Production and Characterization of an Eco-Friendly Oil Based Mud from Synthetic Bio-lubricant Derived from *Chrysophyllum Albidum* Seed Oil

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ABSTRACT

Sequel to the environmental problems of the none biodegradable nature of the conventional oil-based drilling fluids, it is imperative and urgent for environmental sustainability and for the development of eco-friendly products, that use of petroleum diesel oil as the continuous phase of drilling mud warrant urgent reconsideration. Towards the search to provide a better alternative to petroleum diesel oil as a base oil for drilling mud, vegetable oil from the inedible seeds of the African star apple fruits, was examined. In this study, an oil-based drilling mud (OBM) with biodegradable qualities for sustainable environmental applications was developed and characterized. The OBM was produced with *chrysophyllum albidum* (African star apple) oil methyl ester bio-lubricant to replace petroleum diesel as the continuous phase of the mud. The *chrysophyllum albidum* oil methyl ester was synthesized from fatty acid methyl ester obtained through transesterification process of none edible oils extracted from *chrysophyllum albidum* seeds. Tests of physiochemical and rheological properties were carried out on mud samples of *chrysophyllum albidum* oil biolube-based mud (CAOBBM) and petroleum diesel oil-based mud (PDOBM) to characterise the fluids for performance evaluation and environmental consequences. The findings indicated that CAOBBM was lower in density and less acidic than PDOBM, at barite content of 20 g. Also, CAOBBM had lower viscosity which implies less resistance to flow and lower pressure losses. The low oil to water ratio from the filtration loss test, revealed that CAOBBM is more viable to low fluid loss and consequently enhances wellbore stability and less oil retained on drilled cuttings. Similarly, toxicity test confirmed CAOBBM to be more appropriate and less detrimental to the environment compared to PDOBM. Summarily *chrysophyllum albidum* oil biolube based muds stands safer and more eco-friendly for a sustainable environment than petroleum diesel oil-based muds.

Keywords: Oil-based drilling muds, bio-lubricant, *chrysophyllum albidum* oil eco-friendly.

1. INTRODUCTION

The need to drill a usable hole with minimal environment impact and a low-cost imprint as a dream long held by the drilling industries and operators. A key component of the oil well drilling operation known as ‘-the blood of the drilling process-’, is the drilling fluid. It is the foundation which makes a drilling operation either to succeed or fail [1]. The success of drilling program is hinged on the performance of the drilling fluids in the transport the drilled solids from the bottom of the hole to the surface; suspension of the drilled solids and weighting materials when the mud is under static condition; providing a thin impermeable cake to seal pore and other openings in the formation and there by restricting the movement of fluids; containing formation pressure; supporting the weight of casing and drill string; transmitting hydraulic horse power to the bit; aiding in evaluation of the formation; removal of cuttings from the wellbore; prevention of formation fluids flowing into the well-bore; maintaining well-bore stability; cooling and lubricating the bit [1,2]. The fluid is formulated from three principal materials: base liquid - oil, fresh water, or salt water; active solids - clays and polymers; inert solids – such as barite; and other reactive and inert materials as additives for improved fluids performance. The performance of any drilling fluid depends on the rheological properties. A good lubricant for drilling fluids exhibits relatively high viscosity, high lubricating film strength, low corrosively, low pour point, low flammability, high solubility, high thermal and oxidative stability and non-toxic. In addition, higher electrical stability helps to maintain a strong emulsifying strength as the reservoir temperature increases. This is because increase in temperature increases the ionic activity of an electrolyte and the solubility of salts which alters the attractive and repulsive forces among particles as well

as the dispersion and flocculation, consequently affect mud emulsion stability [3,4]. In addition, the environmental impact management of waste drilling forms additional cost implications on the overall budget for the drilling operation.

Oil-based mud (OBM) uses oil as the continuous phase. It is widely used in wells that are prone to drilling problems such as formation damage. It also provides good stability in shale zones and well, good lubricity efficiency for faster rate of drill pipe penetration, thermal stability, lowers rate of corrosion, reduce risk of stuck pipe and low formation damage, lower friction and torque values [5]. In recent times, some vegetable oils have been assured to be adequate oils for the production of sustainable environmentally friendly oil-based drilling mud (OBM) from their renewability to possessing high biodegradability, high lubricity and very less toxicity to the ecosystem [6,7]. Bio-lubricants also referred to as polyol esters are the synthetic biological lubricants from vegetable oils having excellent qualities as feedstock for the eco-friendly OBM production [8].

Bio-lubricants are synthetic esters produced from transesterified oils extracted from seeds and flowers of varieties of plants which include palm kernel oil, canola oil, soybean, castor oil, moringa oil, rapeseed, sunflower, coconut oils, neem seed, karanja, rubber seed, jatropha and African star apple seed [8-11]. Some physiochemical properties of polyols esters of the light brown coloured *chrysophyllum albidum* oil and other vegetable oils are presented elsewhere [8]. Bio-lubricants formulated OBM are lower in cost of production being that vegetable oils are renewable, easily sourced and disposed with no environmental consequence [12]. Thus, the study was aimed at production and characterization of oil-based mud from bio-lubricant derived from the esterified oils from *chrysophyllum albidum* seed. *Chrysophyllum albidum* (commonly known as white star apple or African star apple) is a large berry forest fruit tree containing 4-5 flattened seeds found throughout tropical Africa significantly in western, eastern and southern parts of Nigeria [13]. The study was intended to contribute towards the Nigerian local content initiative (NLCI) and to reduce the effects of environmental impact of waste generated from drilling operations.

2. METHODOLOGY

2.1 Synthesis of the *Chrysophyllum albidum* Bio-lubricant

Materials: The materials used in the study included seeds of African star apple, n-hexane 98%, methanol 99.8% and potassium hydroxide pellet 95% of analytical grade BDH chemicals, trimethylolpropane, sodium methoxide, Soxhlet apparatus, 0-100°C thermometer, model N-1110S rotary evaporator (Rikakikai, Tokyo), separating funnels, pycnometer.

***Chrysophyllum albidum* bio-lubricant synthesis:** In this study, bio-lubricant of *chrysophyllum albidum* oil also referred as *chrysophyllum albidum* oil biolube was synthesised from *chrysophyllum albidum* oil biodiesel, technically known as *chrysophyllum albidum* oil fatty acid methyl esters which was obtained from the transesterification of the fatty acids of the oil extracted from *chrysophyllum albidum* seeds in line with the procedures described elsewhere [7, 8, 14-16].

2.2 Mud Formulation Procedure

***Chrysophyllum albidum* oil biolube-based drilling mud preparation:** *Chrysophyllum albidum* oil biolube-based mud (CAOBMM) was formulated according to the American Petroleum Institute (API) standard; 22.5g of bentonite was dissolved in 350ml of fluid comprising of 117ml of *chrysophyllum albidum* oil biolube and 233ml of water. The mixture was agitated for 5-10 minutes using an electronic mixer followed by the addition of 2g of sodium hydroxide and 1.5g of PAC. When a clear homogeneous mixture was achieved, 8ml of emulsifier, 6ml of dispersant and 10g of barite subsequently added consecutively at 5 minutes interval and allowed to mix until a homogeneous liquid was attained. The prepared fluids were subjected to 24h aging to ensure whole hydration before analyses [12, 17-19].

Petroleum diesel oil-based drilling mud preparation: The procedure adopted for the preparation of *chrysophyllum albidum* oil biolube-based mud preparation was also applied to petroleum diesel oil for the production of petroleum diesel oil-based mud (PDOBM).

2.3 Drilling fluid property characterisation

The characteristics of the *chrysophyllum albidum* oil biolube-based mud (CAOBMM) and petroleum diesel oil-based mud (PDOBM) produced, were evaluated using their properties determined. The properties which were to provide indications on the mud potential performance, were determined with standard procedures. They included pH, density, rheological, sand content and mud toxicity. The ASTM D4380 standard procedure for determination of mud density and specific gravity were adopted, a calibrated mud balance was used for the

process. Physical appearances of colour were based on ASTM D2622 [16,20]. A pH meter was adopted to ascertain the pH of the mud samples and a Brookfield Ultra DVIII programmable rheometer was used to test the prepared mud viscosity. Following the Brookfield Digital Rheometer Model DV-III Operating Instructions Manual No. M98-211-A0701: the rheometer was assembled and leveled, it was then autozeroed, the spindle number was entered using the SELECT SPINDLE key, the spindle was introduced into the mud sample and attached to the coupling nut, the speed of rotation was entered using the number pad and ENTER key, % torque and viscosity were then recorded. Fluid loss determination was done using the standard API filter press by applying differential pressure on a dead weight filter press with filtrates recorded at intervals of 30 minutes [12,18]. Drilling fluid toxicity test experiment was carried out on growing maize plant seedling to examine the effects of both mud types contamination interference on the growth and ascertain the harm to soil and the microorganisms. Maize seedlings were planted in soil contaminated of the two types of prepared mud samples and a control soil containing no mud for 30 days. Growth rates was measured on effective concentration 50% (EC_{50}) as described elsewhere [21]. The EC_{50} is the concentration of the toxic contaminant present in the soil at which half the maximum expected growth response is realized [21].

3. RESULTS AND DISCUSSION

3.1 Physiochemical property analyses

Table 1, presents physiochemical properties of two OBM types formulated from the *chrysophyllum albidum* oil biolube and petroleum diesel oil. The colour of the CAOBBM was grey white while that of the PDOBM was creamy white, hence no significant discrepancy. The whitish coloration is attributed to the large amount of white coloured barite constituent of both mud types.

Table 1: Physicochemical properties of different OBM measured and from literature

Parameters/mud	pH	Density, lb/gal @ 25 °C	Specific gravity @ 15 °C	°API gravity @ 15 °C	Electrical stability (V)
Petroleum diesel oil (This Study)	8	8.53	0.853	34.4	210
^a Petroleum diesel oil	ND	8.26	0.826	39.8	ND
^b Petroleum diesel oil	ND	8.1	0.81	43.2	ND
^c Petroleum diesel oil	ND	8.26	0.826	39.8	ND
<i>Chrysophyllum albidum</i> biolube (This Study)	8.1	8.77	0.877	29.9	210
^a <i>Gamelina</i> oil	11.26	8.32	0.832	38.6	ND
^b Soybean oil	9	10.5	1.05	3.3	ND
^c Algae oil	9	7.81	0.781	49.7	ND
^c Jatropha oil	8.5	8.32	0.832	38.6	ND
^c Moringa oil	9	8.3	0.83	38.98	ND
^c Canola oil	ND	8.47	0.847	35.6	ND
^d Groundnut oil	ND	7.9	0.79	47.6	ND

^a [22]; ^b [17]; ^c [12]; ^d [5]; ND: Not determined

The pH is a vital indicator of the mud quality. The pH of the CAOBBM and PDOBM were 8.2 and 8.1 respectively. Though mildly were alkaline, both mud types agree with the observations that drilling muds are alkaline such that values between 8.5 and 9.5 produces mud with the best hole stability, control properties and protect pipe and casing from acidic fluid corrosion [17, 23]. The pH values of the samples are also comparable with other bio-OBM, however for fluids with values higher than 10, drilling in shale zone is problematic [5,12,17,22]. Similar to pH observations, the density of a drilling fluid another important indicator of the mud quality. The drilling fluid should be designed to provide high density [24]. The densities of CAOBBM and PDOBM oil-based muds were 8.77 and 8.53 ppg respectively. Though weighting materials added during mud formulations contribute to the mud density. The higher the density of CAOBBM, the better its aid to maintain wellbore hydrostatic pressure, prevents influx of other fluids as well as lost circulation in the wellbore and

enhanced cuttings carrying capacity [12,22]. With density, the CAOBBM appears more encouraging over PDOBM. Also, similar characteristics are deducible from the specific and °API gravities. Drilling fluid with higher electrical stability has the tendency to maintain a strong emulsifying strength as the reservoir temperature increases. In this study, the electrical stability at ambient temperature of CAOBBM and PDOBM oil-based muds were equal at 210V. Thus, there was no effect on the electrical stability property with regard to the oil type of the mud.

3.2 Rheological property analyses

The rheological properties consisting of plastic viscosity, apparent viscosity, gel strength and yield point of OBM formulated from *chrysophyllum albidum* oil biolube and petroleum diesel oil together with published values in literatures are contained in the Table 2.

On mud viscosity, the CAOBBM appear more viscous than PDOBM due to its higher plastic and apparent viscosities. Though not a large difference, the high plastic and apparent viscosities, implies that the resistance to flow is greater CAOBBM with than PDOBM. However, CAOBBM appear more viscous than some of the plant seed oils notably *Gamelina* oil, *Jatropha* oil and Groundnut oil. Drilling fluid are known to possess close similar rheological behaviour however, the presence of contaminants affects the flow behaviour and builds up shear stress leading to a yield point. When shear stress exceeds the yield point, it is influenced by the fluid plastic viscosity resulting in reduced friction during flow in the drill pipes [22]. Therefore, since PDOBM had a lower viscosity, it will be more efficiently with less resistance to flow, less circulation pressure and reduced frictional damages in pipes. It consequently would result to lower pumping costs together with reduced circulation loss probabilities. However, the efficiency of PDOBM will not be different from that of the CAOBBM because there is no significant difference in their plastic and apparent viscosities.

On gel strength there is no significant difference between CAOBBM and PDOBM. Both muds have a good gel structure, are capable of suspending drilled cuttings and weighting material when mud circulation is stopped.

Similar to the viscosities and the gel strengths, the yield points of both muds prepared had very close values (14 $\text{Ibf}/100\text{ft}^2$ and 13 $\text{Ibf}/100\text{ft}^2$ for PDOBM and CAOBBM respectively); hence there is no significant difference between both muds. The yield point results showed that both CAOBBM and PDOBM are capable of lifting or removing the cuttings out of the wells. Although, PDOBM with slightly higher yield point will carry cutting slightly better than the CAOBBM; however, which could lead to slightly higher-pressure losses for the PDOBM.

The rheological results stated above strongly infer that CAOBBM can be used in place of PDOBM.

Table 2: Rheological properties of different OBM measured and from literature

Parameters/Mud	Plastics viscosity (cp)	Apparent viscosity (cp)	Gel strength		Yield point ($\text{Ibf}/100\text{ft}^2$)
			@ 10s ($\text{Ibf}/100\text{ft}^2$)	@ 10 mins ($\text{Ibf}/100\text{ft}^2$)	
Petroleum diesel oil (This Study)	15	19	3	5	14
^a Petroleum diesel oil	15	92.5	50	51	92.5
^b Petroleum diesel oil	14	21	5	6	14
^c Petroleum diesel oil	15	92.5	50	51	ND
<i>Chrysophyllum albidum</i> biolube (This Study)	18	24.5	5	7	13
^a <i>Gamelina</i> oil	21	77	54	55	77
^b Soybean oil	15	23	7	9	16
^c Algae oil	8	61	52	43	ND
^c <i>Jatropha</i> oil	21	77	54	55	ND
^d <i>Jatropha</i> oil	28.3	54.2	8	10	ND
^c Moringa oil	11	84.5	52	53	ND
^c Canola oil	8	64	60	72	ND
^d Groundnut oil	35.67	48.7	5	7	ND

^a [22]; ^b [17]; ^c [12]; ^d [5]; ND: Not determined

3.3 Filtration loss property

Table 3 presents the mud filtration properties consisting of mud cake, total fluid volume, oil volume and water loss volume for CAOBBM and PDOBM together with published values in literatures. The CAOBBM showed a cake with lower thickness thus greater ability to increase its weight as well as collected less filtrate volumes of oil and water [12]. The PDOBM had higher filtration loss rate with higher filtrate volumes which implied that its cake was more porous. This may be attributed to PDOBM unsuccessful attainment of a stable oil and water emulsion compared to the CAOBBM achieving stronger emulsion between the oil and water [12]. The low oil to water ratio is indicative that CAOBBM is adequate to low fluid loss an enhanced wellbore stability and less oil retained on drilled cuttings. Therefore, the CAOBBM possessed preferred filtration properties as against PDOBM on the basis of total fluid volume, whereas the latter is preferred on cake thickness.

Table 3: Mud filtration properties of different OBM measured and from literature

Parameters/mud	Total fluid volume (ml)	Oil volume (ml)	Water loss (ml)	Mud cake (mm)
Petroleum diesel oil (This Study)	6.6	2.3	4.4	1.7
^a Petroleum diesel oil	6.9	2.3	4.6	1
^b Petroleum diesel oil	30	11	19	3
^c Petroleum diesel oil	6.9	2.3	4.6	1
<i>Chrysophyllum albidum</i> biolube (This Study)	6.3	2	4.3	1.4
^a <i>Gamelina</i> oil	6.3	2.1	4.2	0.8
^b Soybean oil	35	15	20	2.5
^c Algae oil	6.2	1.1	5.1	0.9
^c Jatropha oil	6.3	1.1	4.2	0.8
^c Moringa oil	7.2	2.5	4.7	0.9
^c Canola oil	6	1	4.3	0.78

^a [22]; ^b [17]; ^c [12]

3.4 Cuttings carrying capacity index

The cuttings carrying capacity indices of the CAOBBM and PDOBM and others from literature are displayed in Table 4. The capability to regulate the movement of drilled from the wellbore depends on some rheological properties. The cuttings carrying capacity index is a measure of the ability of drilling fluid to conduct drilled cuttings up the drill string. The higher a mud cutting carrying capacity index, the better its ability to transport solid out of the drilled hole. Thus, with a higher cutting carrying capacity index, COABBM has higher capability for uptake of drilled cuttings compared to PDOBM.

Table 4: Cutting carrying capacity index for OBMs determined and from literature

Parameters/mud	Cutting carrying capacity index
Petroleum diesel oil (This Study)	15.2
^a Petroleum diesel oil	15.901
<i>Chrysophyllum albidum</i> biolube (This Study)	18.64
^a Jatropha oil	19.067
^a Canola oil	17.846

^a [17].

3.5 Specific Application of the CAOBBM

The CAOBBM and PDOBM and others from literature are displayed in Table 4. The capability to regulate the movement of drilled from the wellbore depends on some rheological properties. The cuttings carrying capacity index is a measure of the ability of drilling fluid to conduct drilled cuttings up the drill string. The higher a mud cutting carrying capacity index, the better its ability to transport solid out of the drilled hole. Thus, with a higher

cutting carrying capacity index, COABBM has higher capability for uptake of drilled cuttings compared to PDOBM.

3.6 Environmental impact

The growth rate (% per day) responses against time (days) of the plant is shown in Figure 1. The soil contaminated with mud of petroleum diesel oil was designated SPDOM while that of *chrysophyllum albidum* methyl ester bio-lubricant was designated SCAOMEM and thirdly the uncontaminated soil sample which represents any fertile soil for comparative purposes was designated SCONTROL. The number of days corresponds with the half maximum effective concentration (EC_{50}) of antagonistic contaminants in the soil. The plant growth rate was gentle and consistent but varied slightly in amount within the first 7 days, thereafter the effects of the contaminants became noticed. In the case of SPDOM, the deterioration rate was rapid and acute resulting to total collapse of the plant in less than 10 days of exposure time. On the other hand, the plants in the SCAOMEM progress at a moderately slow response rate up to the 28 day and thereafter a relapse was noticed. This implies that both soil types ultimately require microbial or mineral beneficiation over time. In similar studies elsewhere [21], the EC_{50} for SCAOMEM was determined as 42.3%, while that of the SPDO was undetermined because the growth response abruptly declined to zero and there was no more growth response up to one half the expected maximum before the 30-day duration. Although, despite a reduced percentage growth rate observed in SCAOMEM compared to SCONTROL, the plants exposed to bio-lubricant formulated mud contaminated soil survived and grew continuously throughout the test duration. This implies that muds of *chrysophyllum albidum* oil bio-lubricant are less toxic and detrimental to environment compared to mud of petroleum diesel oil. Bio lubricant oils are safer and eco-friendlier than petroleum-based fluids. The biodegradation and bioaccumulation of microbes depend on the chemistry of the base fluids. These can also be enhanced with biostimulating agents to increase the intrinsic biodegradation potentials of the microbial populations.

Figure. 1: Growth rate of maize seed plant with time in three soil types

4. CONCLUSION

In this study, OBMs of *chrysophyllum albidum* oil bio-lubricant and petroleum diesel oil were produced. The OBM of *chrysophyllum albidum* oil bio-lubricant indicated a higher average pH which places it more alkaline thus would be preferred for protection of pipe and casing from acidic fluid corrosion and lower density hence improved potentials to maintain wellbore hydrostatic pressure, prevents influx of other fluids as well as lost circulation in the wellbore and enhanced cuttings carrying capacity. The OBM of petroleum diesel oil was lower in viscosity which implies less resistance to flow and lower pressure losses and thus more easily to pump; however, there is no significant difference between its plastic and apparent viscosities and those of the OBM of *chrysophyllum albidum* oil bio-lubricant. Both muds have a good gel structure, are capable of suspending drilled cuttings and weighting material when mud circulation is stopped. The yield point results showed that both muds are capable of lifting cuttings out of the wells. In addition, outstandingly the oil to water ratio was lower making *chrysophyllum albidum* oil bio-lubricant OBM more viable to less fluid loss and better capability to enhance wellbore stability and less oil retained on drilled cuttings. Based on toxicity test outcomes, OBMs of *chrysophyllum albidum* oil bio-lubricant are safer and eco-friendlier for drilling operations for a sustainable environmental than that of petroleum diesel oil. They can be enhanced for extended biodegradation potentials with biostimulating agents to increase the indigenous microbial populations.

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