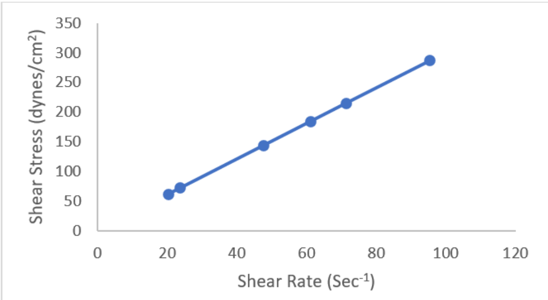


Fig. 5. Shear stress as a function of shear rate for the fine sample at 120°F

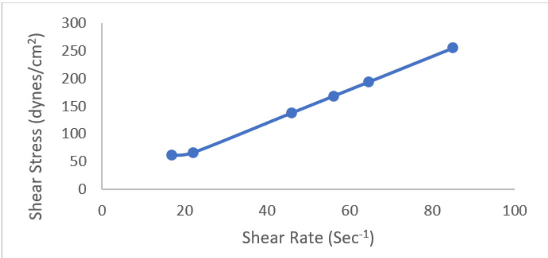


Fig. 6. Shear Stress as a function of shear rate for the fine sample at 150°F

Figures 7 - 9 showed that there was no significant change in the behavior of the drilling fluid as an increase in shear rate brought about a proportionate increase in the shear rate at different temperature values. The coarse carbonate particle added to the drilling fluid still maintained the shear stress-shear rate relationship because as the shear stress increased, the fluid shear thinning increased in the same proportion in all the temperature range of 80°F - 150°F.

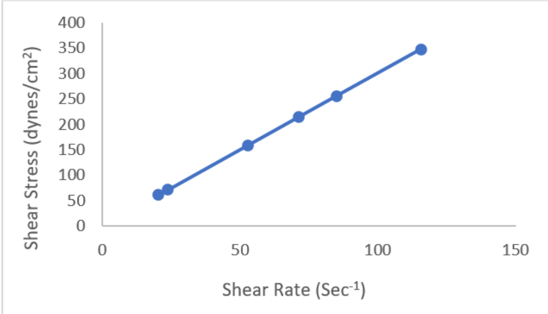


Fig. 7. Shear stress as a function of shear rate for medium sample at 80°F

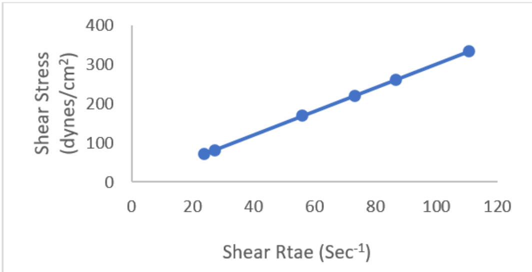


Fig. 8. Shear stress as a function of shear rate for medium sample at 120°F

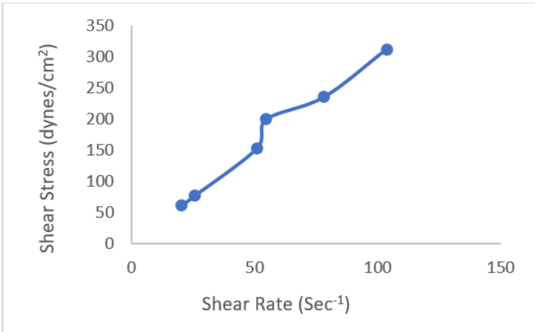


Fig. 9. Shear stress as a function of shear rate for the medium sample at 150°F

Similarly, Figures 10 - 12 demonstrated that there was no significant deviation of the fluid pattern even though the particle sizes of the additive (carbonate) were varied at different temperatures.

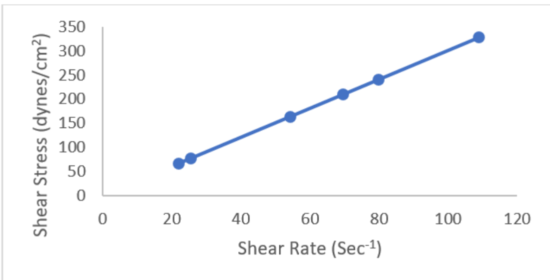


Fig. 10. Shear stress as a function of shear rate for the coarse sample at 80°F

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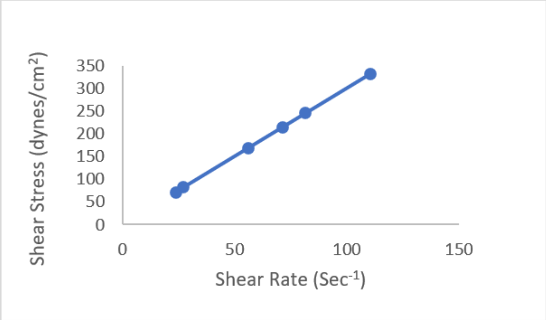


Fig. 11. Shear Stress as a function of shear rate for coarse sample at 120ºF

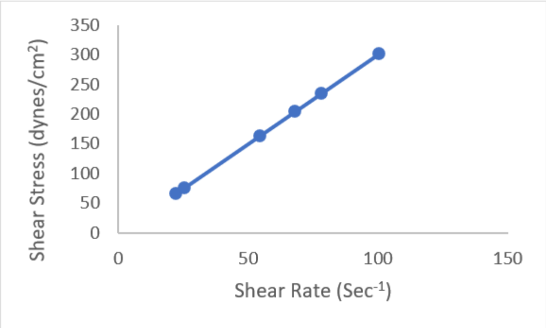


Fig. 12. Shear stress as a function of shear rate for the coarse sample at 150 ºF

4.2 Plastic Viscosity (PV) and Yield Point (YP) variations at different particles

The plastic viscosity and yield point of the drilling mud are key rheological parameters used to determine the performance of drilling fluid in terms of hole cleaning, suspension of drill cuttings when circulation is ceased, and fluid friction losses. The impact of particles of calcium carbonate on the rheological properties of the drilling mud is shown in Figures 12 – 13, respectively.

In Figure 13, the results of the PVs of drilling fluid with carbonate in fine, medium, coarse, and a mixture of different particle sizes at varied temperature values are presented. It is noted that the PV of the carbonate particle size mixture dropped sharply and then increased as the temperature increased. The same trend was observed in the medium, but the decrease and increase in the PV were not as sharp as that of the mixture. However, the PVs of fine and coarse showed an increase and peaked at 120°F and initiated a decline (Figure 13). The behavior demonstrated by the acceptable carbonate additive can be attributed to the increased surface contact. In contrast, the coarse carbonate sample resulted in solid particles in the mud, which tend to change the viscosity of the drilling fluid. From observation, coarse carbonate particle size performed best in terms of increasing the viscosity of the drilling fluid.

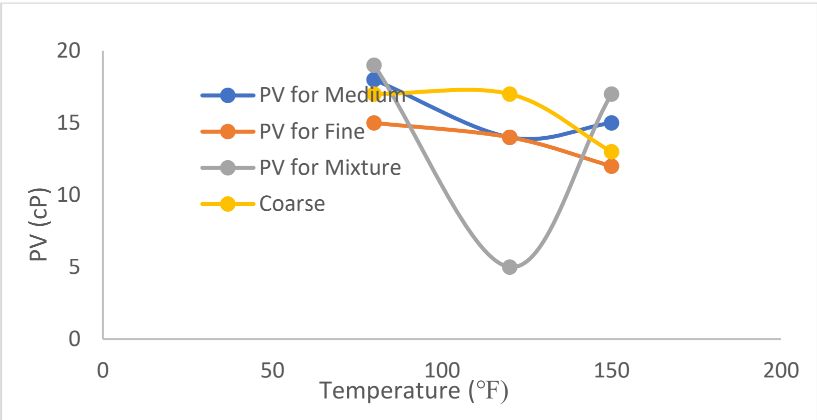


Fig. 13. Plastic Viscosity, PV variation with particle sizes as a function of Temperature

Figure 14 showed the Yield Point, YP of the drilling fluid. It is observed that the YP showed an increased as the temperature of fine, medium and the mixture and peaked at 120°F, but course particle declined the YP and became minimum at 120°F. The mixture sample showed optimum performance because, high YP is an indication that the drilling fluid shear at high temperature and will lose its rheological property due to the high temperature change downhole. The YP of the medium particle size was also observed to conform because of its performance at increasing temperature.

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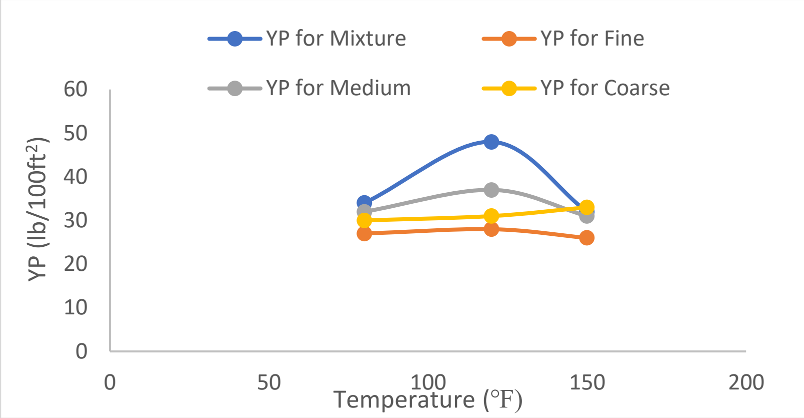


Fig. 14. Yield Point, YP Variation with Particle sizes as a function of Temperature, °F

4.3 Gel Strength Variations with Particle Sizes

The variation in gel strengths of the mud treated with different particle sizes is shown in Figure 15. The result (Figure 15) indicates that the gel strength decreased as the temperature increased. The coarse sample exhibited a sharp decline as the temperature rose, meaning that at higher temperatures, gel strength will decrease, thereby affecting the capacity of the drilling fluid to suspend cuttings. The gel strength of the mixture sample showed a slow decline at various temperatures. The temperature increase had a negligible impact on the gel strength, indicating a stable fluid property. Both medium and fine samples show decreased gel strength, indicating poor performance. Therefore, in terms of performance, the gel strength of the mixture-based drill fluid was better than that of the fine, coarse, and medium.

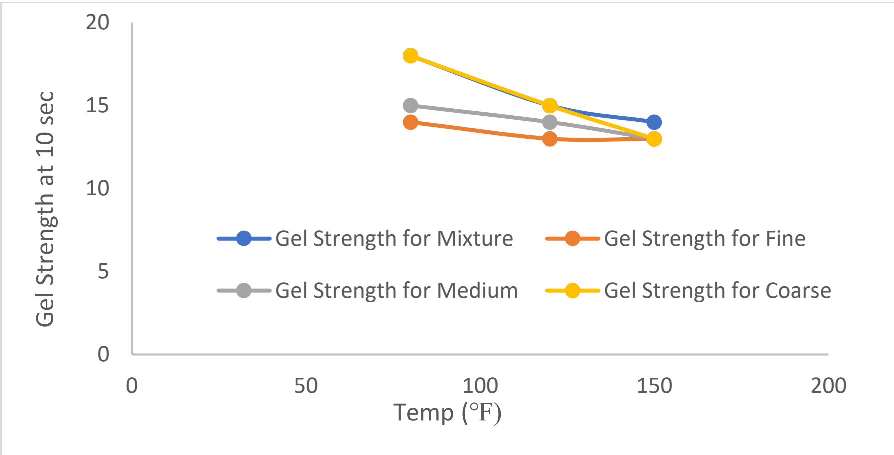


Fig. 15. Gel Strength Variation with particle size as a function of Temperature, °F

## V. CONCLUSIONS

The work aim to investigate the conditions of particle sizes on the drilling fluid properties of water-based drilling fluid. Different particles sizes were study, examined, and analyzed under different conditions. The results obtained were plotted and discussed. However, the following are the conclusions from the study:

- The particle sizes of the carbonate additive did not have a significant impact on the flow properties of the drilling fluid at different temperatures, as the plots of shear stress against shear rate indicated the typical drilling fluid flow model for mixture, medium, fine, and coarse.
- The gel strength of the drilling fluid was found to be optimally improved by a mixture of all three particles of the carbonate as the gel strength increased with an increase in temperature.
- The Plastic viscosity and yield point were also altered by the particle sizes of the carbonate. The Plastic viscosity of the coarse particle size carbonate-based drilling fluid was found to be the best as the PV increased favorably with the temperature increase.

- Shear thinning for all the particle sizes followed the same trend, demonstrating negligible alteration of the apparent viscosity because the slope of the shear stress/shear rate gives apparent viscosity.

5.1 Recommendations

The initially stated aim of this study was to investigate the effect of particle size on drilling fluid properties in water-based drilling fluids. In the process of carrying out the work, there are some gaps in our knowledge around the investigations and analysis of our findings, and it would be beneficial for further research. Hence, the following are recommended:

- Further research should be carried out to show how varied concentrations of carbonate affect the rheological properties of drilling fluid. The work should be done using oil-based mud since this study was carried out using water-based mud.
- Understanding the effect of size and concentration of $CaCO_3$ and the relationship between the size and concentration of $CaCO_3$ in other properties like fluid Loss.
- Investigate the effect of concentration and particle size of $CaCO_3$ on the rheological and filtration properties of drilling fluids and make a comparison for each size and concentration, which is another area of further studies.
- Determination of Particle Size Distribution.- concentration and their pH should also be carried out.
- Investigating the SEM Images for the drilling fluid samples at each particle size and different concentrations should be looked into for further studies.
- Lastly, the government should invest more in research and development to improve local content.

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Conflict of Interest

No conflict of interest

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