Universal Library of Engineering Technology | Research Article
Volume 1, Issue 2
Open Access | PP: 01-07
DOI: https://doi.org/10.70315/uloap.ulete.2024.0102001

# Enhancement of Water Based Mud Cutting Carrying Capacity Using Aluminium Oxide ($Al_2o_3$) Nanoparticle

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## Abstract

*This research seeks to determine how much $Al_2O_3$ nanoparticles can alter the rheological properties and cutting carrying capacity of bentonite-water drilling fluids when different concentration is applied. The aim is to explore these phenomena. The purpose of the research is to produce and describe drilling fluid using nanoparticles and evaluate its cutting-capture capability. The study examined the physiochemical, rheological, and filtration properties, as well as the cutting carry index (CCI) of samples produced from drilling in various concentrations of $Al_2O_3$nanoparticles. The control mud was created using bentonite with a concentration of 2.8g (0% $Al_2O_3$) without any nanoparticles. $Al_2O_3$ was discovered to enhance the plastic viscosity, apparent viscousness, and yield point, but inhibit the gel strength of the drilling fluid. Nevertheless, The Power Law Model was used to describe the Rheological behavior of the prepared mud samples, with a flow behavior index (n) less than 1, which indicated that the formulated muddy samples were all pseudo plastic fluids, ideally suitable for drilling fluid. According to the study, the addition of MgO and $Al_2O_3$ nanoparticles can affect the cutting carrying index, resulting in a high-cutting carrying Index that enhances the hole cleaning potential of the drilling mud.The findings of this study indicate a high cutting carrying capacity index, indicating the feasibility of using nanoparticles in drilling operations.*

**Keywords:** *Hole Cleaning, Nanoparticles, Rheology, Shear Rate, Shear Stress.*

## INTRODUCTION

More extended rich wells, ultra-deep wells, and highly deviated wells are being drilled to meet the growing global energy demand Bakke, Ø. O., (2012). The issue of correct drilling operations, which can be helped by the great carrying capacity of drill cuttings and debris, is one of the major obstacles in highly deviated and prolonged rich wells. This can lead to proper hole-cleaning during drilling Bakke, Ø. O., (2012). The type of drilling fluid used can be the cause of poor hole cleaning, which leads to a variety of drilling issues such as excessively high gel, stuck pipe, potential hole pack-off, fishing operations, fewer drilled holes, formation breakdown and cuttings accumulation, etc. Hossain, et. al., (2018).

This investigation was necessary because there are a number of issues with drilling fluids' good carrying capacities, both for those made with standard materials and those made using local resources Ali, et al., (2020)

The study aims at producing water based mud that will enhance cutting carrying capacity.

## MATERIALS AND METHOD

### Materials

The following apparatus and materials were used for the experiment: Conical Flask, Marsh funnel, Electric Mixer, Baroid mud balance, Speed Rheometer, PH Meter, Heater, Stirrer, Thermometer, Retort Stand, Crucible, Measuring cylinders, Plastic rubber, Mixer, Electric weighing balance,Spatula pH strip, API filter press, Potassium Chloride, Borax, Poly Anionic cellulose, Bentonite, Caustic Soda, Xanthan gum, water based mud, and industrial graded 75nm Aluminum Oxide ($Al_2O_3$) nanoparticle.

### Mud Preparation

In accordance with API (American Petroleum Institute) guidelines, a fresh bentonite mud was made. A combination of about 2.8g Bentonite, 0.20g soda ash, and 0.20g caustic soda was combined with 350ml of water, and it was allowed to sit at room temperature for a whole day (Table 1).The control mud contain 2.8g of bentonite without the addition of $Al_2O_3$ nanoparticle (0% $Al_2O_3$), the second drilling mud contain (2.24g bentonite and

0.56g $Al_2O_3$ (20% $Al_2O_3$nanoparticle), the third mud contained 1.82g bentonite and 0.98g $Al_2O_3$ nanoparticle (35% $Al_2O_3$nanoparticle), the fourth mud contained (1.4g bentonite and 1.4g $Al_2O_3$nanoparticle(50% $Al_2O_3$ nanoparticle), the fifth mud contained 0.98g bentonite and 1.82g $Al_2O_3$ nanoparticle (65% $Al_2O_3$ nanoparticle),the sixth mud contain 0.56g bentonite 2.24g $Al_2O_3$ nanoparticle (80% $Al_2O_3$ nanoparticle), the seventh mud contained 0g bentonite and 2.8g $Al_2O_3$ nanoparticle (100% $Al_2O_3$ nanoparticle). Thereafter, all of the mud samples' rheological characteristics, mud cake thickness, mud cake permeability, pH, and density tests were carried out.

**Table 1.** Drilling Mud Additives

| S/N | Additives | Concentration | Property |
|---|---|---|---|
| 1 | WBM | 350ml | Base-fluid |
| 2 | Potassium Chloride | 18.00g | Inhibition control Agent |
| 3 | Borax | 2.00g | Preservative |
| 4 | Xanthan gum | 2.80g | Viscosifier |
| 5 | Polyanionic cellulose | 2.00g | Filtration control |
| 6 | Barite | 76.80g | Weighting material |
| 7 | Soda ash | 0.20g | Calcium ion remover |
| 8 | Caustic Soda | 0.20g | Alkalinity control |
| 9 | Bentonite | 2.8g | Viscosifier |
| 10 | Aluminium oxide | Varying | Filtration loss reducer/rheology modifier |

## Rheological Properties Determination

For the 600 rpm reading, a constant indicator dial value was found and noted. In addition to recording a constant indicator value at 200, 100, 60, 30, and 6 rpm, the switch was adjusted to a speed of 300 rpm. For repeatability, dial readings were made three times, and the average results were given. AV, PV, μe, YP, and the gel strength (GS) after 10 seconds and 10 minutes were calculated using the Bingham plastic fluid model, which is represented by Equations (1) through (4):

$$\text{PV (cP)} = \theta_{600} - \theta_{300} \tag{1}$$

$$\text{YP (cP)} = \theta_{600} - PV \tag{2}$$

$$\text{AV (cP)} = \frac{\theta 600}{2} \tag{3}$$

$$\mu_e = 300 \times \frac{\theta}{\omega} \tag{4}$$

Where,

$\theta_{300}$ = dial reading at 300 rpm

$\theta_{600}$ = dial reading at 600 rpm

PV = plastic viscosity,

AV = apparent viscosity, and

YP = yield point.

The drilling mud's capacity to suspend drilled cuttings is measured using the 10 sec and 10 min gel strength (G_s)

As a result, the fluid consistency index (K) and flow behaviour index (n) may be calculated. Previously, the resulting dial readings and the rotor speed data were transformed using Equations (5) and (6) to shear stress (τ) and shear rate values (γ), respectively:

$$\tau\left(\frac{ib}{100ft^2}\right) = 1.067 \times \theta \tag{5}$$

$$\gamma(1/s) = 1.704 \times \omega \tag{6}$$

$$n = 3.23 \times log \frac{\theta_{600}}{\theta_{300}} \tag{7}$$

$$K\left(\frac{ib}{100ft^2}\right) = \frac{\tau}{\gamma^n} = \frac{\theta_{600}}{1022^n} \tag{8}$$

Where;

θ (lb/100 $ft^2$) shows the dial reading, 1.067 is the viscometer's geometry factor, ω is the viscometer's (rotor) speed (rpm), and 1.704 is the factor obtained from the viscometer's sleeve and bob geometry.

## Power Law Constants (N and K) Calculation

According to the behavior between the Bingham Plastic model and the Newtonian fluid model, several varieties of drilling mud are categorized as non-Newtonian fluids Obuebite, et al., (2023). The power law model that follows defines the link between shear rate and shear stress:

$$\text{Shear Rate } (\gamma) = \text{Rotational Speed x } 1.703 \tag{9}$$

$$\text{Shear stress } (\tau) = k\gamma^n \tag{10}$$

Where:

$\tau = shear\ stress$

K=$constitency\ factor$

$\gamma = shear\ rate$

$n$= flow behavior index

Shear rate and shear stress values of any two may be used to compute n and K. A V-G metre is used to determine the shear rate on the rig. Every mud test usually yields readings of 600 rpm, 300 rpm, and 3 rpm, which we may use to calculate n and K.

The following equations are used to get the Power law constants (n and K).

$$n = 3.22log\frac{(2PV+YP)}{(PV+YP)} \tag{11}$$

$K = (511)^{1-n}(PV+YP)$

## Determination of Cutting Carrying Capacity

A CCI value of 0.5 or below indicates inadequate hole cleaning, whereas a CCI value larger than or equal to one to unity indicates the proper hole cleaning Du, et al., (2018)..

Equation 7 may be used to get K, which is the fluid consistency index (power law constant) in this equation. The annular velocity, expressed in feet per minute, is called Vann. While PV and YP are the same characteristics of the Bingham plastic model and are expressed in cp and lb 100ft2, respectively, MW is the drilling fluid density in Al-Shargabi, et al., (2022). The dimensionless flow behaviour index is denoted by n.

The CCI is an empirical relationship from real data and the give below:

$$CCI = \frac{(K \times AV \times MW)}{400{,}000} \qquad (12)$$

Where;

AV is annular velocity in ft/min.

MW is mud weight in ppg.

K is a Power Law Constant.

The Power Law constant (K) can be calculated from the equation below:

$$K = (511)^{1-n}(PV+YP) \qquad (13)$$

Where;

PV is plastic viscosity in centipoises.

YP is yield point in lb/100sqft

n is flow behavior index.

The flow behavior index (n) can be determined by the following equation:

$$n = 3.22 log \frac{(2PV+YP)}{(PV+YP)} \qquad (14)$$

Where;

PV is plastic viscosity in centipoises.

YP is yield point in lb/100sqft.

## RESULTS AND DISCUSSION

### Plastic Viscosity

Figure 1 shows that the addition of $Al_2O_3$ nanoparticle to WBM prepared using bentonite at different varying concentration of bentonite and $Al_2O_3$ nanoparticle 0% $Al_2O_3$, 20% $Al_2O_3$, 35% $Al_2O_3$, 50% $Al_2O_3$, 65% $Al_2O_3$, 80% $Al_2O_3$, 100% $Al_2O_3$. "The plastic viscosity of n-WBM increases as concentrations of nano- $Al_2O_3$ added into the WBM increases as shown in Figure 1. Even though the increment is infinitesimal, the plastic viscosity (30 – 39 cP) obtained in this study for 20-100 wt% concentrations of nano-$Al_2O_3$ in n-WBM and the plastic viscosity of n-WBM increases as concentrations of nano-$Al_2O_3$ added into the WBM increases. The plastic viscosity (30 – 39 cP) obtained in this study for 20-100 wt% concentrations of nano- $Al_2O_3$ in n-WBM, was found to be consistent with literature."

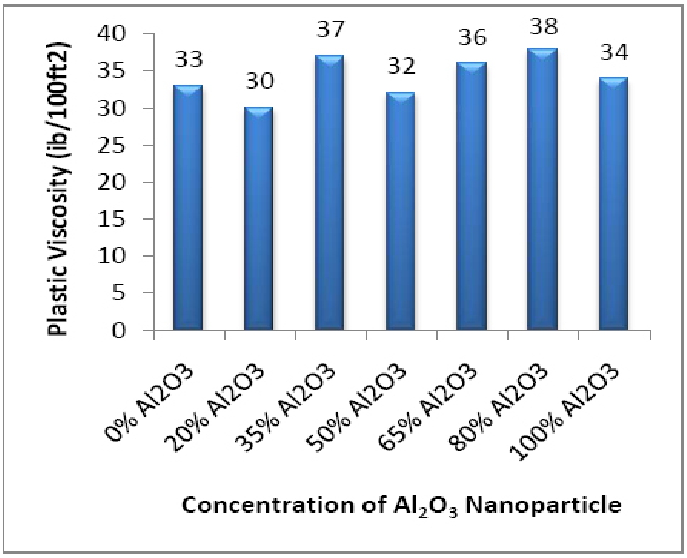


**Fig 1.** Effect of varying concentration of $Al_2O_3$ nanoparticle on plastic viscosity in water based drilling mud

### Yield Point

Figure 2 shows that the yield point of the drilling mud increases as the concentration of mud increases. Before adding the magnesium oxide nanoparticle, the yield point of the mud water based mud was 113 Ib/100ft$^2$.

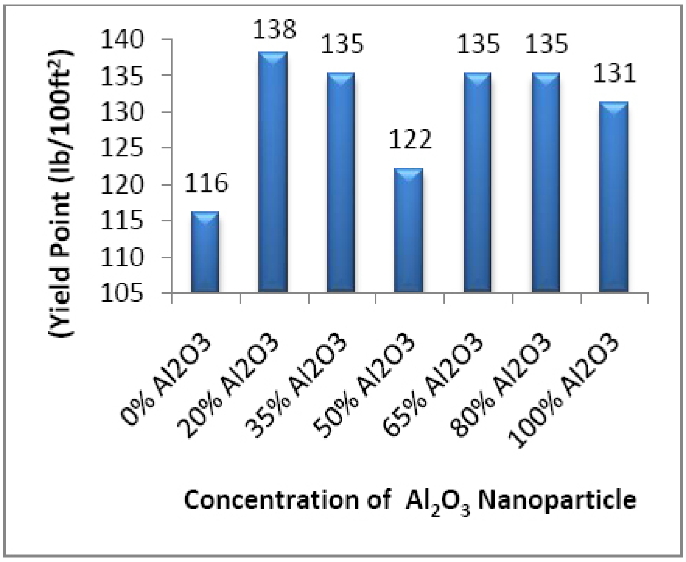


**Fig 2.** Effect on yield point of at varying concentration of $Al_2O_3$ nanoparticle in drilling fluid samples

### Apparent Viscosity

Before adding the aluminum oxide nanoparticle, the apparent viscosity of base mud was 73cp. While with varying concentration $Al_2O_3$ at different ratio, 20% $Al_2O_3$, 35% $Al_2O_3$, 50% $Al_2O_3$, 35% $Al_2O_3$, 65% $Al_2O_3$ 80% $Al_2O_3$ and 100% $Al_2O_3$, Drilling mud's average volumetric variation (AV) grew dramatically from 84 to 86 to 77 to 85.5 to 86.5 and 82.5, respectively. Therefore, we may conclude that the addition of 20% $Al2O_3$ nanoparticle to the Al2O3 water base mud enhanced its AV and stabilised its viscosity throughout drilling.

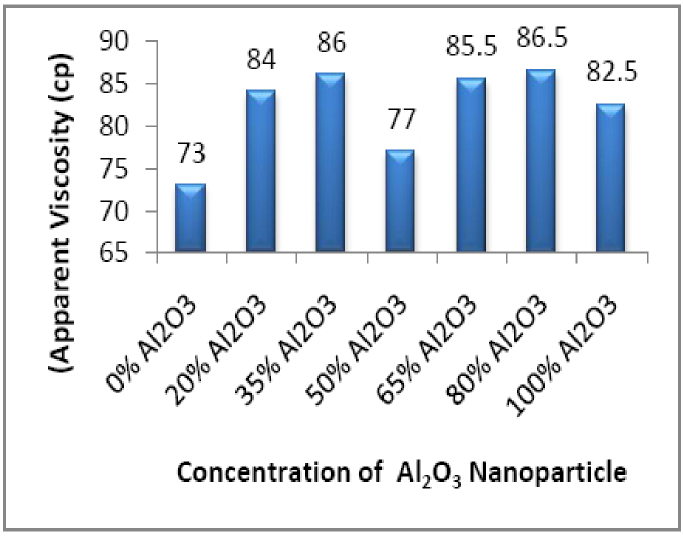


**Fig 3.** Effect of varying concentration of $Al_2O_3$ nanoparticle on apparent viscosity water based drilling mud

## Gel Strength

The viscometer is utilized to assess the gel strength of drilling fluid, mainly at 3 RPM, at intervals of 10 seconds and 10 minutes. In static conditions, it represents the strength of the attractive forces in the drilling mud Salih, A. H., et al., (2016). According to Kasmi, et al., (2017), the addition of different concentrations of nanoparticles to the base mud steadily enhanced the gelation of drilling fluids, as demonstrated by the gel 0 and gel 10 values of the various percentage concentrations of drilling fluids created utilising nanoparticles.

The gel strength of the formulated muds are represented above in Fig 4. The gel strength of the formulated muds using $Al_2O_3$ nanoparticles were 42 ib/100ft$^2$ at 10seconds and 41 at 10mins for the control mud produced without adding the $Al_2O_3$ nanoparticles, at 20% $Al_2O_3$ nanoparticle, the gel strength was 38 ib/100ft$^2$ at 10secs viscometer and 40 ib/100ft$^2$ at 10mins , at 35% MgO the gel strength was 36 ib/100ft$^2$ at 10secs viscometer and 36 ib/100ft$^2$ at 10mins, at 50% $Al_2O_3$ the gel strength was reduced 30 ib/100ft$^2$ at 10secs viscometer and 30ib/100ft$^2$ at 10mins , at 65% MgO the gel strength was reduced 34 ib/100ft$^2$ at 10secs viscometer and 33ib/100ft$^2$ at 10mins , at 80% $Al_2O_3$ the gel strength was 36 ib/100ft$^2$ at 10secs viscometer and 36ib/100ft$^2$ at 10mins, at 100% $Al_2O_3$ the gel strength was 38 ib/100ft$^2$ at 10secs viscometer and 38ib/100ft$^2$ at 10mins. Which indicate that the the gel strength reduces with addition of nanoparticles. Additionally, excessive gel strength shouldn't be promoted since it might result in a variety of drilling issues Okie-Aghughu, et al., (2013).

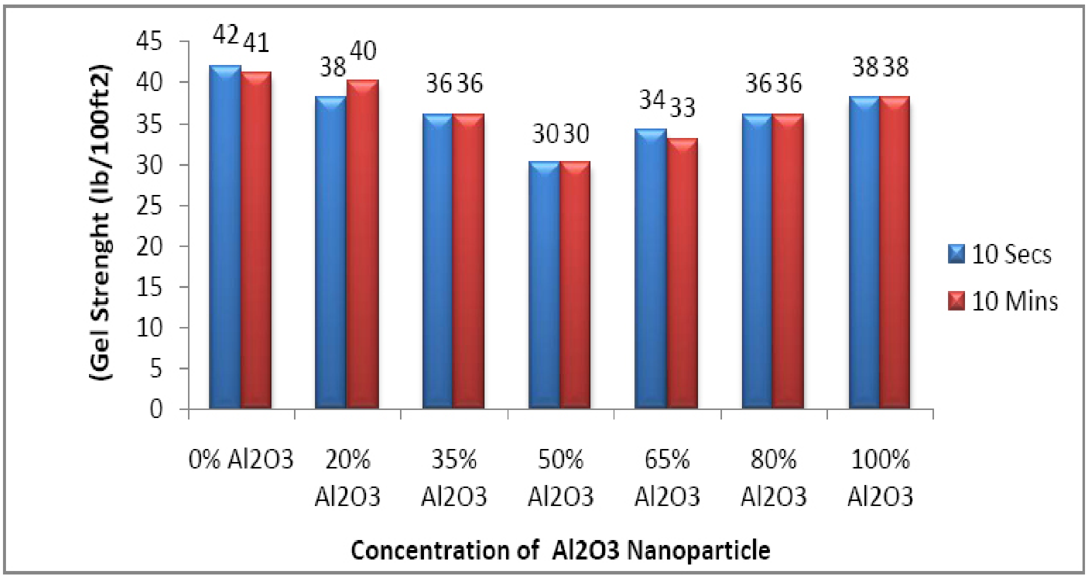


**Fig 4.** Effect of varying concentration of $Al_2O_3$ nanoparticle on gel strength water based drilling mud

## Mud Density

Figure 5shows the mud density of mud samples produced with a varing concentration of bentomnite and $Al_2O_3$ nanoparticle. The control of mud with contain drilling mud produce using bentonite and other additive had the density of 9.9 and specific gravity of 1.19, 20% $Al_2O$ had a mud density of 9.9, 35% $Al_2O$ had a mud density of 9.9, 50% $Al_2O$ had a mud density of 9.95, 65% $Al_2O$ had a mud density of 10.1, 80% $Al_2O$ had a mud density of 10 and 100% $Al_2O$ had a mud density of 9.9, the result shows that the mud density of drilling mud was increased significantly.

The reservoir conditions will determine the density of the water-based mud to be utilised, and high-density oil has the benefit of requiring less barite, which lowers formulation costs Paswan, et al., (2016). Muds with high density are desirable.

Figure 5 shows the mud density of mud samples produced with a varying concentration of bentonite and $Al_2O_3$ nanoparticle

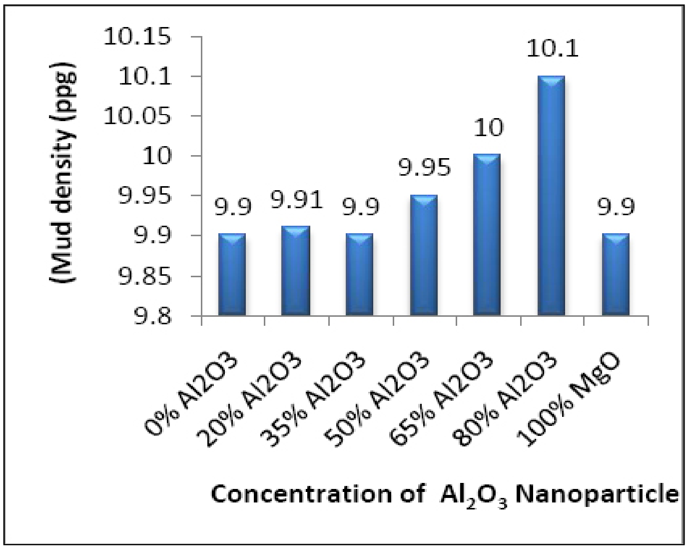


**Fig 5.** Mud Density of $Al_2O_3$ Mud Samples

## Mud Filtrate Properties

### *Filtration Volume*

As seen in Figure 6, the filtrate volume saw a small reduction in filtering loss as the content of aluminium oxide increased. But thereafter, a rising trend was noted due to the increased aluminium content of the mud suspensions. The results corroborate the theory that the more magnesium contained in the mud suspension, the higher the degree of flocculation Unegbu, et al., (2010). The rise in filtration loss is well recognised as a sign of flocculation, which is caused by the increasing attraction force between the particles Robertson, et al., (1976).

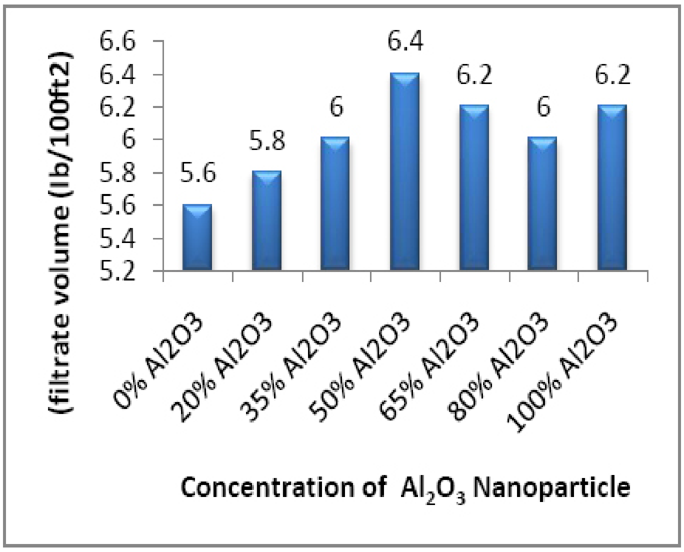


**Fig 6.** Filtration Volume of $Al_2O_3$ Mud Samples

### *Filter Cake Thickness*

Figure 7 shows the mud samples' filter cake thickness. Figure 7 displays the filter cake thickness and filtration rate results. Reduces in the thickness of the filter cake were seen from the low concentrations of Aluminium nanoparticles, beyond which mud samples began to create thicker filter cakes, as was evident from the filtering volume data. As shown in figure 4.7 before the addition of the Aluminum oxide $Al_2O_3$ nanoparticle, filter cake thickness of water based mud was 4.57mm. While with varying concentration $Al_2O_3$ at different percentage ratio of bentonite and nanoparticle, 20% $Al_2O_3$ had a yield point of 4.21mm, 35% $Al_2O_3$ had a yield point of 4.25 mm, 50% $Al_2O_3$ had a yield point of 3.94 mm, % $Al_2O_3$ had a yield point of 4.05 mm, 80% $Al_2O_3$ had a yield point of 4.24 mm and 100% $Al_2O_3$ had a yield point of 4.17 mm. Therefore, the Aluminum oxide nanoparticle mud with lesser mud cake thickness prove to be better.

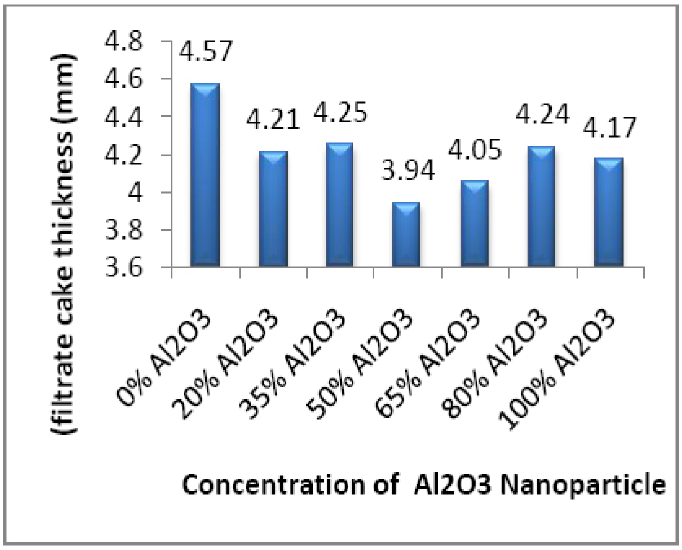


**Fig 7.** Filter Cake Thickness of $Al_2O_3$ Mud Samples

## Shear Properties

Fig 8 shows the Shear Stress vs Shear Rate Plot for Aluminium Oxide nanoparticle.

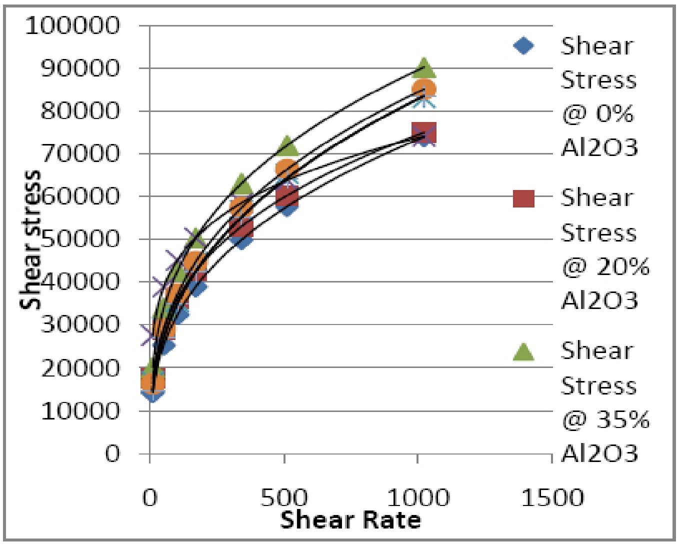


**Fig 8.** Shear Stress Vs Shear Rate Plot for Aluminium Oxide nanoparticle drilling mud

The Power Law Model was used to calculate shear rate and shear stress, using equations 3.9 and 3.10. The Power Law Constant (K) also known as Consistency Factor and Flow Behavior Index (n) are the two parameters used here to describe the flow characteristics Speers, et al., (1987) and Power, et al., (2003).They were calculated using equations 3.7 and 3.8 to be 0.358,0.2866, 0.3367, 0.3261, 0.3494, 0.3352, 0.362 (lbs.sn/100ft$^2$) for the various percentage weight concentration of the drilling mud produced using $Al_2O_3$ nanoparticle and 6192.76, 11291.75, 8512.0496, 8157.6398, 8402.53, 7002.35, 7748.242 respectively. A typical Power law model plot gives a strong flow curve [24]. Due to the value of n obtained from this study, the Power law model plot gives a strong curve which indicates that the value of is appropriate for the drilling mud produced using $Al_2O_3$ nanoparticle.

## Cutting Carrying Capacity Index Of Nanoparticle Water Based Drilling Mud

Cutting Carrying Index (CCI) it measures a drilling fluid's capacity to transport drilled cuttings within the hole Andaverde, J. A., et al., (2019)A higher cutting carrying index indicates better hole cleaning capabilities [28].

How the CCI tells us about hole cleaning;

i. If the CCI is 0.5 or lower, the hole cleaning is poor, and issues with the hole may arise.

ii. If the CCI is 1.0 or higher, it indicates that the hole cleaning is effective.

iii. A higher CCI indicates a better cutting carrying capacity

This was analyzed using equations 3.6, 3.7 and 3.8 and the calculations are presented in Appendix A, equation 3.9 and 3.10 were used to calculate n and K.

Annular velocity of 150ft/min was used for the calculations the cutting carrying index, CCI as it is a standard for annular velocity in oil wells.

**Table 2.** Cutting carrying capacity of $Al_2O_3$ Nanoparticle Mud

| Mud sample | CCI |
|---|---|
| 0% $Al_2O_3$ | 22.8 |
| 20% $Al_2O_3$ | 41.9 |
| 35% $Al_2O_3$ | **31.6** |
| 50% $Al_2O_3$ | 30.3 |
| 65% $Al_2O_3$ | 31.5 |
| 80% $Al_2O_3$ | 29.3 |
| 100% $Al_2O_3$ | **25.7** |

This study is found to be consistent with study by Skadsem, et al., (2019). of which they stated that Higher CCI's, mean better hole cleaning capacities.

## CONCLUSION

The study investigates the use of $A_l2O_3$ nanoparticles to enhance the filtration properties of water-based mud. Through rheological and filtration loss tests, it was found that the addition of these nanoparticles significantly affects the rheological properties of drilling fluids. The study also found that the addition of $Al_2O_3$ nanoparticles increases the yield point, apparent viscosity, and plastic viscosity of the drilling fluids. The gel strength of the drilling mud produced using these nanoparticles decreases with increasing concentration. The results indicate a high cutting carrying capacity index, indicating the feasibility of using nanoparticles in drilling operations.

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**Citation:** Godloves, T. N., Ebri, R. U., Ihua-Maduenyi I. E., Alerechi, U.P, "Enhancement of Water Based Mud Cutting Carrying Capacity Using Aluminium Oxide ($Al_2o_3$) Nanoparticle", Universal Library of Engineering Technology, 2024; 1(2): 01-07. DOI: https://doi.org/10.70315/uloap.ulete.2024.0102001.