Quest Journals
Journal of Research in Mechanical Engineering
Volume 12 ~ Issue 2 (Mar. – Apr. 2026) pp: 09-23
ISSN(Online):2321-8185
www.questjournals.org

Research Paper

Formulation of Multi-walls Carbon Nanotubes and Bamboo Raw Modified for Strength at Various Temperature in Local Base Mud

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Abstract
This paper studied the formulation of Multi-walls carbon nanotubes and Bamboo raw modified for Strength at various temperature in local base mud. The formulation of drilling fluids often involves several variables such as bentonite content, polymer concentration, pH, salinity, and temperature, all of which interact in complex and nonlinear ways to influence the viscosity. Small variations in any of these parameters can significantly alter the rheological properties of the fluid, sometimes resulting in operational problems such as inadequate hole cleaning, excessive pressure losses, poor lubrication, or stuck pipes. Many additives is also added to influence properties such as density, viscosity, and wettability. The cutting suspension and lifting ability of the mud is the most important functions. Conventional based muds are made of Wyoming bentonite dispersed in water or oil as continuous phase in the presence of synthetic additives to enhance its property. The focus of this study is to formulate the multi-walls carbon nanotubes and Bamboo raw to modify the Strength at various temperature in local base mud with biopolymers and Nanoparticles (Multiwall Carbon nanoparticles and Bamboo raw and Modified) to meet API standards and serve as a substitute to the expensive and environmentally unfriendly synthetic muds. Modified Clay was enhanced with a composite of Arabic Gum and Cocoyam starch, Sodium Hydroxide, Potassium Chloride and weighted with barite to create a base mud formulation The plot shows that as temperature increases; the yield point also increases. When compared to the formulation without CNTs, some MWCNT and BRM formulations gave higher values of yield point. It indicates that the gel strength at 10' seconds increased exponentially with temperature, but highest in 0.1g MWCNT at temperature of 94°C and gel strength of 30.5 lb/100 sqft. As the concentrations of Gum Arabic increased between 2 to 20 g, Plastic and Apparent viscosities increased accordingly. Gel strength was observed to decrease with the addition of 2, 5 and 15g concentration, the gel increased to its previous value as before and at 20 g, it increased a little at 10 minutes gel.

Keywords **–** *Multi-walls, carbon nanotubes, Bamboo raw modified, Strength, temperature.*

*Received 28 Mar., 2026; **R**evised 06 Apr., 2026; **A**ccepted 08 Apr., 2026 © The author(s) 2026.*
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I. Introduction

In practical drilling operations, the formulation of drilling fluids often involves several variables such as bentonite content, polymer concentration, pH, salinity, and temperature, all of which interact in complex and nonlinear ways to influence the viscosity (Rana, 2015). Small variations in any of these parameters can significantly alter the rheological properties of the fluid, sometimes resulting in operational problems such as inadequate hole cleaning, excessive pressure losses, poor lubrication, or stuck pipes (Rana, 2015). The traditional method of adjusting drilling fluid formulations by trial and error or changing one factor at a time is inefficient, time-consuming, and costly. Moreover, these conventional approaches do not account for the combined or interactive effects of multiple variables, which often play a crucial role in determining the overall performance of the fluid. Drilling fluids experience an extreme range of different external conditions such as temperatures, pressures, and shear rates. Extensive testing is therefore required for prediction of behaviour and to generate accurate models before these polymers are deployed on the field. The application of local clays and additives at field level has not been widely reported. This is due to certain inherent property limitations when compared with the API requirements. Studies (Rabia, 2001) have shown the potential of local biopolymers and clay in oil and gas. The hydraulics of bentonite and other local additives dispersed in water are not widely reported. Research (Ogunride and Dosunme 2012) has shown that the use of 100% local materials in the formulation of drilling mud suffers poor lifting capacity, high-pressure loss and thermal instability due to altered rheological properties at downhole conditions. Hence, this study intends to improve on cuttings carry ability and thermal stability of local-based mud using synthetic multi-walls carbon nanotubes (MWCNTs) and locally sourced Activated carbon (BRM) produced from a Bamboo tree.

II. Materials and Methods

2.1 Materials

Clay samples were collected by using hand auger to scoop the clay materials from swamp forest Omuike Aluu in Rivers State, Nigeria. The samples were collected from Ikwerre local government at location with latitude 6.97514º N and longitude 3.74545º E between Aluu and Isiokpo, Ikwerre, Rivers state, Nigeria.

- **Clay Purification and Processing**

The raw clay samples were purified to remove all gross impurities in the sample. Samples were ground using the electric grinder to reduce the particle size to less than 60 µm. The powder was wet sieved using distilled water to separate the clay from impurities such as rocks and sand. The resulting slurry was allowed to sediment and decanted. Wet sieved clay was be air - dried to reduce the moisture content and thereafter be oven dried at 70 ºC in an electric oven until a constant weight was achieved.

- **Clay Beneficiation / Selection**

Clay beneficiation was carried out according to Kuna et al. (2023). The beneficiating agent that was employed was Na2CO3 at concentrations ranging from 1.1 M to 5.5 M. The selection of the concentration range was based on previous research by Kelvin et al. (2022). The processed clay (100 g) was dispersed in 100 ml of distilled water to form slurry and the slurry was preheated to 60 ºC for 5 minutes. The beneficiating agent (100 ml) was added to the preheated slurry and the mixture heated to 90 ºC between 60 and 80 mins under continuous stirring. The slurry formed was sun-dried to reduce the moisture content and later oven-dried in an electric oven (Surgifield Laboratory oven, SM9053A) at 80 ºC until a constant weight was achieved. The dried clay was ground to less than 100 microns using an electric grinder (Marlex Appliances PVT Limited).

The equipment used in this study to achieve the objectives are Zeiss Scanning electron microscope, Weighing balance, Sand Retort Kit, Multi-Mixer, Mud balance, variable speed rheometer in Mechanical Engineering and Petroleum Engineering Laboratories of university of Port Harcourt.

- **Scanning electron microscope (SEM):** The scanning electron microscope is an electron microscope that produces a surface image of samples with a focused beam of electrons is allowed to interact with the atoms of the samples thereby producing signals that display the surface topography and composition of the sample. Energy dispersed spectroscopy (EDS) involves the elemental analysis and chemical characterization of a sample through some source of X-ray excitation from a sample caused by allowing a focused beam of the electron into the sample
- **Weighing balance:** Weighing scale or balance is a device used to measure the mass or weight of samples.
- **Sand retort kit:** The volume of sand sized particles in the drilling fluid is determined by a sand content kit. Materials with size greater than 74 µm (200 mesh) are sand particles and not fit for drilling usage.
- **Multi-mixer:** To get accurate results from drilling fluid experiments, drilling mud samples in the process of their preparation are mixed thoroughly to create an homogeneous mixture. Multimixers are used to mix drilling mud samples in preparation for laboratory tests.
- **Mud balance:** Mud balance is used to determine the density or weight of a given volume of liquid or drilling mud. It is are calibrated in pounds per gallon (Ib/gal), specific gravity (SG, kg/m3), Pounds per cubic feet (Ib/ft3),Pounds per square inch per 1000feet (Ib/in2/1000ft).
- **Variable speed viscometer:** Variable speed viscometers are used to study rheological or flow behaviour of drilling mud suspensions. It gives the shear stress and shear rate relationship of drilling fluids with respect to time and temperature. Properties such as plastic and apparent viscosity, yield point, gel strength can be determined by the use of an 8 speed viscometer.

The materials used in the drilling mud formulations and their functions are given in the table below:

Table 2.1: Components of Drilling Mud Formulations.

Component	Functions
Modified Gombe Clay	Local based clay to be suspended in water
Barite	Weighting agent

Cocoyam Starch	Viscosifier and fluid loss additive
millet Starch	Viscosifier and fluid loss additive
Gum Arabic	Viscosifier and fluid loss additive
Caustic soda(NaOH)	PH Modifier
Potassium Chloride(KCl)	Shale Inhibitor additive
Water	The continous phase of the drilling mud sample
Carbon Nanotubes	Fluid loss additive

III Methods

The experimental design is in three stages and is shown below;

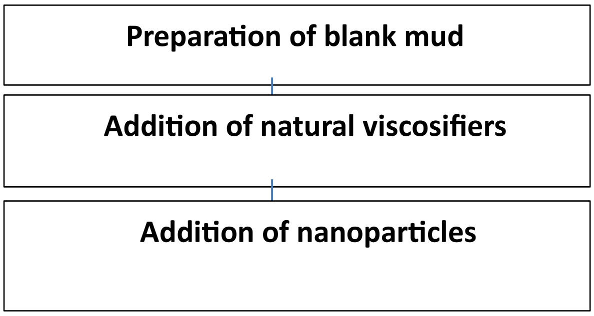

Figure 2.1: Experimental design

- **2.2.2 Blank mud preparation**
  - A water-based mud is prepared with 24.5g of Gombe clay and 350ml of water. Density, Apparent and plastic viscosity, Yield point, Gel strength, solid content and thixotropy is taken immediately and after 24 hours to observe aging effect.
  - The previous step is repeated with imported bentonite.
- **2.2.3 Natural viscosifiers addition**
  - Three new mud formulations having 2g, 5g and 8g Corn starch in Hydrated Gombe clay mud samples is prepared and the density, apparent and plastic viscosity, Yield point, Gel strength, solid content and thixotropy is measured.
  - The above procedure is repeated with Gum Arabic to give three formulations.
  - Various new formulations are created using composite of gum arabic and cassava starch and their density, apparent and plastic viscosity, yield point, gel strength, solid content and thixotropy were measured.
- **Addition of nanoparticles**
  - The formulation in the previous stage with optimum property values close to API standard is selected
  - Three new formulations by adding 0.1g,0.2g, 0.5g, 0.8g CNTs each to the previously selected mud formulation and thixotropic, filter and gel test is done at Room Temperature, 60oc and 94oF and the final mud formulation is selected.
- **Rheology and hydraulics**

Rheology of the finally selected Gombe mud is taken and the hydraulic pressure losses is determined using existing pressure loss models.

- **Procedure for preparation of mud with and without additive**

A water base mud was prepared by dispersing 24.5g of Gombe clay in 350ml of water and stirred with a multi-mixer.

- **Procedure to determine mud density**
  - Mud mixture with or without additives was prepared and stirred with a multi-mixer and their temperature recorded.
  - Then after, the mud balance base was placed on a flat level surface.
  - The fill cup was filled with the mud sample. The lid was placed on the cup with care taken to prevent trapped air or gas. Some mud that expelled through the hole on the cap helped to ensure the cup is filled.
  - The expelled mud was cleaned off the cup and arm and the balance placed on the knife edge. Afterwards, the rider was moved along the arm until the cup and arm was balanced. This is indicated by the bubble on the arm.
  - Finally, the mud density was read at the edge of the rider towards the mud cup as soon as the bubble stabilizes.

- **Procedure for solid content measurement**
  - The sand content tube was filled to the indicated mark with drilling mud
  - Afterward, the wash bottle was used to add water to the tube to raise its level to the next mark. While ensuring that the mouth of the tube was closed, the tube was shaken vigorously.
  - Then after was the mixture poured onto a screen and water added to the tube to aid flushing of all mixtures onto the screen.
  - The screen was flushed as well to make sure no sand particle is left on the mud remaining on the screen.
  - The funnel was fitted upside down over the top of the screen. The assemble was inverted and the tip of the funnel placed on a mouth of a glass measuring tube
  - Water is poured onto the screen to further flush sand left in the funnel.
  - Finally, the tube containing the flushed sand and water mixture was allowed to settle to get a clear separation of the sand and water and the sand content is measured.
- **Procedure to determine rheology using 8-speed viscometer**
  - The test mud sample was placed in the sample cup and the rotor sleeve immersed in the mud to the fill line by raising the platform and tightening the locknut on the platform.
  - Afterwards, the switch was pressed to turn on the device.
  - The sample was mixed on the "STIR" setting for 10 seconds.
  - Then after the knob was rotated to one of the speed settings and allowed to stabilized and the readings recorded. This is repeated for other speed settings and readings were taken from highest RPMs to lowest RPMs.
- **Procedure to determine gel strength using 8-speed viscometer**
  - The sample was mixed on "STIR" for 10 seconds
  - Then after, the knob was rotated to "GEL" and the power was immediately shut off.
  - As soon as the rotation of the sleeve stopped, the clock was set to 10 seconds after which the power was turned on and the maximum deflection was recorded as the dial reading which the 10 seconds gel strength is.
  - To get the gel strength for 10 minutes, the sample was re-stirred for 10seconds and the second and third step above was repeated by waiting for 10 minutes.
- **Calculations for rheology and API standards**

According to Adam et al, (1986), apparent viscosity, plastic viscosity and yield point can be calculated with the expressions stated below.

Plastic viscosity, $\mu_p = \theta_{600} - \theta_{300}$ (2.1)

Where Θ_{600} and Θ_{300} is dial reading at 600 rpm and 300rpm

Apparent viscosity, $\mu_a = \frac{300\theta_N}{N}$ (2.2)

Where Θ_N is dial readings in degrees and N is the speed of rotor in revolution per minute.

Yield point $\tau y = \theta_{300} - \mu_p$ (2.3)

Shear stress, τ in pounds per 100 ft^2 (Ibf/100ft^2) = $\frac{\text{Force}}{\text{Area}}$ = Dial reading x 1.067

Shear rate, in per seconds (sec^{-1}) = 1.701x Revolution per minute (RPM)

(Ofite manual, 2019).

IV. Results and Discussion

Table 1: API Standards for Drilling Fluid Properties.

Properties	**API Standard**
Viscometer reading at 600RPM	minimum of 30cp
Density	8.65-9.5 Ib/gal
Plastic Viscosity	Less than 65 cp
Yield Point	15 to 45 Ib/100sq ft
Gel Strength at 10 seconds	3 to 20 Ib/100sq ft
Gel Strength at 10 Minutes	8 to 30 Ib/100sq ft
Filtrate Loss	15 ml max

Table 2: Property Values of Mud Formulations without Additives

Properties	At Start	After 24 Hours
θ_{600}	4	4.5
θ_{300}	3	3
Plastic Viscosity	2	2.5
Apparent Viscosity	2.5	2.75
Yield Point	2	1.5

Gel Strength at 10 Seconds	2	2
Gel Strength at 10 Minutes	2	2
Density, lb/gal	9.7	9.7
Temperature, ºC	28	25
Sand Content	< 1%	< 1%

Table 2 above shows little or no difference in the properties of the mud after 24 hours of aging. Rheological properties and sand content of the blank mud formulation before and after aging were quite low with no potential threat to drilling operations according to API requirements. However, the mud formulated still needs some improvements. To enhance the rheological properties, new muds formulations laden with Millet Starch, Arabic Gum, and Cocoyam Starch additives were prepared and their properties were tested at room temperature.

It is observed that as the mass of millet starch increased from 2 to 15 g the plastic viscosity increased accordingly. However, Yield point and gel strength at 2 and 5 g remained almost constant but increased a little upon addition of 8 and 15 g concentrations. As the concentrations of Gum Arabic increased between 2 to 20 g, Plastic and Apparent viscosities increased accordingly. Gel strength was observed to decrease with the addition of 2, 5 and 15g concentration, the gel increased to its previous value as before and at 20 g, it increased a little at 10 minutes gel. These properties of the mud formulations with additive proved to have changed on the addition of various additives but not yet up to the optimum standard required for drilling purposes. This suggests that new formulations that meet optimum requirements are required. It is observed that the mud sample was more responsive and suited to Arabic gum compared to Millet starch. Since the values already obtained are not sufficient enough, composites of additives in muds were prepared. The mud formulation with 20 g Arabic gum and 20 g Cocoyam starch showed tremendous improvement on plastic and apparent viscosities and yield point. However, the gel strength values remained poor.

Table 3: Mud Formulations with Additives

Drilling Mud Formulations	θ_{600}	PV	YP	10'	10''	Density, lb/gal	Temperature, ºC
Hydrated Mud + 2g of Millet Starch	5	2.5	1	1	1	8	30
Hydrated Mud + 5g of Millet Starch	7	3.5	1	1	1	8.5	30
Hydrated Mud + 8g of Millet Starch	8.5	5	-1	1	1.5	8.75	29.4
Hydrated Mud +10g of Millet Starch	9	6.5	-1.5	1	2	8.8	29
Hydrated Mud +15g of Millet Starch	10	8.5	-2	1.5	2.5	8.82	28.5
Hydrated Mud +20g of Millet Starch	10.5	12	-2.5	2	3	8.85	27.5
Hydrated Mud + 2g of Arabic Gum	5	2.9	0.2	0.5	0.5	8.86	29.5
Hydrated Mud + 5g of Arabic Gum	6	3.5	0	1	1	8.7	29.7
Hydrated Mud + 8g of Arabic Gum	8	4.5	0	1	1	8.79	30.5
Hydrated Mud +10g of Arabic Gum	10	5.5	1	1	1	8.91	30.2
Hydrated Mud +15g of Arabic Gum	18.5	11.5	-2.5	1	1	8.95	28.5
Hydrated Mud +20g of Arabic Gum	29.5	18.5	-7.5	1	2.5	8.98	28.2
Hydrated Mud +15g of	5	2.9	0.2	1	1	8.8	29.5

Cocoyam Starch							
Hydrated Mud +10g of Cocoyam Starch + 15g of Arabic Gum	26	14	-1	1	1	8.93	26
Hydrated Mud +20g of Cocoyam Starch + 20g of Arabic Gum	42.5	23.5	-4.5	1	1	9	30.5

PV =Plastic Viscosity, YP= Yield Point, 10'= 10 seconds gel strength .10"= minutes gel strength, Θ_{600} =Dial Reading at 600RPM.

Table 4: Effect of 0.1g, 0.2g, 0.5g and 0.8g Concentrations of MWCNT and BRM on 10 Seconds Gel at Different Temperatures

Temperature (°C)	26	60	94
0.1g MWCNT	5	5	30.5
0.1g BRM	5.5	5.5	26.5
NO CNT	5	6	12.5
0.2g MWCNT	5	5	25
0.2g BRM	5	4	18
0.5g MWCNT	5	5	24
0.5 BRM	4.5	5	17.5
0.8 MWCNT	5	5	22.5
0.8 BRM	4.5	5	17
NO BRM	5	6	12.5

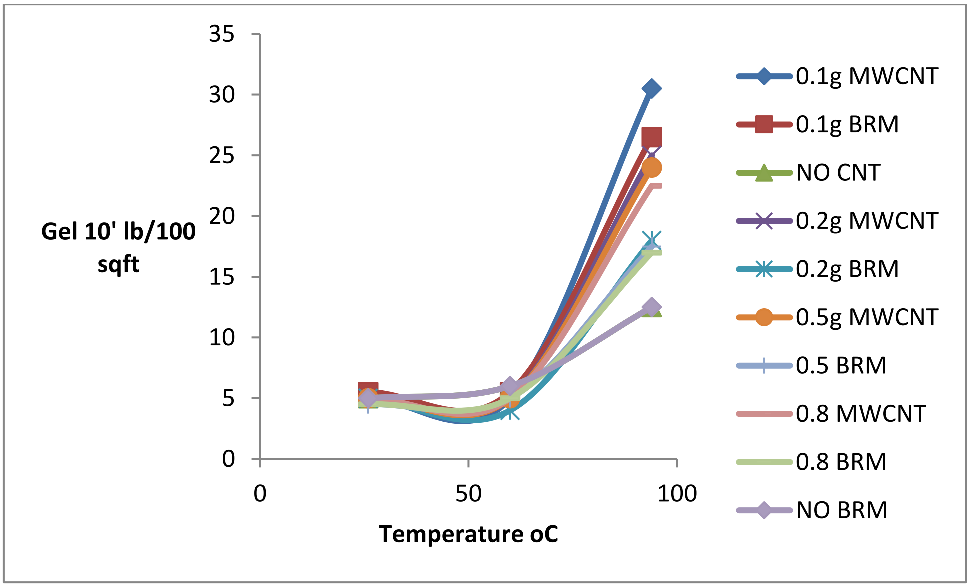

Figure 4: Effect of 0.1g, 0.2g, 0.5g and 0.8g concentrations of MWCNT and BRM on 10 seconds gel at different temperatures.

Figure 4 illustrates the relationship between gel at 10' seconds at concentrations of 0.1g, 0.2g, 0.5g, 0.8g, NO BRM and NO MWCNT with temperature. It indicates that the gel strength at 10' seconds increased exponentially with temperature, but highest in 0.1g MWCNT at temperature of 94ºC and gel strength of 30.5 lb/100 sqft.

Table 5: Effect of 0.1g, 0.2g, 0.5g and 0.8g Concentrations of MWCNT and BRM on 10 Minutes Gel at Different Temperatures

Temperature (ºC)	26	60	94
0.1g MWCNT	9	7	29.5
0.1g BRM	8.5	7.5	25
NO CNT	8	9	15
0.2g MWCNT	8	7	24
0.2g BRM	6	5	17
0.5g MWCNT	8	8	21
0.5 BRM	7	8	16.5
0.8 MWCNT	7.5	8.5	19.5
0.8 BRM	6.5	8.5	15
NO BRM	8	9	15

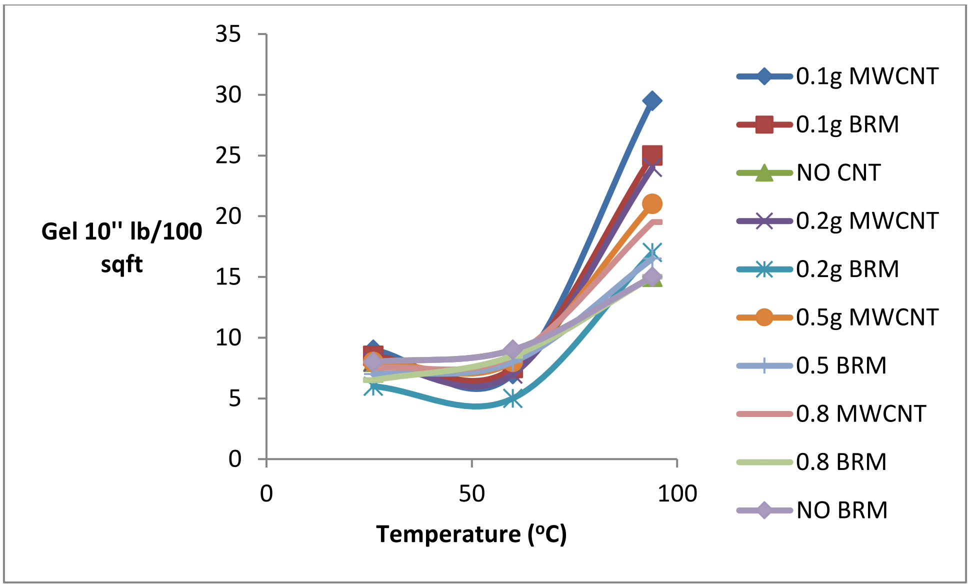

Figure 5: Effect of 0.1g, 0.2g, 0.5g and 0.8g concentrations of MWCNT and BRM on 10 minutes gel at different temperatures

Figure 5 demonstrates the relationship between gel at 10'' minutes at concentrations of 0.1g, 0.2g, 0.5g, 0.8g, NO BRM and NO MWCNT with temperature. It indicates that the gel strength at 10'' minutes increased exponentially with temperature, but highest in 0.1g MWCNT at temperature of 94ºC and gel strength of 29.5 lb/100 sqft.

Table 6: Effect of 0.1g, 0.2g, 0.5g and 0.8g Concentrations of MWCNT and BRM on Plastic Viscosity at Different Temperatures

Temperature (ºC)	26	60	94
0.1g MWCNT	21	8.5	73
0.1g BRM	25.5	9.5	82
NO CNT	23	8	69.5
0.2g MWCNT	21	8	52
0.2g BRM	23	10	64.5
0.5g MWCNT	17	9.1	51.5

0.5 BRM	19	8	73
0.8 MWCNT	17.2	10	74.5
0.8 BRM	21.5	9.5	79
NO BRM	23	8	69.5

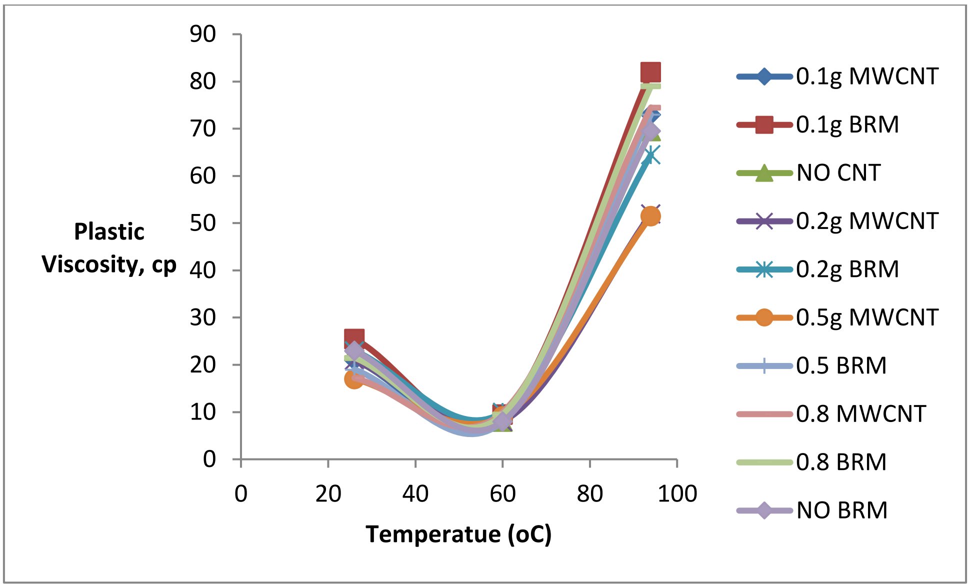

Figure 6: Effect of 0.1g, 0.2g, 0.5g and 0.8g concentrations of MWCNT and BRM on Plastic viscosity at different temperatures

Figure 6 illustrates the relationship between plastic viscosity at concentrations of 0.1g, 0.2g, 0.5g, 0.8g, NO BRM and NO MWCNT with temperature. It indicates that plastic viscosity increased exponentially with temperature, but highest in 0.8g BRM at temperature of 94^{o}C and plastic viscosity of 79cp.

- **Effect of MWCNT and BRM on yield point at different temperature**

The yield point and gel strength have similar properties because they are both affected by particle aggregation. The plot shows that as temperature increases; the yield point also increases. When compared to the formulation without CNTs, some MWCNT and BRM formulations gave higher values of yield point.

Table 7: Effect of 0.1g, 0.2g, 0.5g and 0.8g Concentrations of MWCNT and BRM on Yield Point at Different Temperatures.

	26	60	94
0.1g MWCNT	-2.5	4.5	72
0.1g BRM	-7.5	5	66
NO CNT	1	7	79
0.2g MWCNT	-3	4.5	103
0.2g BRM	-5.5	5.5	78
0.5g MWCNT	3	5.8	137
0.5 BRM	2	5	74
0.8 MWCNT	1.8	4	102.5
0.8 BRM	-3.5	4	66
NO BRM	1	7	79

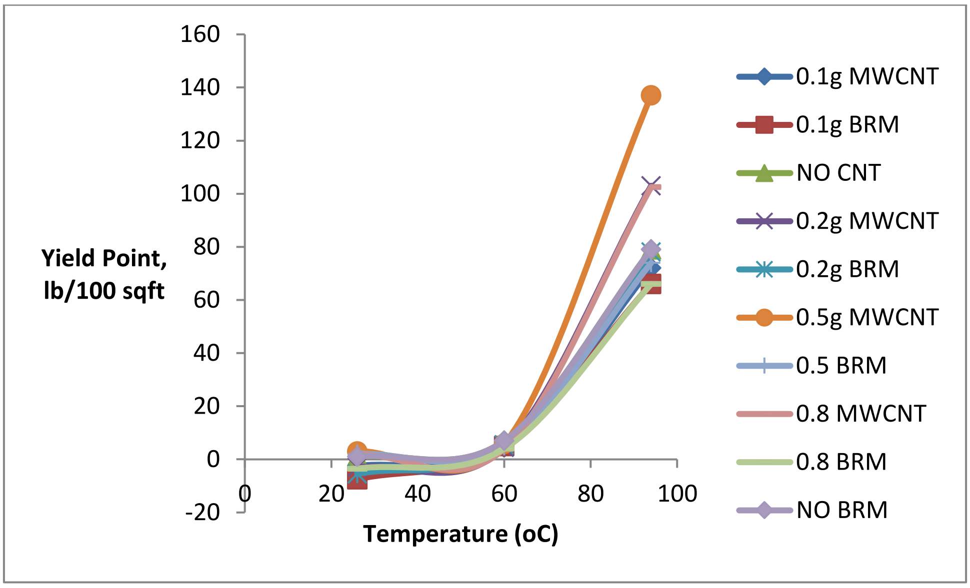

Figure 7: Effect of 0.1g, 0.2g, 0.5g and 0.8g concentrations of MWCNT and BRM on yield point at different temperatures.

Figure 7 shows the relationship between yield point at concentrations of 0.1g, 0.2g, 0.5g, 0.8g, NO BRM and NO MWCNT with temperature. It indicates that the yield point increased exponentially with temperature, but highest in 0.5g MWCNT at temperature of 94°C and yield point of 137 lb/100 sqft.

- **Rheological models and consistency plots**

From all the tables and figures of MWCNT and BRW weighted mud formulations effect, it is observed that optimum values of the drilling mud lie between the 0.1g and 0.2g MWCNT formulations and also between 0.1g and 0.2g BRM formulations. In this section, models of an estimate of the optimum which is at 0.1g MWCNT at room temperature and 94°C is created using Bingham, Power-law and Herschel-Bulkley models using regression. Consistency plots are shown below to compare the effect of 0.1g MWCNT and BRM on Base weighted mud formulations. It is observed that at room temperature the Base weighted mud formulation exhibited greater shear stress at both low and high shear rates compared to the 0.1g MWCNT and 0.1g BRM formulations indicating higher values for apparent viscosity, yield point and gel strength compared to CNT formulations. At 60°C apparent viscosity, yield point and gel strength values for 0.1g BRM formulation were highest at low hear rates compared to the Base weighted mud formulation and 0.1g MWCNT formulation. However, at 94°C, 0.1g MWCNT formulation had greater shear stress values at both low and high shear rates compared to the Base weighted mud formulation and 0.1g BRM formulations indicating higher values for apparent viscosity, yield point and gel strength compared to Base and 0.1g BRM formulations.

Table 8: Consistency for 0.1g MWCNT and 0.1g BRM at 26°C

Shear Rate (1/s)	Shear Stress 0.1g BRM	Shear Stress 0.1g MWCNT	Shear Stress 0g
0	5	5	5
25	6	6.2	7
50	6.5	6.7	10
100	12	12.2	15
200	17	17.2	19
300	18	17.8	25
600	37	35	45

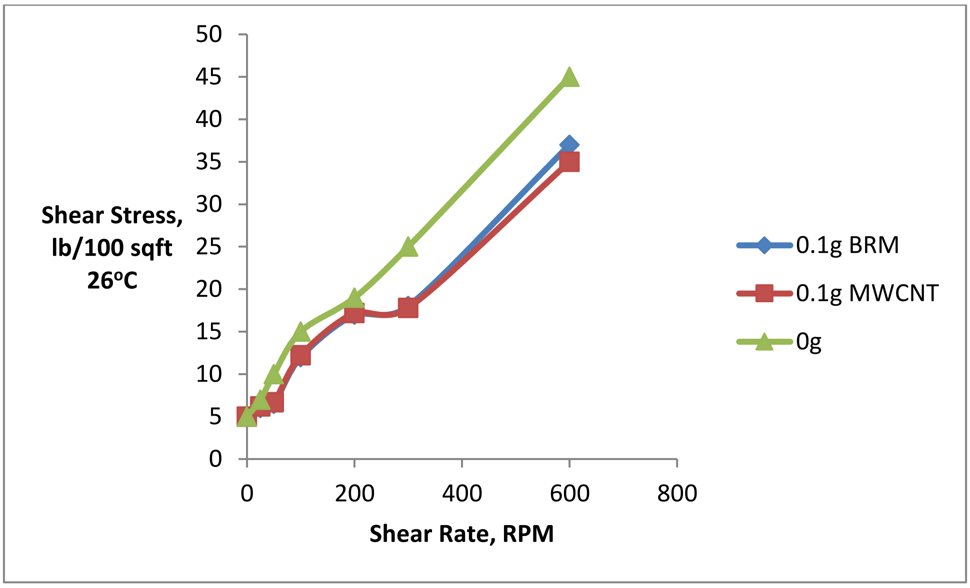

Figure 8: Consistency Plot for 0.1g MWCNT and 0.1g BRM at 26ºC

Figure 8 illustrates the relationship between shear stress at 26ºC and shear rate. It shows that as shear rate increases; the shear stress also increases. The increase is highest in 0g, followed by 0.1g BRM and least in 0.1g MWCNT.

Table 9: Consistency for 0.1gMWCNT and 0.1gBRM at 60ºC

Shear Rate (1/s)	Shear Stress 0g	Shear Stress 0.1g MWCNT	Shear Stress 0.1g BRM
0	6.3	6	6.5
25	7	6.5	7.2
50	7.8	7	8
100	10	8	10
200	13	10	14
300	15	14	15
600	22	18	24

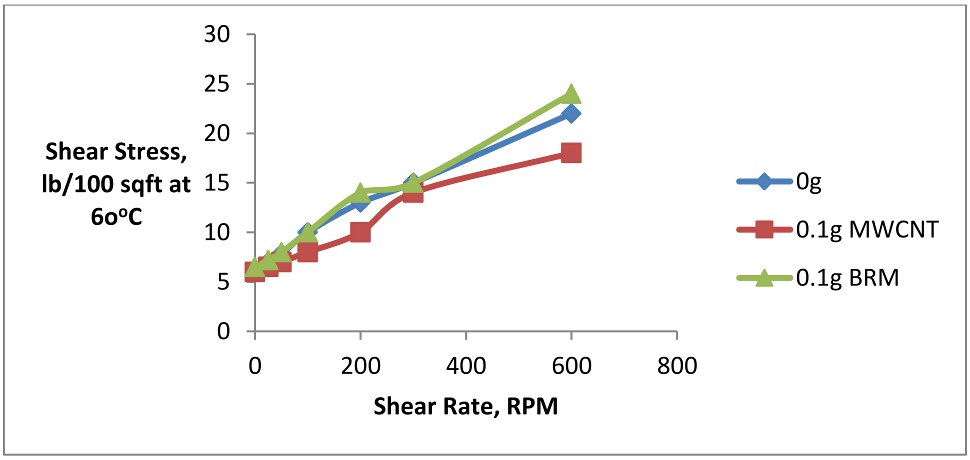

Figure 9: Consistency Plot for 0.1gMWCNT and 0.1gBRM at 60ºC

Figure 9 demonstrates the relationship between shear stress at 60ºC and shear rate. It shows that as shear rate increases; the shear stress also increases. The increase is highest in 0.1g BRM, followed by 0g and least in 0.1g MWCNT.

Table 10: Consistency for 0.1gMWCNT and 0.1gBRM at 94°C

Shear Rate (1/s)	Shear Stress 0g	Shear Stress 0.1g MWCNT	Shear Stress 0.1g BRM
0	10	35	45
25	40	42	65
50	60	65	80
100	70	75	90
200	110	115	130
300	140	145	160
600	220	220	230

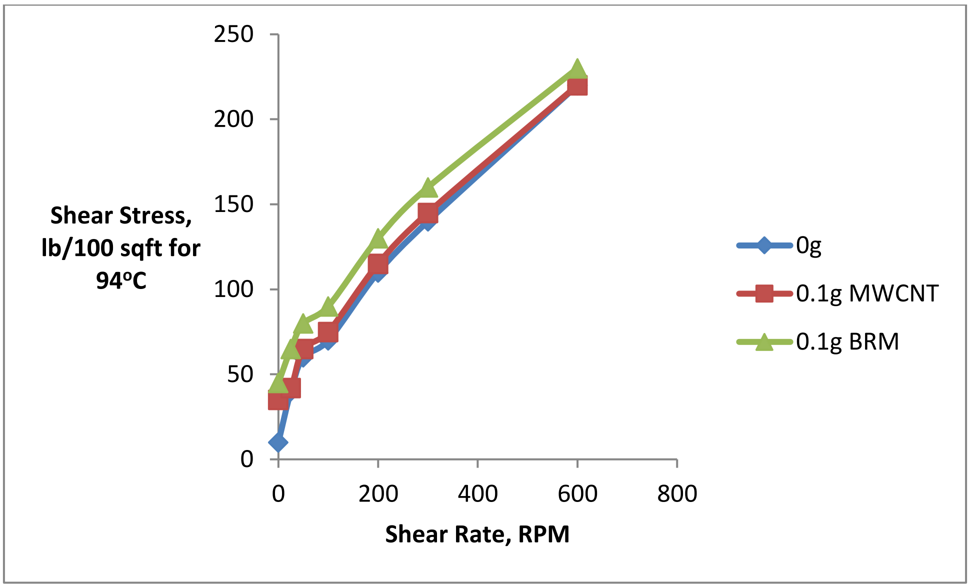

Figure 10: Consistency Plot for 0.1gMWCNT and 0.1gBRM at 94°C

Figure 10 illustrates the relationship between shear stress at 94°C and shear rate. It shows that as shear rate increases, the shear stress also increases. The increase is highest in 0g, followed by 0.1g MWCNT and least in 0.1g BRM.

- **3.1.3 Models for Base Mud Formulation at 26°C**

Table 11: Bingham Model for Weighted (Base) Mud Rheology at 26°C

Shear Rate (RPM)	Shear Stress (lb/100 sqft)
0	5
25	10
50	12
100	13
200	18
300	24
600	45

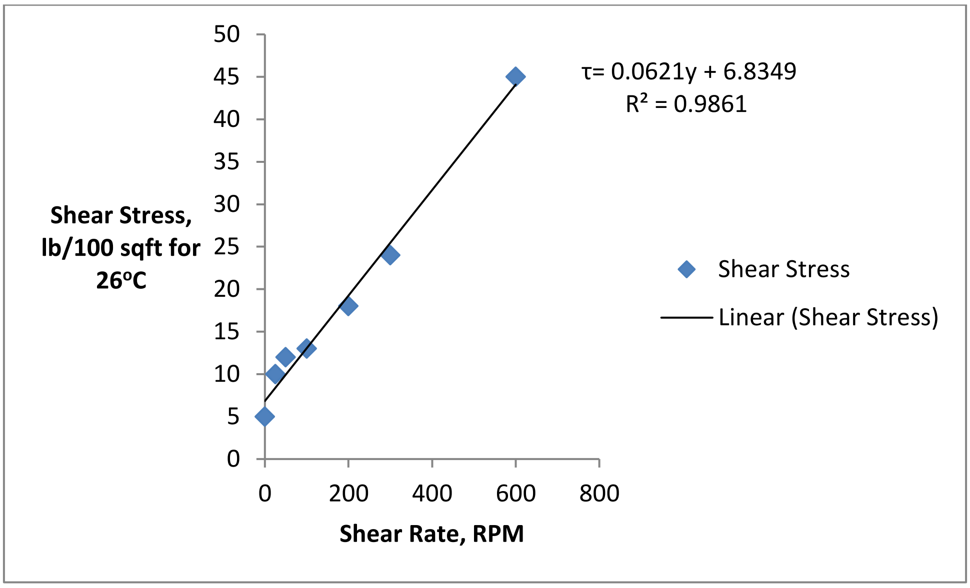

Figure 11: Bingham Model for Weighted (Base) Mud Rheology Plot at 26°C

Figure 11 indicates the relationship between shear stress at 26°C and shear rate of Bingham model. It shows that as shear rate increases; the shear stress also increases. The equation of curve is expressed as $\tau = 0.0621y + 6.8349$ with the square of best fit $R^2 -$ value of 0.9861

Table 12: Power Law Model for Weighted (Base) Mud Rheology at 26°C

Log Shear Rate	Log Shear Stress
-	0.7
1.4	1
1.7	1.1
2	1.1
2.3	1.3
2.5	1.4
2.8	1.7

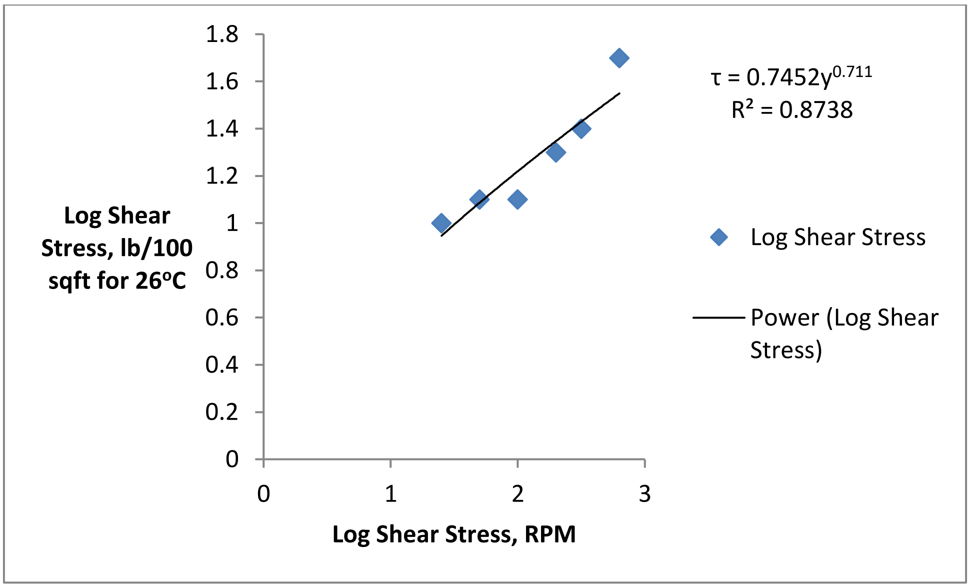

Figure 12: Power Law Model for Weighted (Base) Mud Rheology Plot at 26°C

Figure 12 illustrates the relationship between shear stress at 26°C and shear rate of Power Law model. It shows that as shear rate increases; the shear stress also increases. The equation of curve is expressed as $\tau = 0.7452y^{0.711}$ with the square of best fit $R^2 -$ value of 0.8738

Tables 13 and 14 show the frictional pressure losses using Herschel Buckley's rheological parameters at 26.5 and 94°C of base mud (weighted mud without nanoparticles) and MWCNT mud formulations for a conventional pipe configuration for a 10.75 by 9.95 inches and 7.625 by 6.875 inches and 5.5 by 4.892 inches and assumed flow rates of 100gal/min,200 gal/minutes and 300 gal/minutes using Shanghani model.

Table 13: Pressure loss model data for base case and MWCNT formulations at 26°C

D(inches)	Kbase	KMWCNT	nbase	nMWCNT	Q(gal/min)	ΔPf/ΔL(Psi/ft)base	ΔPf/ΔL(Psi/ft)
4.892	0.091	0.072	0.9476	0.9296	100	0.003655635	0.002727261
4.892	0.091	0.072	0.9476	0.9296	200	0.007050482	0.005194745
4.892	0.091	0.072	0.9476	0.9296	300	0.010353397	0.007572838
6.875	0.091	0.072	0.9476	0.9296	100	0.000988672	0.000751271
6.875	0.091	0.072	0.9476	0.9296	200	0.001906815	0.001430982
6.875	0.091	0.072	0.9476	0.9296	300	0.002800094	0.002086069
9.95	0.091	0.072	0.9476	0.9296	100	0.00023883	0.000185141
9.95	0.091	0.072	0.9476	0.9296	200	0.000460623	0.000352648
9.95	0.091	0.072	0.9476	0.9296	300	0.000676409	0.000514086

Table 14*: Pressure Loss Model Data for Base Case and MWCNT Formulations at 94°C*

D(inches)	Kbase	KMWCNT	nbase	nMWCNT	Q(gal/min)	ΔPf/ΔL(Psi/ft)base	ΔPf/ΔL(Psi/ft)
4.892	2.4216	1.2629	0.7017	0.7789	100	0.043467979	0.029212873
4.892	2.4216	1.2629	0.7017	0.7789	200	0.070697198	0.050124094
4.892	2.4216	1.2629	0.7017	0.7789	300	0.093964852	0.068739127
6.875	2.4216	1.2629	0.7017	0.7789	100	0.015110559	0.009385517
6.875	2.4216	1.2629	0.7017	0.7789	200	0.024576117	0.016103878
6.875	2.4216	1.2629	0.7017	0.7789	300	0.032664537	0.022084519
9.95	2.4216	1.2629	0.7017	0.7789	100	0.004794635	0.002733693
9.95	2.4216	1.2629	0.7017	0.7789	200	0.007798091	0.004690531
9.95	2.4216	1.2629	0.7017	0.7789	300	0.010364576	0.006432496

Pressure losses increase with flow rate for various pipe diameters for base mud and 0.1g MWCNT muds flowing in vertical pipes. The figures 15 and 16 below are pressure loss versus flow rate plot at 26°C and 94°C for base and 0.1g MWCNT mud formulations. It is observed in these plots that as pipe diameter increases from 4.892" to 9.95"in the presence of a constant mud formulation, there is a reduction in pressure loss. The pressure losses appear to be almost constant with diameter 9.95 inches at different flow rates. It also gives information on the effect of MWCNT on pressure losses of the flowing mud. Pressure losses of base mud formulations flowing through pipes of different diameters were higher in comparison to MWCNT mud formulations at room temperature and 94°C.

Table 15: Pressure Loss Profile at 26°C for Base Case and 0.1g MWCNT Mud Formulations

Flow Rate (gal/min)	4.892" Base Case	4.892" MWCNT Mud	6.875" Base Case	6.875 MWCNT Mud	9.95" Base Case	9.95" MWCNT Mud
100	0.004	0.003	0.001	0.0008	0.0002	0.0002
200	0.007	0.005	0.002	0.001	0.0004	0.0004
300	0.01	0.008	0.003	0.002	0.0007	0.0005

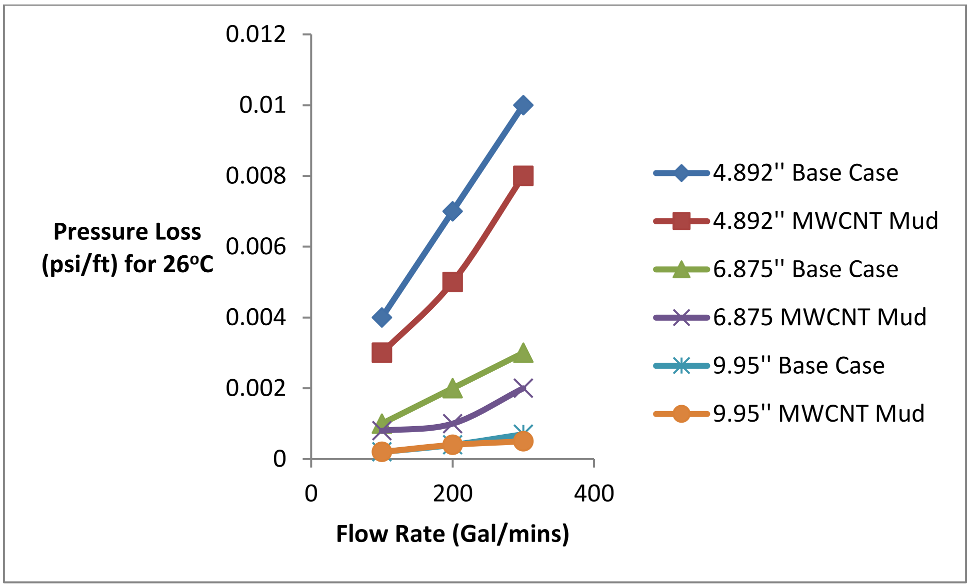

Figure 15: Pressure Loss Profile at 26°C for Base Case and 0.1g MWCNT Mud Formulations

Figure 15 illustrates the relationship between pressure loss at 26°C and flow rate for base case and 0.1g MWCNT. It shows that as flow rate increases; the pressure loss also increases. The increase was highest in 4.892'' minutes at flow rate of 0.01 gal/mins and least in 9.95'' minute at flow rate of 0.0005 gal/mins. The order of increase is 4.892" Base Case > 4.892" MWCNT Mud > 6.875" Base Case > 6.875 MWCNT Mud > 9.95" Base Case > 9.95" MWCNT

Table 16: Pressure Loss Profile at 94°C for Base Case and 0.1g MWCNT Mud Formulations

Flow Rate (gal/min)	4.892" Base Case	4.892" MWCNT Mud	6.875" Base Case	6.875 MWCNT Mud	9.95" Base Case	9.95" MWCNT Mud
100	0.04	0.03	0.02	0.009	0.005	0.003
200	0.07	0.05	0.025	0.016	0.008	0.005
300	0.09	0.07	0.033	0.022	0.01	0.006

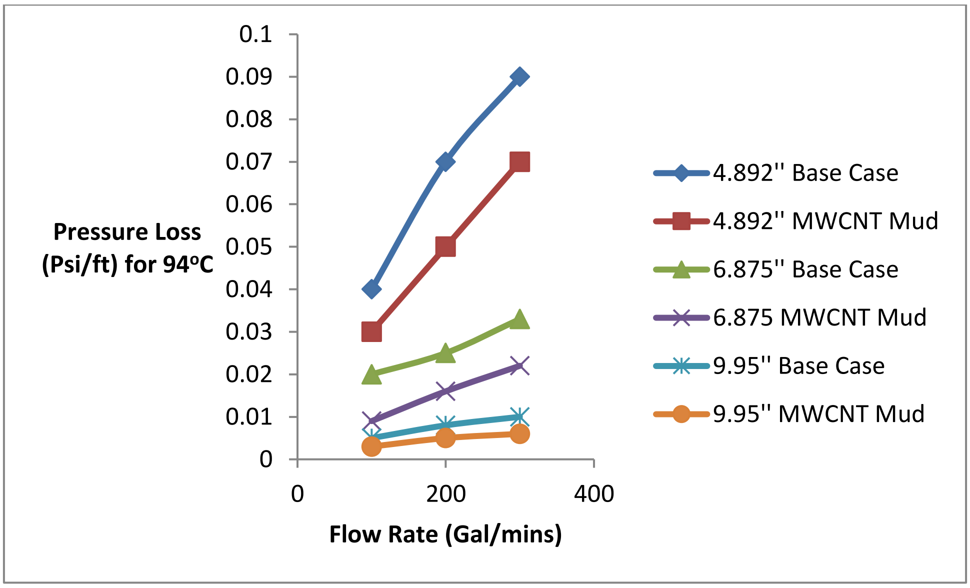

Figure 16: Pressure Loss Profile at 94°C for Base Case and 0.1g MWCNT Mud Formulations

Figure 16 demonstrates the relationship between pressure loss at 94°C and flow rate for base case and 0.1g MWCNT. It shows that as flow rate increases, the pressure loss also increases. The increase was highest in 4.892'' minutes at flow rate of 0.09 gal/mins and least in 9.95'' minute at flow rate of 0.01 gal/mins. The order of increase are 4.892" Base Case > 4.892" MWCNT Mud > 6.875" Base Case > 6.875 MWCNT Mud > 9.95" Base Case > 9.95" MWCNT Mud.

V. Conclusion

The paper has studied the formulation of Multi-walls carbon nanotubes and Bamboo raw modified for Strength at various temperature in local base mud. The formulation of drilling fluids often involves several variables such as bentonite content, polymer concentration, pH, salinity, and temperature, all of which interact in complex and nonlinear ways to influence the viscosity.

Based on the analysis, the following conclusion can be drawn: MWCNT and BRM formulations had little or no significant effect on gel strength at room temperature but gave better gel strength at high temperature in comparison to mud formulations having no CNT. Composites of Arabic gum and cocoyam biopolymers gave better dial reading at 600RPM and plastic viscosity of modified Aluu clay in comparison to formulations having individual polymers of millet starch, cocoyam starch and Arabic gum. Gel readings were still below API standards. The temperature increases; the yield point also increases when compared to the formulation without CNTs, some MWCNT and BRM formulations gave higher values of yield point. It indicates that the gel strength at 10' seconds increased exponentially with temperature, but highest in 0.1g MWCNT at temperature of 94^{o}C and gel strength of 30.5 lb/100 sqft.

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