

European Journal of Technology (EJT)



Evaluation of the Rheological Properties of Raphia Sese Oil Based Mud (Ester Oil) for Oil Field Drilling Applications

*Manuella-Grace Syllou-Kongo, Richard Amorin, and Anthelme
Tsoumou*



Evaluation of the Rheological Properties of Raphia Sese Oil Based Mud (Ester Oil) for Oil Field Drilling Applications

Manuella-Grace Syllou-Kongo^{1*}, Richard Amarin¹, Anthelme Tsoumou²

¹Department of Petroleum and Natural Gas Engineering, University of Mines and Technology, Ghana.

²Bioecology, Ecole Normale Supérieure, Marien Ngouabi University, Republic of Congo.

Corresponding Author's Email: gracesyllou1@gmail.com

Abstract

Purpose: The environmental challenges posed by oil-based drilling fluids along with legislation associated with their use have necessitated the development of synthetic organic liquids that are able to both meet the technical and environmental requirements of the industry. In this regard, an environmentally friendly vegetable oil-based mud from Raphia Sese oil (ester oil) was formulated and its rheological properties and economics abilities analyzed.

Methodology: The rheological properties of the mud such as plastic viscosity, yield point, flow index, apparent viscosity, consistency index, dial readings, density, and pH were evaluated at unaged conditions from 80 °F to 200 °F.

Findings: The results showed that Raphia sese oil base mud was compatible with the conventional oilfield additives. Though its mud naturally recorded a low pH (8.3) due to the low pH of the Raphia sese oil (5.53), with improved extraction process and with the addition of pH additives, this could be enhanced. When compared with diesel-based mud, the Raphia sese based oil mud recorded higher density values and promising rheological properties. Though the initial cost of conditioning Raphia sese oil for mud formulation purposes was high, it was offset by its disposal cost as compared to that of diesel oil (saves about 34% the cost of using diesel).

Recommendation: From the findings, it is recommended that the recovery process of the Raphia sese oil as well as its thermal oxidation stability should be improved. Again, higher thermal conditioning testing must be done to ascertain the stability of the Raphia sese oil at higher temperatures. Also, the Congolese nation could consider the domestication of the Raphia sese palm to increase the production of its oil and the nation could go into the improved cultivation to promote local content and participation policy of the oil.

Keywords: *Raphia sese oil (ester oil), drilling fluid, pollution, disposal, rheology, density.*

1.0 INTRODUCTION

Drilling mud also called drilling fluid is a weighted viscous fluid mixture that is used in oil and gas drilling operations to carry rock cuttings to the surface, provide hydrostatic pressure, lubricate and cool a drilling bit. The performance of these drilling fluids depends on the rheological and filtration properties of the mud and associated cost since by estimation, drilling fluid costs represent about 20% of the total drilling cost of a well (Okorie *et al.*, 2015). For better control of high temperature high pressure formations and deviated wells, Oil-Based Muds (OBM) are the preferred choice of mud system to use. However, most of the conventional oil-based systems are associated to challenges such as initial high cost, health, safety and environmental concerns, disposal challenges among others (Amorin *et al.*, 2015; Okorie *et al.*, 2015).

The introduction of synthetic base fluids in drilling mud formulations over the past two decades has considerably reduced the challenges usually associated with these conventional drilling fluids (Amorin *et al.*, 2015). Some key advantages of Synthetic Based Muds (SBM) over Water Based Muds (WBM) and OBMs are higher penetration rates, thermal stability, lower reservoir damage, higher lubricity, low corrosion, longer bit life and lower fluid loss (Amorin, and Broni-Bediako, 2020; Udoh *et al.*, 2012). Though SBFs are environmentally friendly over OBMs, they are sometimes more costly. Also, not all chemically produced SBFs are biodegradable and economical like the ester (vegetable oils) SBFs. The importation of these commercial oils increases the over drilling and cementing cost (Woodland *et al.* 2022; Amorin *et al.*, 2015). The use of local oils for such drilling campaigns could reduce the overall cost of drilling activities in the Republic of Congo. One potentially untapped environmentally friendly local SBM is Raphia Sese oil (*Mafuta kolo in Lingala language*) which is produced and of less usage in the Republic of Congo. This work therefore, formulated an environmentally friendly synthetic based drilling fluid using the Raphia Sese oil for oil field applications.

2.0 MATERIALS AND METHODS

2.1 Sample Collection

The oils used for this experiment were diesel and Raphia sese oils. The Raphia sese oil, was obtained from one of the local markets of Brazzaville in Congo Republic. Before it was used for the work, it was conditioned to dehydrate it. This also helped the fatty content of the oil to accumulate for separation and disposal purposes.

2.2 Mud Formulation

Two different mud samples were formulated in this work. The first one was formulated using diesel oil (A) and the second one using Raphia sese oil (B) as base fluids for comparison as presented in table 1. The rheological properties of the mud such as plastic viscosity, yield point, flow index, apparent viscosity, consistency index, shear stress (Pa) shear rate (sec⁻¹), density, and pH were determined using equations in Table 2. These tests were carried out at unaged conditions from 80 °F to 200 °F.

Table 1: Quantity of additives needed for the formulation

Additives	A (Diesel)	B (Raphia Oil)
Oil volume, ml	280	280
Water volume, ml	35	35
CaCl ₂ , g	9	9
PE, ml	5	5
SE, ml	2	2
Lime, g	5	5
OC, g	1	1
CaCO ₃ , g	99	61

Table 2: Equations needed for the work

Parameter	Equation
Plastic viscosity	$\mu_p = \theta_{600} - \theta_{300}$
Yield point	$YP = \theta_{300} - \mu_p$
Flow index	$n = 3.32 \log\left(\frac{\theta_{600}}{\theta_{300}}\right)$
Apparent viscosity	$\mu_a = \frac{\theta_{600}}{2}$
Consistency index	$K = \theta_{300} / (511)^n$
Shear stress (Pa)	$\tau = 4.79 * Dial\ Readings$
Shear rate (sec ⁻¹)	$\gamma = 1.7034 * RPM$

3.0 RESULTS

3.1 pH and Density

Figure 1 presents the pH and density of the samples. RO (Raphia sese), presented an acidic pH with a value of 5.53 while Diesel (DO) recorded a neutral pH of 7.0. These therefore affected the final mud pH samples. API recommends a density of 7.5 to over 22 lb/gal and pH of 8.5 to 10.5 for various drilling conditions. The pH for the RO was slightly lower than the 8.5 minimum PH value for API, but could easily be enhance with the addition of more lime. On the other hand, because of the higher viscosity of RO, it recorded a higher value mud density (9.3 ppg) than DO mud system (8.4 ppg) and therefore would require lesser amount of weighting material to produce the same mud weight (saving cost in that regard).

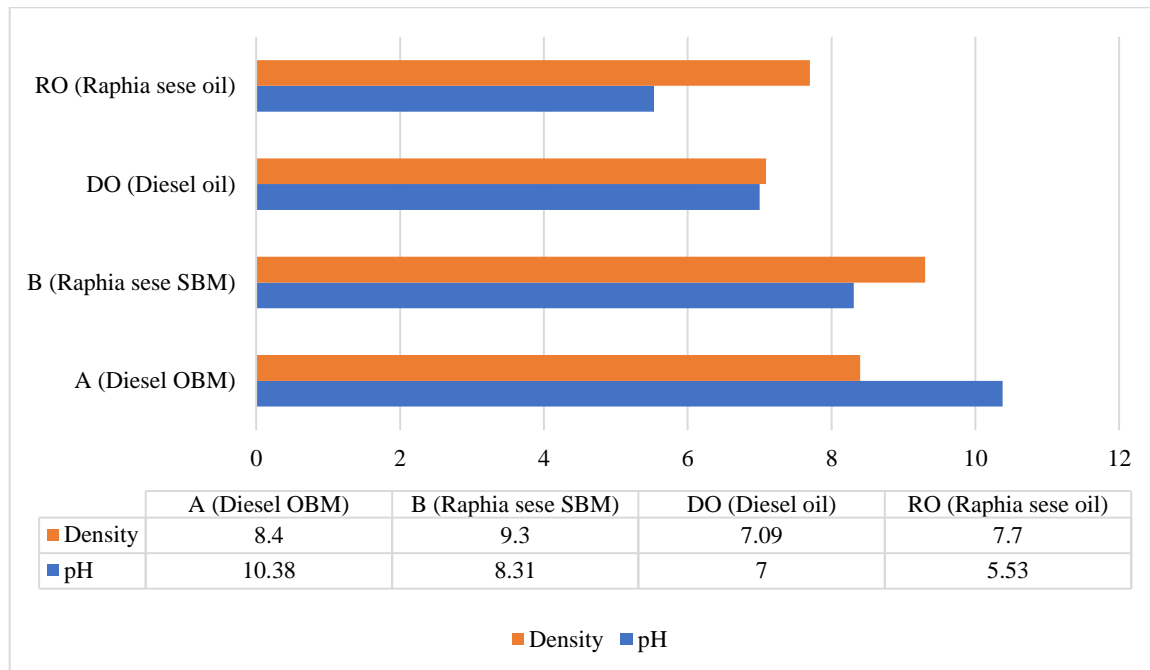


Figure 1: pH and Density of the Samples

3.2 Rheological Properties of Unaged Samples

The values recorded for the unaged samples are presented in table 3.

Table 3: Rheological Properties of Unaged Mud Samples

Sample ID	A				B				
	80	120	160	200	80	120	160	200	
Temp (°F)									
	600	27	21	16	13	281	173	92	73
	300	14	11	8	7	153	97	59	46
Dial Reading	200	9	6	5	4	115	41	39	33
	100	5	4	3	3	56	5	21	18
	6	2	2	2	2	7	4	4	4
	3	1	2	1	1	5	4	3	3
Gel Strength @	10"	2	2	2	1	6	5	5	4
	10'	2	3	2	2	8	7	7	4
PV	13	10	8	6	128	76	33	27	
YP	1	1	0	1	25	21	26	19	
n	0.947	0.932	0.999	0.893	0.877	0.834	0.641	0.666	
K	0.038	0.033	0.016	0.027	0.647	0.534	1.086	0.723	
AP	13.5	10.5	8	6.5	140.5	86.5	46	36.5	
PV/YP	13	10	-	6	5.12	3.619	1.269	1.421	
Yield Stress	1	2	1.7	1	5	4	3	3	

3.3 Rheological Models of Mud Samples

From Table 3, the viscosity decreased with increase in temperature. Also, it is seen that the values of n (flow index) were less than one for all the samples except sample A at 160 °F. Those of K (consistency index) were less than one for all samples except sample B at 160 °F also suggesting that the fluids were less viscous. Due to their yield values, almost all the mud samples recorded rheological plots not passing through the origin suggesting a Bingham or the Herschel Bulkley rheological model as shown in Figure 2. There n values less than one suggest

a Herschel Bulkley rheological model. Only sample B at 160 °F and 200 °F passed the PV/YP ratio with their values being in the API range (0.8 - 1.5). The PV/YP curves can be used for evaluating the stability of drilling fluids. They can also serve as guidelines in the field control of the drilling fluid systems and in taking timely actions (Chilingarian *et al.*, 1983).

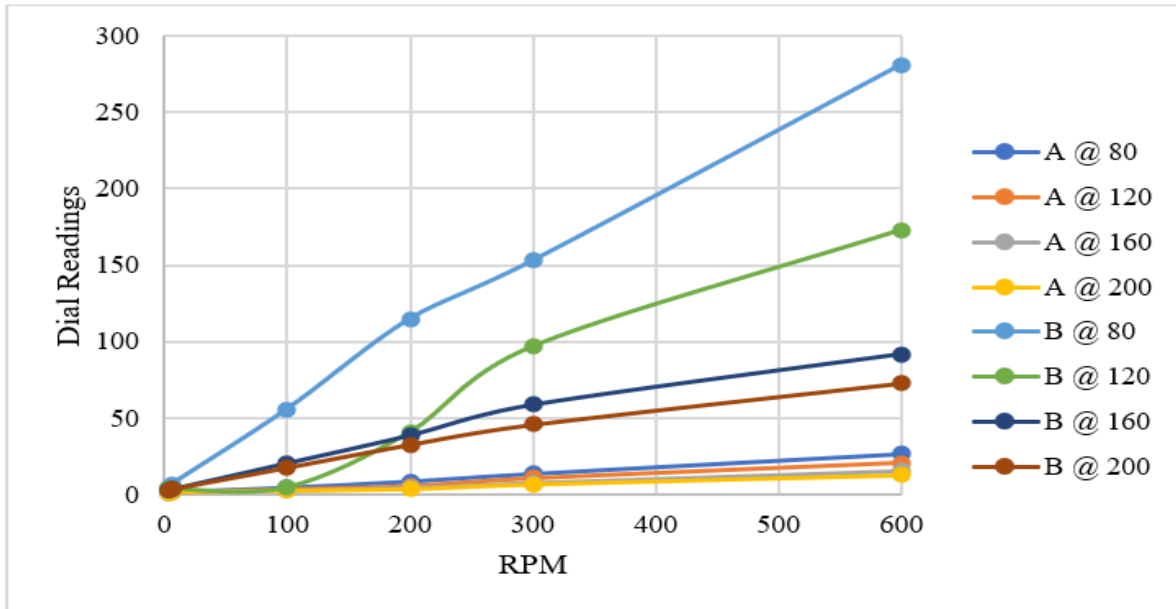


Figure 2: Dial readings for the various mud samples

3.4 Plastic Viscosity

Plastic viscosity is that part of resistance to flow caused by mechanical friction. According to API standards, the PV should be as low as possible to prevent solid sagging and provide easy cleaning of the wellbore (Blay-Sam, 2015). A low PV indicates that the mud is capable of drilling rapidly because of the low viscosity of mud exiting at the bit. High PV is caused by a viscous base fluid and by excess colloidal solids (Anon, 2016a). Figure 3 depicts the PV of the mud samples. Sample A passed the test at all the temperatures. B passed the test at 160 and 200 °F. The PV efficiency was in the following order: B<A.

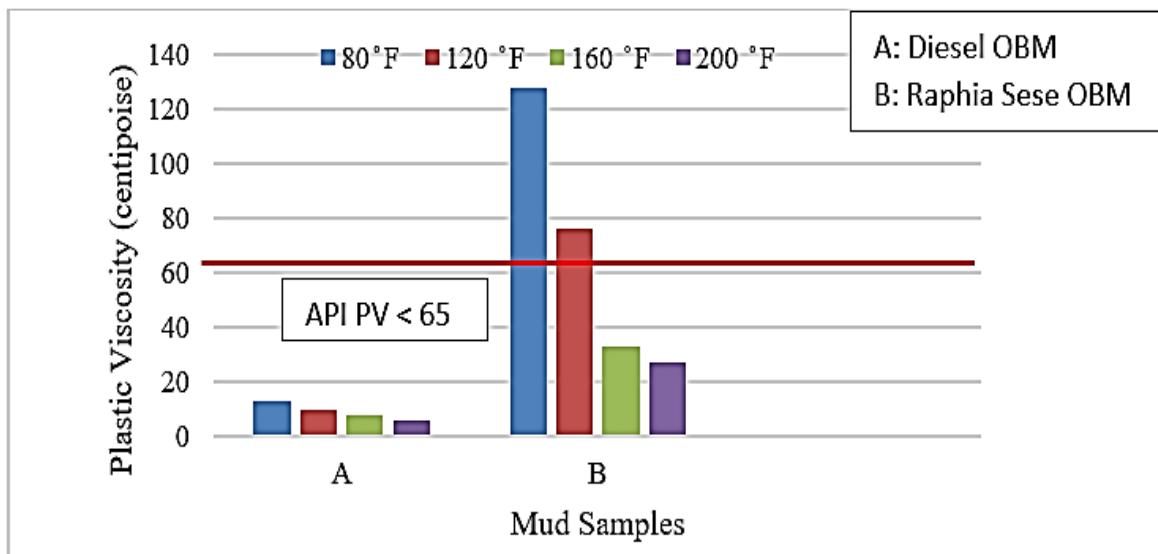


Figure 3: Plastic viscosity for mud samples

3.5 Yield Point

The yield point is the initial resistance to flow caused by electrochemical forces between the particles (Amorin, 2015a). API recommends a range value of 15 - 45 lb/100 ft² for YP. Figure 4 depicts the YP of the mud samples. A higher YP implies that drilling fluid has ability to carry cuttings better than a fluid of similar density but lower YP (Anon, 2016b). Only sample B was able to pass the test and its best YP was recorded at 200 °F.

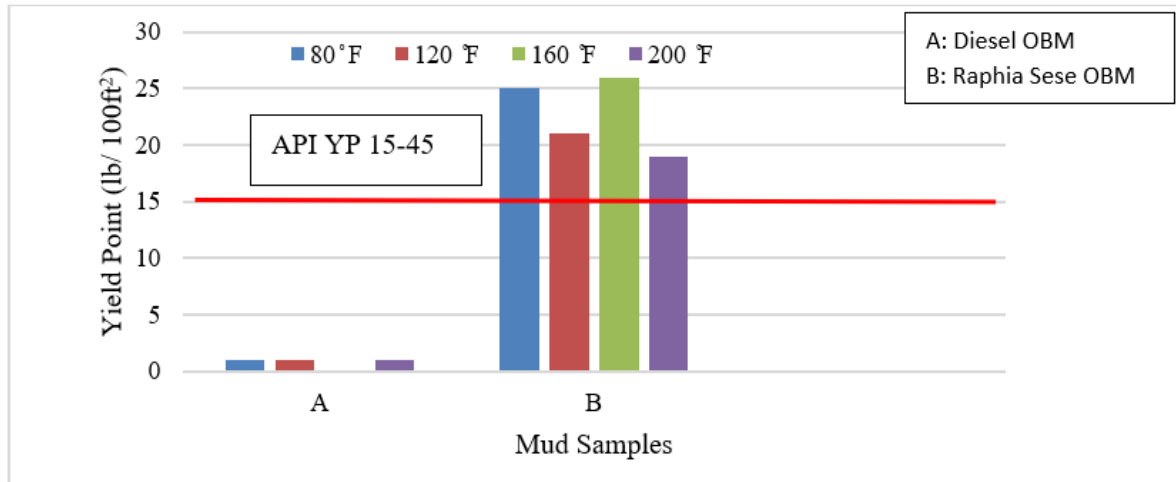


Figure 4: Yield Point for Mud Samples

3.6 Gel Strengths

Gel strength indicates strength of attractive forces in drilling under static conditions. This also describes the ability of the mud to suspend cuttings in a static condition and the pressure to flow the mud after it has been static for some time (Amorin, 2015a). API recommends ranges of 3 - 20 (lb/100 ft²) and 8 - 30 (lb/100 ft²) for 10 seconds and 10 minutes gel strength respectively. As shown in Figures 5 and 6, sample A failed both tests. Sample B passed the 10 seconds gel test. Sample B passed the 10 minutes gel strength at 80 °F only.

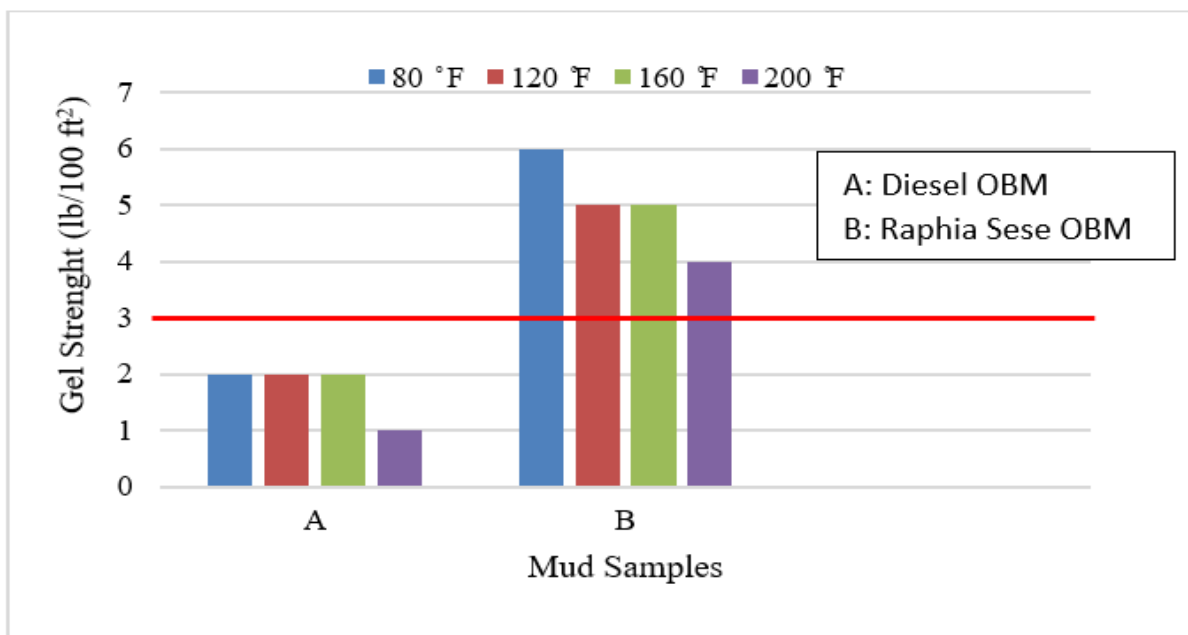


Figure 5: 10 seconds gel strength

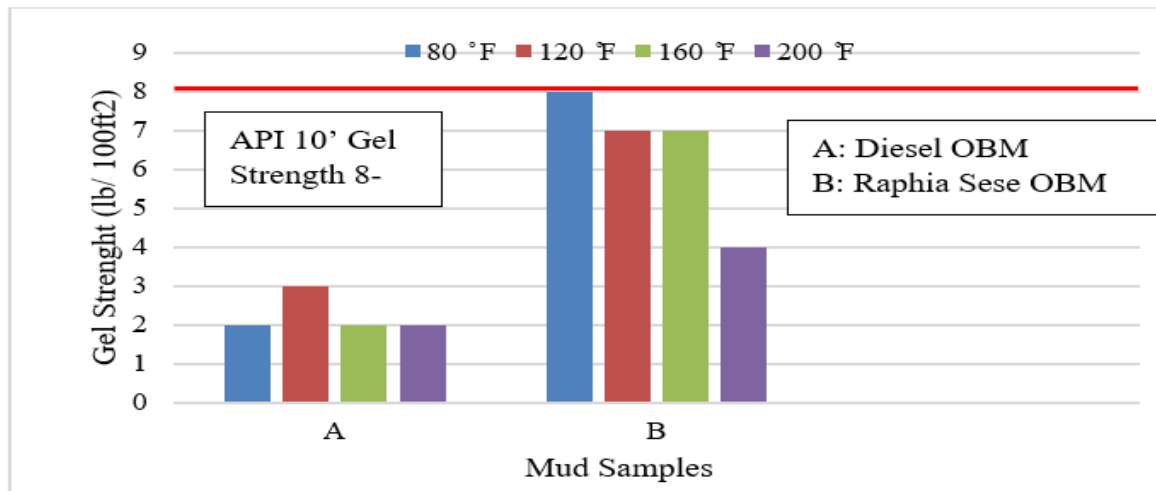


Figure 6: 10 minutes gel strength

4.0 ECONOMIC ANALYSIS

According to Amorin and Broni-Bediako (2020), the purchase costs of SBMs generally are several times higher than the costs of OBMS. However, the cost disadvantage is overcome if cuttings from wells drilled with SBMs can be discharged on-site, saving transportation and disposal costs. The costs considered in this work covered the cost of formulation and disposal options offshore. For this work, only the offshore (OFS) disposal and injection options were considered.

4.1 Cost of Materials Used for Oil Mud

The costs of DO and RO were obtained from Shell Tarkwa filling station and the local market of Tchikapika in Congo Brazzaville respectively. The average exchange rate used in the work was obtained from Anon, (2016c) at a rate of Ghana Cedis 3.86 = \$ 1 and CFA 575.65 = \$ 1. Data of some other items used for the analysis were obtained from Amorin, 2015b. An assumed 1000 bbls (159 m³) of mud samples were formulated for each sample.

4.2 Cost Analysis

Table 4 shows the cost of conditioning RO for SBM purposes. Its conditioning cost was higher than that of DO. The initial high cost was then offset when the disposal charges were considered.

Table 4: Total cost (\$/1000 Bbls) for the mud samples

Parameters	Cost/Unit	A	B
Oil	\$/280 ml	0.218	0.973
CaCO ₃	0.00013 \$/g	0.0128	0.008
Other additives held constant in all samples			
Lab	\$/350 ml	0.230	0.981
	\$/1000 ml	0.659	2.8021
Field	\$/bbl	104.707	445.538
	(X) \$/1000 bbls	104706.8	445537.7
OFS Disposal Cost	(Y) \$/Well	1,250,000	450,000
Total Cost (\$/1000 bbls) (X+Y)		1,354,707	895,538
Total Cost Savings %		-	34

4.3 Offshore Disposal and Injection Options

When grading oils, vegetable oils belong to Group III oils and they can be discharged offshore easily because of their non-toxicity and biodegradability. However, DO belongs to Group I oils and can only be discharged offshore by injection into deep formation because of their toxicity and non-biodegradability. Figure 7 presents the cost for formulating 1 bbl of oil mud sample and Table 4 shows their costs from formulation to disposal. Diesel OBM presented the highest total cost. The offshore disposal costs were obtained from Bernier *et al.* (2003). Thus, RO saves about 34% the cost of using DO.

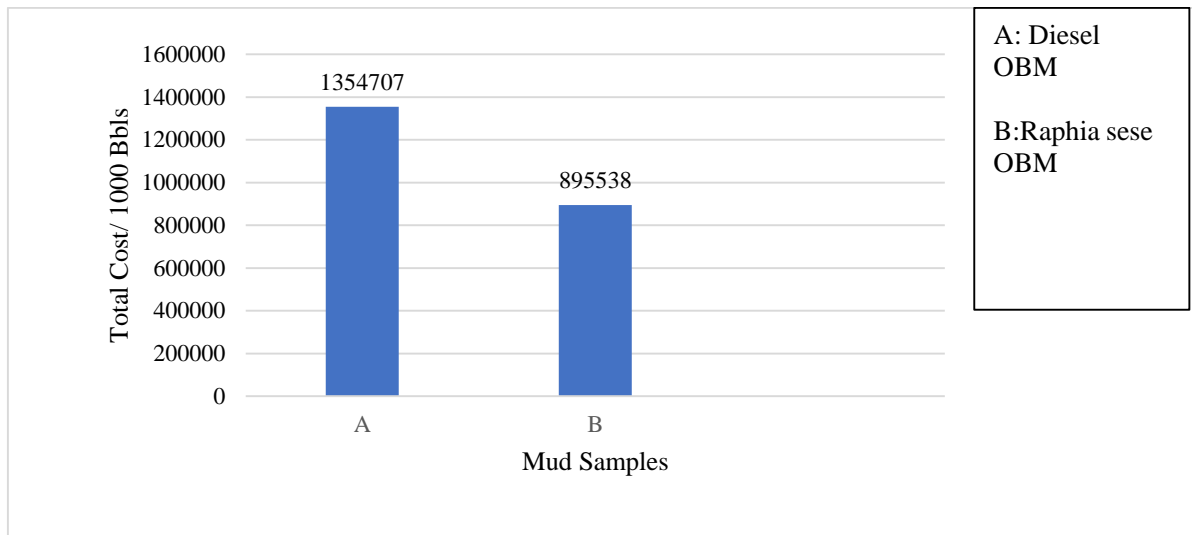


Figure 7: Total cost in \$/1000 bbls (cost of mud formulation and offshore disposal)

5.0 CONCLUSION

Raphia sese oil was used as based fluid for the formulation of a SBM and the rheological properties of that mud sample were compared to those of a drilling mud having diesel oil as based fluid. The results showed that Raphia sese oil base mud was compatible with the conventional oilfield additives. Though its mud naturally recorded a low pH (8.3) due to the low pH of the Raphia oil (5.53), with improved extraction process and with the addition of pH additives, this could be enhanced. With further beneficiation, the Raphia sese oil will be a promising synthetic based fluid for oil field drilling application since it performed better than the diesel oil mud. Again, the Raphia sese oil is considered to be very economical over diesel oil since its total cost/1000 bbls of formulation and disposal is about 66% lesser than the use of diesel oil.

Based on the study findings, it is recommended that the recovery process of the Raphia sese oil as well as its thermal oxidation stability should be improved. Also, higher thermal conditioning testing must be done to ascertain the stability of the oil at higher temperatures. If the Raphia sese oil is to be used in cold areas as a base fluid, additives should be used to improve upon its cloud and pour points. Again, the Congolese nation could consider the domestication of the Raphia sese palm to increase the production of its oil and the nation could go into the improved cultivation to promote local content and participation policy of the oil.

Acknowledgements

The team wishes to acknowledge the petroleum laboratory team of the University of Mines and Technology for their support during the study.

REFERENCES

- Amorin, R. (2015a), "Drilling Fluids", *Unpublished BSc Lecture Notes*, University of Mines and Technology, Tarkwa, 74 pp.
- Amorin, R. (2015b), "Evaluation of the Rheological Properties of Antioxidated Local Oils for Pseudo Oil Base Mud Formulation for Drilling Operations", *Unpublished PhD Thesis Report*, University of Mines and Technology, Tarkwa, 199 pp.
- Amorin, R. & Broni-Bediako, E. (2020), "Evaluating the Rheological Properties of Antioxidated Local Pseudo Oil Base Muds for Geothermal Drilling Environment", *Ghana Journal of Technology*, Vol. 5, No. 1, pp. 93-103.
- Amorin, R., Dosunmu, A. & Amankwah, K. R. (2015), "Enhancing the Stability of Local Vegetable Oils (Esters) For High Geothermal Drilling Applications", *Journal of Petroleum and Gas Engineering*, Vol. 6, No. 8, pp. 90-97.
- Amorin, R., Dosunmu, A. & Amankwah, R. K. (2015), "Economic Viability of the Use of Local Pseudo-Oils for Drilling Fluid Formulation", *Ghana Mining Journal*, Vol. 15, No. 2, pp. 81 - 90.
- Anon. (2016a), "Plastic Viscosity", www.glossary.oilfield.slb.com. Accessed: April 6, 2016.
- Anon. (2016b), "Yield Point (YP)", www.drilling-mud.org/yield-point-yp/. Accessed: April 6, 2016.
- Anon. (2016c), "XE: (USD/INR) US Dollar to Indian Rupee Rate", <http://www.xe.com/currencyconverter/convert/?From=USD&To=INR>. Accessed: March 30, 2016.
- Bernier, R., Garland, E., Glickman, A., Marathon, F. J., Mairs, H., Melton, R., Ray, J., Smith, J., Thomas, D. & Campbell, J., (2003), "Environmental Aspects of the Use and Disposal of Non-Aqueous Drilling Fluids Associated with Offshore Oil and Gas Operations" *Unpublished Technical Report by International Association of Oil and Gas Producers*, Report No. 342, 114 pp.
- Blay-Sam, D. (2015), "Evaluation of Rheological Properties of Antioxidated Coconut Oil Base Mud", *Unpublished BSc Project Report*, University of Mines and Technology, Tarkwa, 34 pp.
- Chilingarian, G. V., Alp, E., Al-Salem, M., Uslu, S., Gonzales, S. & Dorovi, R. J. (1983), "Drilling Fluid Evaluation Using Yield Point-Plastic Viscosity Correlation", *One Petro*, 16 pp.
- Okorie E. Agwu, Anietie N. Okon, & Francis D. Udoh (2015), A Comparative Study of Diesel Oil and Soybean Oil as Oil-Based Drilling Mud, *Journal of Petroleum Engineering* Volume 2015, pp. 1-10.
- Udoh, F. D., Itah J. J. and Okon, A. N. (2012), "Formulation of Synthetic-Based Drilling Fluid Using Palm Oil Derived Ester", *Asian Jr. of Microbiol. Biotech. Env. Sc.*, Vol. 14, No. 2, pp. 175-180.
- Woodland, F., Dankwah, J. R., Amorin, R. & Dabo, K., (2022), "Evaluation of the Effect of Water Hyacinth Ash (WHA) as an Additive on Local Portland Cement for Oil Well Cementing", *International Journal of Scientific Development and Research*, Vol. 7, No. 8, pp. 1-11.