
DETERMINATION OF LOW-TEMPERATURE LOW-PRESSURE (LTLP) FILTRATION PROPERTIES OF DRILLING MUD FORMULATED FROM ARAWA BENTONITE CLAY FOR OIL AND GAS DRILLING APPLICATION

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ABSTRACT

Filtration control is an essential activity during drilling because excessive fluid loss to permeable formation causes wellbore instability, acute drilling performance, differential pipe sticking and formation damage. In this study, Low-Temperature Low-Pressure (LTLP) Filtration Properties of Drilling Mud Formulated from Nigerian Arawa Bentonite Clay was investigated. Filtrate loss, spurt loss and leak-off coefficients for API base, API Standard, raw Arawa, Arawa base, Arawa standard and Arawa standard treated with sub-micron calcium carbonate formulation was evaluated using API low temperature filter press at 100 psi at room temperature. Filtrate volume was measured as a function of time up to 30 minutes while spurt loss (V_s) and leak-off coefficient (K) were determined by fitting the experimental data into Carter filtration model. The results have shown that API base, API Standard, raw Arawa, Arawa base, Arawa standard formulation and Arawa standard formulation treated with sub-micron calcium carbonate formulation have LTLP fluid loss of 8ml, 7.6ml, 14ml, 12ml, 8.6ml, and 7.8ml respectively making the fluid loss within API standard requirement of ≤ 15 ml. The formulations have shown spurt loss of 6.7423×10^{-16} ml, 4.86×10^{-16} ml, 9.9449×10^{-16} ml, 1.0337×10^{-16} ml, 3.7923×10^{-17} ml and 5.7679×10^{-17} ml respectively, and leak-off coefficient of $1.46 \text{ml.min}^{-1/2}$, $1.37 \text{ml.min}^{-1/2}$, $2.49 \text{ml.min}^{-1/2}$, $2.12 \text{ml.min}^{-1/2}$, $1.49 \text{ml.min}^{-1/2}$ and $1.34 \text{ml.min}^{-1/2}$ respectively. The model performance statistics have shown good correlation between Experimental and model parameters with average R-square, adjusted R-square and Sum of Square Error (SSE) of 0.97697, 0.97121 and 0.5 respectively. The study demonstrates the potential of beneficiated and standardized Nigerian Arawa bentonite clay as locally sourced constituents of drilling mud for Oil and Gas drilling application.

Keywords: Drilling mud; LTLP; bentonite; Carter model; API; spurt loss (V_s); leak-off coefficient and R-square

1. INTRODUCTION

Drilling mud is critical to drilling operations. It performs essential functions such as cuttings transport, protection of oil and gas production zone, cooling and lubrication drill bit, ensuring wellbore stability, filtration control, and controlling formation pressure. Among these, filtration control is particularly important because excessive filtrate invasion into the formation can cause formation damage especially in water-sensitive shales, cause wellbore instability, and differential sticking and ultimately affecting drilling efficiency (Agwu *et al.*, 2021). Filtration performance of drilling mud is commonly evaluated under low-temperature low-pressure (LTLP) and high-temperature high-pressure (HTHP) conditions to mimic surface and downhole environments, respectively (Sun *et al.*, 2026).

For low-temperature low-pressure, filtrate loss, spurt loss and leak-off coefficient are important parameters in LTLP filtration. While filtrate loss is the cumulative amount of filtrate lost to the formation during specific time of filtration, spurt loss is the filtrate loss to the formation before an effective filter cake formation. Leak-off coefficient which is a function of filter cake permeability is the rate or ease with which the filtrate is lost to the formation during cake-controlled filtration (Fu and Liu, 2019). It is proportional to the square root of time (Shad *et al.*, 2021).

For LTLP oil and gas drilling application, water-based drilling muds (WBMs) are widely used due to their environmental compatibility and lower cost compared to oil-based muds (OBMs) and synthetic-based muds (SBM); however, their performance strongly depends on the properties of the bentonite clay used, reservoir characteristics and formation temperature and pressure (Singh *et al.*, 2026).

Bentonite clay which is primarily composed of montmorillonite as major clay mineral, is the most common viscosifier and filtration control component of drilling mud due to its swelling and colloidal characteristics. Nevertheless, bentonite clay deposits in Nigeria are predominantly calcium-based (Igwilu *et al.*, 2020), which exhibit lower swelling capacity and inferior filtration performance compared to sodium-based bentonite (Bilal *et al.*, 2016; Okorie *et al.*, 2021). Consequently, beneficiation and activated may be required to meet the standard of a sodium-based bentonite. Hence, use of locally sourced clay could potentially reduce dependence of imported drilling-grade bentonite for oil and gas drilling in Nigeria.

Many research works have focused on rheological and physiochemical properties of Nigerian bentonite; limited attention has been given to filtration properties of locally sourced bentonite. Therefore, this study investigates LTLP filtration properties of drilling mud formulated from indigenous Nigerian bentonite. Experimental filtration tests conducted under LTLP conditions would be used to evaluate the fluid loss, spurt loss and fluid leak-off coefficient. The findings also aim to support the development of cost-effective, locally sourced drilling mud as viable alternatives to imported bentonite.

2. METHODOLOGY

2.1 Sample Collection and Preparation

Samples of the raw bentonite clay were collected by removing the overburden material from Arawa bentonite clay location in Arawa, Gombe state. The collected clay sample were brought to laboratory, dried, crushed and pulverized using jaw crusher and ball mill machine respectively. The ball milled sample is sieved using 200 mesh size to give 63 µm based on API 13A specification for drilling mud materials

2.2 Determination of Cation Exchange Capacity (CEC) of Clay

Methylene blue test was used to determine the clay cation exchange capacity based on Equation 1. This procedure was adopted from Bilal *et al.*, 2016.

$$CEC \left(\frac{meq}{100} \right) = \frac{V * N * 100}{W} * 100 \quad (1)$$

V=Volume of methylene solution used (mL)

N= Normality of methylene blue solution used in titration (mol/L)

W= Weight of dry clay sample (g)

2.3 Clay Beneficiation and Activation

The bentonite clay after wet beneficiation was allowed to settle, and the supernant water layer was discarded after leaving it to stand for 48 hours. Then finally the solid clay was dried in oven at 60 °C for 48 hours to completely dry the samples ready for soda activation.

Soda activation was done by adding an equivalent quantity of NaOH based on the cation exchange capacity (CEC) of the clay. The cation exchange capacity of the raw clay is 34 meq/100g of clay and was found to increase to 74 meq/100g of clay after activation. This method is a noble approach in which the property of the clay compares closely with that of an optimum quantity of soda in an iterative method. The calculation of amount of soda based on x meq/100g of clay CEC is shown below.

Therefore, for a clay with CEC of y meq/100 g of clay, it has been established that x mol of Na⁺ is needed to activate w g of the clay sample as shown in Equation 2. Therefore, for 11.58g of clay, 0.156g of NaOH is needed to activate the clay.

$$x \text{ mol} = y * w * 10^{-5} \quad (2)$$

2.4 Drilling mud formulation

One laboratory barrel (350 ml) of drilling mud was formulated using API grade and Arawa bentonite clay according to the formulation in Table 1. The samples are; API base formulation, API standard formulation, Raw formulation, base formulation (formulation with soda activated clay only), standard formulation with micro size reduced calcium carbonate, standard formulation with sub micro size calcium carbonate. The sub micro size calcium carbonate was formed by mechanically reducing the micro size calcium carbonate to particle size less than 1µm in size. Table 1 shows adopted mud formulation based on the nomenclature. The mud components were mixed by measuring the required water volume and adding the NaOH to ensure pH is between 8.5-10 because Xanthan gum and PAC mix well in the pH range. This is then followed by addition of bentonite and polymer (PAC and Xanthan). This order is to avoid 'fisheyes' formation in the mud mixer cup as explained by Agwu *et al.*,2021 and other components were then added. The formulation was then mixed using a Hamilton Beach mixer for 10 min and aged for 24 hours as done by Ruosh *et al.*,2025.

Table 1: Mud formulation

Additive	Wt. %	Mass (g)
Water	69.48	243.16
Bentonite	3.31	11.58
NaOH	0.02	0.06
XG	0.22	0.77
PAC	0.51	1.79
Barite	22.06	77.19
CaCO ₃	4.41	15.44
Total	100	350

2.5 Determination of Low Temperature Low Pressure Filtration Properties

After drilling mud formulation, the next thing is to characterise the mud by determining its filtration properties.

2.5.1 Determination of low temperature low pressure (LTLP) fluid loss (FL)

Low temperature low pressure API filter press was used for fluid loss measurement in accordance with API RP 13B-1 procedure. The sample drilling mud was poured into the API filter press cell to 350 ml of the O-ring ledge mark while ensuring that all spilled fluid was cleaned along the gasket edge. The filter press cell was assembled ensuring that the filter paper on the gasket was properly seated to prevent leakage, and the top cap was securely fixed. A graduated cylinder placed under the drain tube to collect the filtrate. Differential pressure of 100 psi supplied by hand pump to the filter cell through a regulator and the filtrate collected over a period of 30 minutes at 5 minutes interval.

2.5.2 Determination of spurt loss and leak-off coefficient

The spurt loss (Vs) and K were determined by fitting the experimental data generated in Section 3.1 into Carter filtration model (Modified Darcy filtration model) as shown in Table 2. The data was fitted into Equation 3 (Carter filtration model). The data was fitted using a generated MATLAB code. R-square, adjusted R-square and Sum of square error were used to determine goodness of fit for the data.

$$V(t)=V_s+K\sqrt{t} \quad (3)$$

$V(t)$ =Filtrate loss after time t

V_s =Spurt loss

K = Leak-off coefficient.

3. RESULTS AND DISCUSSION

3.1 Filtrate Loss

The fluid loss for API base, API standard (API STD), Arawa raw, Arawa base and Arawa standard (Arawa STD) and Arawa standard formulation (Arawa STD+X) is shown in Table 2

It can be seen from the table that API base has higher fluid loss than API standard across all time step due to enhancement of the mud formulation. Similar trend was observed for Arawa bentonite formulation as the raw sample is enhanced by soda activation and ultimately treated with sub-micron calcium carbonate.

Table 2: Fluid loss (FL) for API and Arawa bentonite formulation

Time(min)	$\sqrt{t}$ (min ^{1/2})	API Base FL (ml)	API STD FL (ml)	Arawa Raw FL (ml)	Arawa Base FL (ml)	Arawa STD FL (ml)	Arawa STD+X FL (ml)
5	2.236	3	2.8	5.5	4.5	2.8	2.5
10	3.162	4	3.8	7.5	6.5	4.5	4
15	3.873	6	5.7	9.5	8	5.5	5
20	4.472	6.5	6.2	11	9.5	6.5	5.8
25	5	7.5	7	12.5	10.5	7.6	6.8
30	5.477	8	7.6	14	12	8.6	7.8

Comparison of Low Temperature-Low Pressure filtrate loss for API base formulation, API standard (API STD) formulation, raw Arawa formulation, standard Arawa formulation (Arawa STD), standard formulation treated with sub-micron CaCO₃ (Arawa STD+X). The result is presented in Figure1 .

From Figure 1, it can be deduced that API base formulation has LTLP fluid loss of 8 ml after a cumulative filtration of 30min. The fluid loss is within API requirement of ≤ 15 ml for drilling grade bentonite. The value is in comparison with finding of Ruosh *et al.*, 2025 who reported for water-based mud low temperature fluid loss of 5.9 ml and 5.6 ml at optimum concentration of 0.9% for polyanionic cellulose and Xanthan gum respectively. However, after standardization, API standard (API STD) formulation was found to have a fluid loss of 7.6 ml. The reduction was because of plugging of pore spaces by micro calcium carbonate that was used in the formulation.

Raw Arawa formulation has shown filtrate loss of 14ml indicating poor filtration control. This is due to untreated nature of the Arawa bentonite clay sample making it have low hydration. The higher fluid loss for the raw Arawa bentonite is an indication of that filter cake formed is highly permeable. Hence, high leak-off coefficient is expected.

After soda activation, Arawa base formulation was found to have fluid loss of 12 ml. This reduction could be as result of improved clay hydration caused by soda activation. This value did not completely match that of API base and API standard formulation. The higher value demonstrated by Arawa base formulation when compared to API base and API standard formulation indicates that more of the continuous phase was lost through the filter cake of the Arawa base formulation.

Furthermore, standardization of soda activated Arawa bentonite (Arawa STD) and treatment with sub micron calcium carbonate (Arawa STD+X), fluid loss of 8.6 ml and 7.8 ml. The fluid loss of after treatment with sub micron calcium carbonate matches that API standard formulation. The decrease demonstrate the plugging capacity of the smaller particles of calcium carbonate as explained by Karakosta *et al.*, 2021. When compared to raw Arawa bentonite formulation, the fluid loss decreased by approximately 38.6% and 44.3% Arawa standard and Arawa Standard formulation treated with sub-micron calcium carbonate which tallies with the finding of Al-Shargabi *et al.*, 2022.

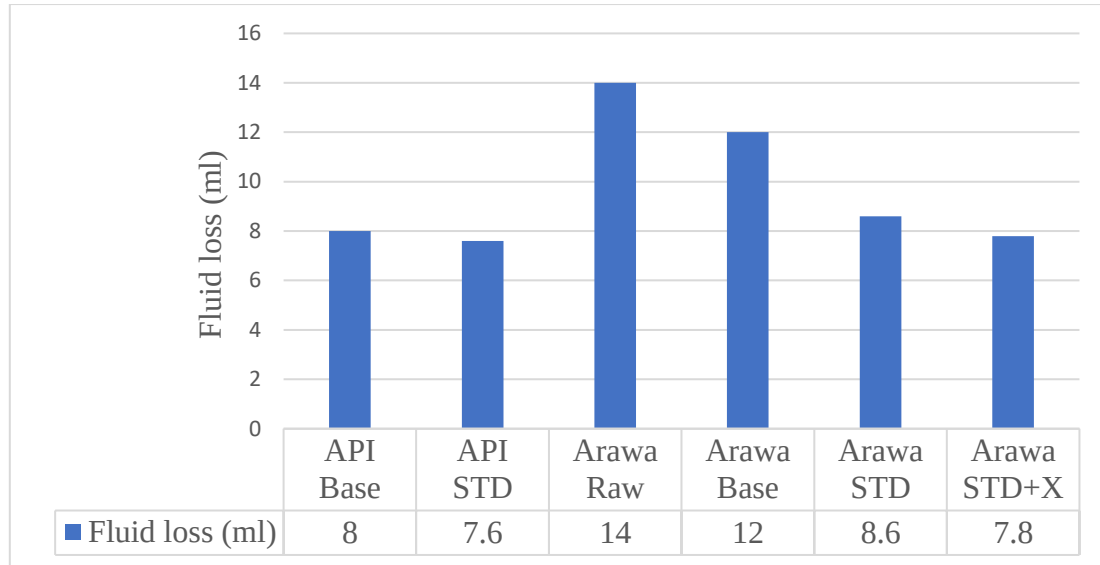


Figure 1: Low Temperature-Low Pressure filtrate loss for API and Arawa formulation

Spurt loss, leak-off coefficient and correlation coefficients for fitted fluid loss data is shown in Table 3 as deduced from Table 2. It was observed that API base and API STD formulation has spurt loss of 6.74×10^{-16} ml which reduced to 4.86×10^{-16} ml for API standard formulation with corresponding decrease in leak-off coefficient from $1.46 \text{ mlmin}^{-1/2}$ to $1.38 \text{ mlmin}^{-1/2}$ due to formation of lower permeability filter cake standardization.

For Arawa bentonite formulation, the spurt loss was found to be 9.94×10^{-16} ml for raw formulation and decreased to 1.03×10^{-16} ml, 3.79×10^{-17} ml and to 5.77×10^{-17} ml for base, standard and sub-micron calcium carbonate treated formulation respectively. The decrease in leak of coefficient from $2.49 \text{ mlmin}^{-1/2}$ to $2.12 \text{ mlmin}^{-1/2}$, $1.49 \text{ mlmin}^{-1/2}$ and $1.34 \text{ mlmin}^{-1/2}$ for raw Arawa, Arawa base, Arawa standard and sub-micron calcium carbonate treated (Arawa STD+X) formulation respectively is an indication of decreases in ease with which the continuous phase passes through the formed filter cake. Hence, a reduction in fluid loss was observed.

The data was fitted into Carter filtration model using lsqcurvefit in MATLAB and strong correlation between model and experimental data was observed as shown in Table 3 bellow.

The fitted model gave average values of 0.97697, 0.97121, 0.50085 for R-square (R^2), Adjusted_ R^2 and Sum of Square Error (SSE) respectively.

It can also be deduced from Table 3 that relative to raw Arawa bentonite formulation that the leak-off coefficient has decreased by 14.9% for Arawa base to 40.2% for Arawa standard to 46.2 % for Arawa standard formulation treated with submicron calcium carbonate indicating continuous decrease in in ease with which the mud passes through the filter cake.

Table 3: Spurt loss, leak-off coefficient and correlation coefficients for fitted fluid loss data

Formulation	Vs(ml)	K(mlmin ^{-1/2})	R ²	Adjusted_ R ²	SSE
API Base	6.74×10^{-16}	1.46	0.96845	0.96057	0.6099
API STD	4.86×10^{-16}	1.37	0.96902	0.96127	0.5381
Arawa Raw	9.94×10^{-16}	2.49	0.99368	0.99209	0.3162
Arawa Base	1.03×10^{-16}	2.12	0.99189	0.98986	0.3042
Arawa STD	3.79×10^{-17}	1.49	0.97123	0.96404	0.6406
Arawa STD+X	5.77×10^{-17}	1.34	0.96755	0.95943	0.5961

4. CONCLUSION

This paper investigated the low-temperature low-pressure (LTLP) filtration properties of drilling mud formulated from indigenous Arawa bentonite clay, soda activation, standardization, and drilling mud treatment with sub-micron calcium carbonate.

It was found that

- I. Raw Arawa formulation exhibited the highest filtrate loss of 14.0 mL after 30 min, while soda activation reduced the filtrate loss to 12.0 mL. The standardized formulation reduced the filtrate loss to 8.6 mL, and treatment of standardized formulation with sub-micron calcium carbonate produced a further reduction to 7.8 mL, which is comparable to the 7.6 mL obtained for the API standard formulation.
- II. All tested formulations recorded filtrate losses within the stated API requirement of ≤ 15 mL.
- III. The fitted filtration model provided a good representation of the experimental data, with R-square, adjusted R-square, and SSE values of 0.97697, 0.97121, 0.5 respectively.
- IV. The leak-off coefficient decreased progressively from $2.49 \text{ mL min}^{-1/2}$ for raw Arawa to $1.49 \text{ mL min}^{-1/2}$ for Arawa STD and $1.34 \text{ mL min}^{-1/2}$ for Arawa STD+X, indicating improved filtration resistance after treatment with sub-micron calcium carbonate.
- V. The leak-off coefficients for Arawa STD and Arawa STD+X formulation compare closely with leak-off coefficients for API base and API standard formulation respectively with leak-off coefficients of $1.46 \text{ mL min}^{-1/2}$ and $1.37 \text{ mL min}^{-1/2}$ respectively.
- VI. The results demonstrate the potential of soda activated and standardized Arawa bentonite as a locally sourced material for drilling mud applications. Further studies should evaluate its filtration performance under high-temperature high-pressure (HPHT) conditions and investigate the long-term stability of the formulated mud systems. Additionally, the experiment only addresses three key filtration parameters. Others like filter cake thickness, cake permeability and mud rheology were not investigated.

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