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Application of re-refined used lubricating oil as base oil for the formulation of oil based drilling mud - A comparative study

Oghenejoboh K. M.[1]*, Ohimor E. O.[2] and Olayebi O.[3]

[1]Department of Chemical Engineering, Delta State University, Oleh Campus, P. M. B. 22, Oleh, Nigeria.
[2]Industries Department, Ministry of Commerce and Industry, Agbor, Delta State, Nigeria.
[3]Department of Chemical Engineering, Faculty of Engineering, Federal University of Petroleum Resources, Ugbomoro, Delta State, Nigeria.

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The viability of using re-refined used lubricating oil (RULO) extracted with an aromatic selective normal methylpyrolidone (NMP) as base oil for the formulation of drilling mud was investigated. The rheological and other properties of this formulation were compared with formulations from three locally produced synthetic base oils. The synthetic base oils were Paradril® made from saturated linear ethylene polymer, Emcaid® manufactured from a blend of olefin isomers and Ty-Chem-Low Tox® made from catalytic dimerization of linear alpaolefins. RULO based mud, though alkaline in nature with a pH of 8.5 exhibits very poor filtration properties with the thickest filter cake when compared with the other formulations. It is also the least stable of the four formulations with an electrical stability (ES) of 480 volts. RULO formulation is very toxic as the cassava plant on which it was spilled survived for only 5 days compared to 15 days for Paradril®. It is therefore, not environmental friendly and may not also be cost effective as the cost of re-refining and extraction may far exceed the cost of producing synthetic base oil. RULO may not therefore be a viable alternative to existing base oils for the formulation of drilling mud.

Key words: Used lubricating oil, base oil, drilling mud, rheological properties, emulsifier, environment.

INTRODUCTION

The oil industry in Nigeria had in the past relied too heavily on imported drilling chemicals (fluids) for her drilling operations which in turn have increased their operating cost and engendered capital flight. Different types of drilling fluids are used by the oil producing companies in Nigeria due to their onshore/offshore operational nature. These drilling fluids are water-based mud (WBM), oil-based mud (OBM) and synthetic-based mud (SBM). The type used for a particular drilling operation depends on the nature and location of the oil wells to be drilled. WBM which is made from bentonite clay with some chemicals such as potassium formate added to achieve various effects like viscosity control, shale stability, enhance drilling rate of penetration, cooling and lubricating of equipment are used mainly for drilling shallow onshore wells (Broni-Bediako and Amorin, 2010). However, oil wells are rarely shallow and sometimes complex evolving from vertical, inclined, horizontal, sub-sea to deep-sea drilling; as a result WBM becomes ineffective in accomplishing the required

*Corresponding author. E-mail: kmoghene@yahoo.com.

objective of an efficient drilling mud, therefore the use of OBM becomes imperative. OBM is a mud having a petroleum product such as diesel fuel as the base fluid. Oil-based muds are used for many reasons, some being ability to withstand greater heat without breaking down and cost environmental considerations. Other advantages of OBM over WBM are its excellent fluid loss control, no shale swelling, adequate lubrication of drill bits and good cutting carrying ability. Synthetic-based fluid is a mud with synthetic oil as the base fluid. This is most often used on offshore rigs because it has the properties of an oil-based mud, but the toxicity of the fluid fumes are much less than an oil-based fluid. This is important when men work with the fluid in an enclosed space such as an offshore drilling rig. Due to the environmental advantages of synthetic-based mud, it is more preferable by drilling companies despite its exorbitant cost. Synthetic oil based mud (SOBM) is basically water-in-oil or 'invert', emulsion. The water-in-oil emulsion itself is usually stabilized with a "primary emulsifier" (often a fatty acid salt), while the weighting material, along with drill solids which the mud acquires in use, is made oil-wet and dispersed in the mud with a "secondary emulsifier" (typically a strong wetting agent, such as a polyamide) (Broni-Bediako and Amorin, 2010; Growcock et al., 1994). For SOBM to be effective the emulsion formed must be stable, such stability is derived from the strong visco-elastic characteristics caused by the presence of asphaltenes and resins in the mixture (Akpabio and Ekott, 2013; Langevin et al., 2004). The SOBM premixes or invert emulsions are formulated to contain some amount of water (up to 30%). The amount of synthetic oil and water in the SOBM premix is referred to as the Oil-Water-Ratio (OWR). Emulsifiers are then added to emulsify the water as the internal phase and prevent the water from breaking out and coalescing into larger droplets (Huda and Nour, 2011). These water droplets, if not tightly emulsified, can water-wet the already oil-wet solids and dramatically affect the emulsion stability (Abdel-Raouf, 2011). To achieve this therefore, compounds with higher solubility in the oil phase rather than in the aqueous phase are used as emulsifiers (Dimitrov et al., 201).

To minimize the drilling industries' operating cost index, concerted efforts are ongoing to find an effective, inexpensive and ecologically safe drilling fluids that can be sourced locally in line with the current Nigerian Oil and Gas Industry Content Development Policy. To this end, the company, Skyward Resources Ltd based in Port-Harcourt, Nigeria has developed some drilling fluids chemicals such as oil mud thinner (OMT 5), oil mud wetter (OMW 5), drilling detergent (DD 3100), primary emulsifier (PEM 5) and secondary emulsifier (SEM 5) from vegetable extracts. These chemicals have been used with biodegradable plant based oil such as jatropha oil, rapeseed oil, soyabeans oil and cottonseed oil (Fadairo et al., 2012) as well as other low aromatic synthetic mineral base oil for the formulation of SOBM that are environmental friendly and non-toxic. However, it is the belief of the authors that the production cost of drilling fluids can further be reduced by using discarded used lubricating oil as base oil for the formulation of SOBM, since plant oil is not usually available in commercial quantity. This is however, based on the fact that the used lubricating oil must meet the basic environmental requirements for such use (Nweke and Okpokwasili, 2003). Used lubricating oil is currently a source of environmental nuisance in Nigeria since it is indiscriminately dumped into rivers, soil and the environment as a result of lack of stringent enforcement of environmental laws (Oghenejoboh and Ohimor, 2012; Ogbo et al., 2009). Used lubricating oils can therefore be collected at no cost from mechanic workshops and other outlets involved in rotating machine repairs and maintenance. Used lubricating oil contains lot of impurities such as mixture of high molecular weight aliphatic and aromatic hydrocarbons as well as heavy metals acquired from engine wear and tear (Wang et al., 2000). Used lubricating oil also contains combustion products (water, un-burnt fuel, soot and carbon) as well as abrasive materials such as road dust. All these contaminants must be removed through re-refining before it can be used as base oil for the formulation of drilling mud. Re-refining of used lubricating oil involve three steps - dehydration, stripping and distillation. The dehydration step entails physical treatment in which the used oil is stored in a container for a period of time to allow water and solids to separate out of the oil followed by boiling to break water emulsion and to allow fuel diluents to evaporate from the oil. The stripping step involves normal fractionation where the bulk of the feedstock is distilled off as lubricating oil fractions. The final step in the re-refining process is the extraction process whereby a suitable solvent is used to remove all carcinogenic compounds such as poly aromatic compounds contained in the oil. This step also remove odour and colour from the oil.

In the present study, the stability and toxicity of SOBM formulated from re-refined used lubricating oil is compared with those from three commercial base synthetic base oil - Paradril® (made from saturated linear ethylene polymer), Emcaid® (made from a blend of olefin isomers) and Ty-Chem-Low Tox® (made from catalytic dimerization of linear alphaolefins) as well as results obtained with plant base oil by other workers.

MATERIALS AND METHODS

The materials used for the experiments were spent lubricating oil, soxhlet extractor fixed with 500 ml flask, distillation column, digital weighing balance, Hamilton beach mixer, mud balance, hot plate, digital thermometer, 1000 ml measuring cylinders, 500 ml measuring cylinder, 100 ml beaker, 5 ml syringes and ES-meter. Other materials used were, synthetic base oils, primary emulsifier (PEM 5) and secondary emulsifier (SEM 5) both obtained from Skyward Resources Ltd based in Port-Harcourt, organoclay, soltex,

Table 1. Viscometer reading for mud formulated from the base oils used in this work.

Dial reading (D) (RPM)	Base oil samples (lb/100 ft^2)			
	A	B	C	D
600	186	122	144	130
300	168	111	129	109
100	158	93	124	101
100	151	86	114	92
60	147	71	105	85
30	136	68	93	70
3	72	51	68	55

lime, calcium chloride, distilled water and barite.

Experimental procedure

Treatment and re-refining of used lubricating oil

Ten litres of used lubricating oil obtained from a motor mechanical workshop in Warri, Delta State of Nigeria was left in a 20 L plastic paint bucket for 5 days to allow water and solids to separate out of the oil after which the oil was decanted. Some of the decanted oil was then heated in a closed vessel immersed in a water bath maintained at 120°C for 60 min to boil off some of the emulsified water and fuel diluents. The dehydrated oil was then fractionated using a laboratory scale distillation column following the normal crude oil distillation process. The refined lubricating oil obtained as intermediate from the fractionation process is then extracted with N-methylpyrolidone (NMP) using a soxhlet extractor. The extraction step is aimed at removing unwanted aromatic contaminants present in the paraffinic lubricating oil fraction since NMP is an aromatic selective solvent. The solvent also removes colour and odour from the oil. The re-refined lubricating oil was then used as base oil for the formulation of drilling mud.

Formulation of drilling mud

175 ml of the re-refined lubricating oil and 75 ml of de-ionized water were measured into a mixing vessel using the measuring beakers. 4, 6, 6 and 2 g of organophilic clay, lime, PEM 5 and SEM 5 were then added to the mixture. 0.5 ml of brine solution prepared from 25 g of $CaCl_2$ in 100 ml of de-ionized water was added before subjecting the mixture to thorough mixing using Hamilton Beach mechanical mixer, model 936 to attain a homogeneous mixture. The formulated drilling mud was allowed to age for 24 h. The same procedure was repeated for the three synthetic base oils (Paradril®, Emcaid® and Ty-Chem-Low Tox®). For ease of identification, the base oil samples used for the drilling fluid formulation were labeled:

Sample A	re-refined used lubricating oil
Sample B	Paradril® synthetic base oil
Sample C	Emcaid® synthetic base oil
Sample D	Ty-Chem-Low Tox® synthetic base oil

Measurement of formulated fluid properties

The density, viscosity, gel strength, pH, filtered volume, filter cake thickness, electrical stability as well as the toxicity of the formulated drilling fluids were determined and compared. The density and viscosity of the fluids were measured using the method outlined by Fadairo et al. (2012) with the values of apparent viscosity (μ_A), and plastic viscosity (μ_p) obtained from the equations developed by Amorin et al. (2011) as reproduced below.

$$\mu_p = D_{600} - D_{300} \tag{1}$$

$$\mu_A = \frac{D_{600}}{2} \tag{2}$$

Where D_{600} and D_{300} is the viscometer dial reading at 600 and 300 rpm in centipoises (cP) respectively.

The electrical stability of the tested drilling fluids was determined using an ES meter according to API 13B-2 procedure. Gel strength was determined using the rotational viscometer at 10 s and 10 min respectively, while the pH of the fluids was estimated by means of the pH colorimeter paper method of Fadairo et al. (2012). The API filter press was used to determine the filtered volume of the drilling fluid following the procedure of Amorin et al. (2011). The filter cake thickness of the fluids was determined using the filter paper and cake formed during the filtered volume experiment. The filter paper was thoroughly washed and placed in between two glass slides of equal diameter as the filtered paper before subjecting it to a pressure of 300 N/m^2 for 3 min. Then the slides, the filter paper and cake formed were put in an extensometer to determine the thickness of the cake formed.

To test the environmental friendliness of all the formulated fluids, 100 ml of each were spilled on 4 weeks old cassava plants and the number of days of the plants' survival was noted.

RESULTS

The result of the viscosity test is presented in Table 1, while Table 2 shows the pH, density, plastic viscosity, apparent viscosity, gel strength (10 s/10 mins) as well as the electrical conductivity of the formulated fluids.

DISCUSSION

From the results presented in Table 2 we can see that sample A (re-refined used lubricating base oil) has the highest apparent viscosity followed by sample C (Emcaid® synthetic base oil) while sample B (Paradril® synthetic base oil) exhibited the least viscosity. This result infer that re-refined lubricating base oil offers the greatest resistance to fluid flow with the least resistance offered by Paradril®

Table 2. Rheological and other properties of the formulated drilling muds.

Base oil samples	pH (-)	Density (ppg)	Plastic viscosity (μ_P) (cP)	Apparent viscosity (μ_A) (cP)	Gel strength lb/100 ft^2	ES (volts)
A	8.5	8.32	18	93	53/54	480
B	8.8	8.30	11	61	55/55	697
C	9.8	8.13	15	72	60/72	550
D	7.7	8.47	21	65	48/42	596

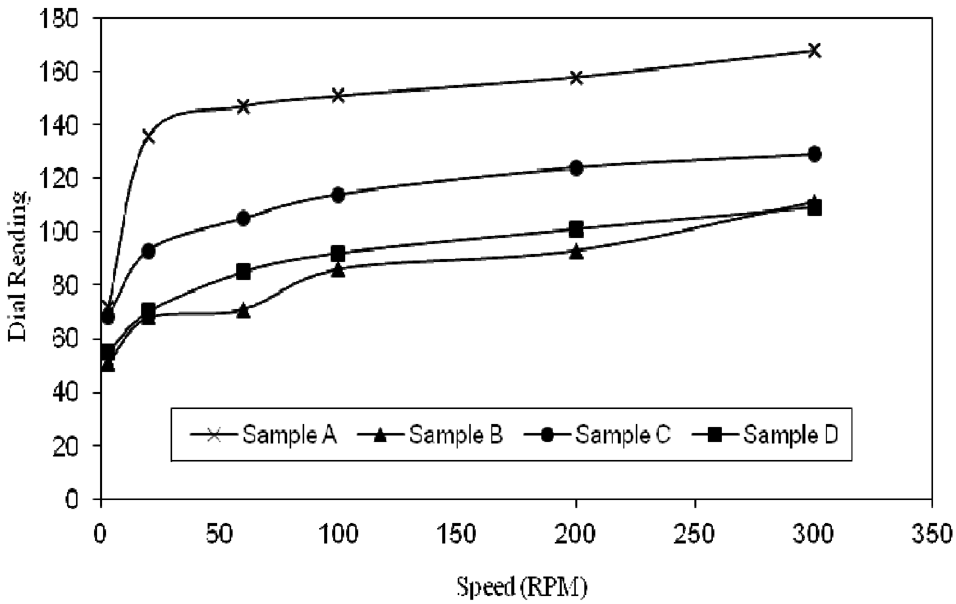

Figure 1. Viscometer plot for the formulated drilling muds.

synthetic base oil. Re-refined used lubricating base oil therefore posed the least prospect for the formulation of a good drilling fluid when compared with the three synthetic base oils used in this work since low viscosity drilling fluid lead to reduced wear in the drill string (Mitchell, 1995). However, the formulated muds from the four base oils have similar rheological behavior as they all approximately exhibit the Bingham plastic model from the plots of the rotary viscometer dial reading against speed generated as shown in Figure 1. This is an indication that re-refined used lubricating oil has the potential to be used as base oil for formulating drilling mud if the viscosity is reduced by adding appropriate polymers. The formulated drilling fluid from the four base oil samples show the same range of densities, with Ty-Chem-Low Tox® synthetic base oil having the highest density of 8.47 ppg followed by re-refined used lubricating oil (8.32 ppg) and Paradril® with 8.30 ppg while Emcaid® had the least density of 8.13 ppg. According to Fadairo et al. (2012) the denser the base oil, the higher the amount of barite needed to build. From the results it is evident that Ty-Chem-Low Tox® and re-refined used lubricating oil that have slightly higher densities will require the highest amount of barite to build.

Hydrogen ion potential (pH) is a very important parameter to consider when formulating drilling mud. Effective drilling muds are expected to be highly alkaline (that is, pH >7). This is because acidic (low pH) mud increases the corrosion of metals (pipes and casing) when it comes in contact with it. A drilling mud having a pH of between 7 and 9.5 had been reported to have the least effect on bentonite since the viscosity of such fluid remains relatively constant over a wide range of temperatures (Fadairo et al., 2012). However, a pH above 9.5 increases the mud viscosity thereby affecting the effectiveness of the drilling mud leading to complicated shale problems. As we can see from Table 2 the pH of the four formulated drilling fluids fall within the desired value, however, fluids formulated from re-refined used lubricating oil and Paradril® appear to give best hole stability and control over mud properties, since these requirements are met by fluid having a pH of 8.5 to 9.5

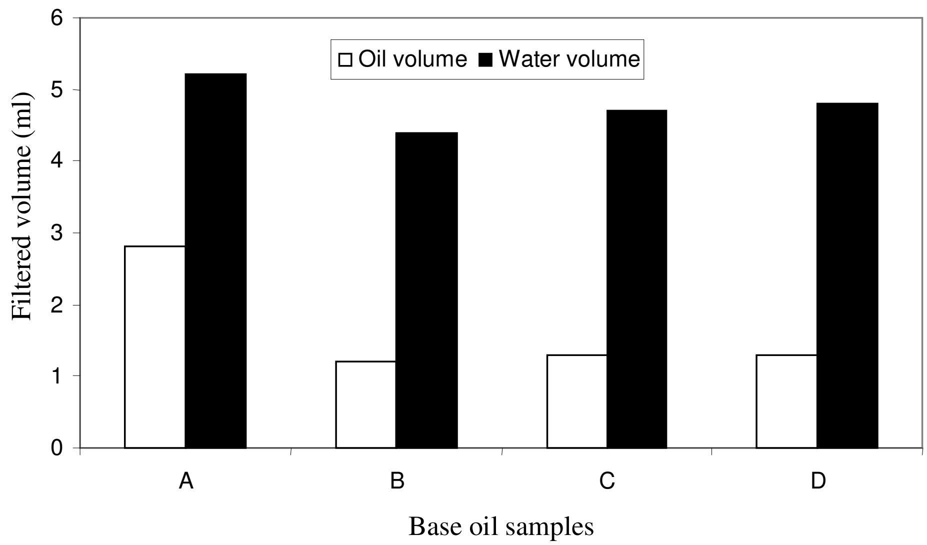

Figure 2. Filtration property of formulated drilling muds.

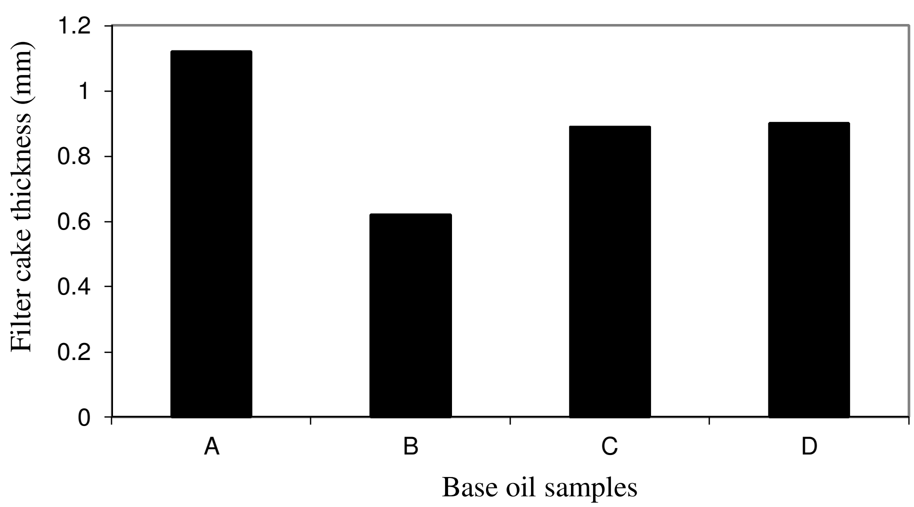

Figure 3. Filter Cake Thickness of formulated drilling muds.

(Fadairo et al., 2012).

The gel strength of the drilling fluids formulated from re-refined used lubricating oil was compared with those formulated from the three synthetic base oil used in this work. Gel strength is the ability of a drilling mud to suspend cuttings and other solid additives. From Table 2, the gel strength of mud produced from re-refined used lubricating oil and Paradril® synthetic base oil promised to be more effective than mud formulated from the other two synthetic base oils, since the shear rate of the mud remained consistent and high. High gel strength mud has the ability to suspend drill cuttings along the length of the drillpipe or bore annulus when the drilling mud circulation is stopped during pump tripping or any other secondary operations (Shah et al., 2010). A low gel strength mud on the other hand do not efficiently suspend cuttings thereby allowing cuttings to quickly drop leading to pump shut-down, stuck pipe, hole pack-off, barite sag as well as accumulation of cutting beds. From the results, it is clear that re-refined used lubricating oil mud has excellent cutting transport capabilities even at low values of viscosity. This result is similar to that obtained by Fadairo et al. (2012) for diesel based mud.

Another factor determining the successful performance of a drilling fluid tested for, in the formulated muds was the mud filtration capacity. From Figures 2 and 3 we can see that re-refined OBM has the highest filtration rate and as a result a thicker filter cake due to its high porosity

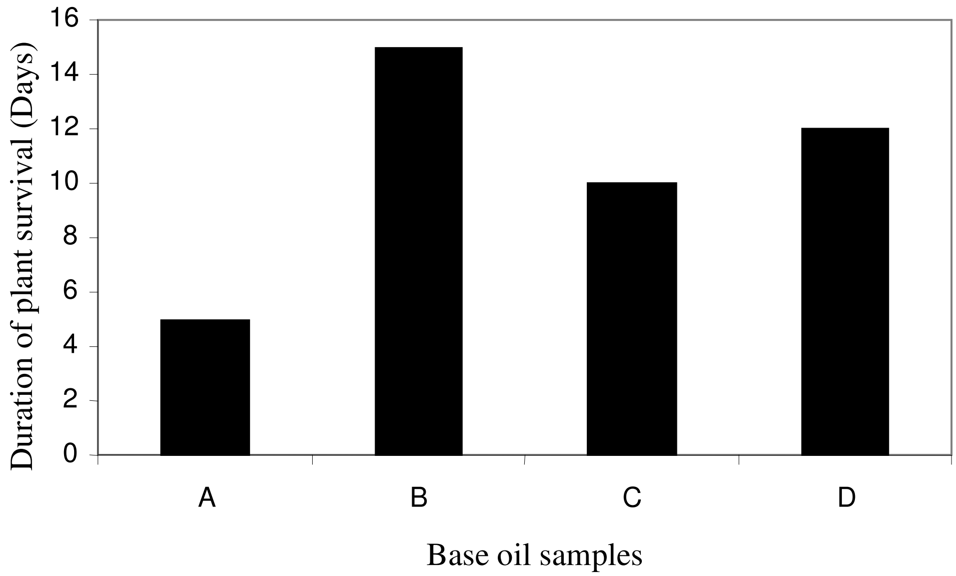

Figure 4. Survival days of cassava plants spilled with equal volume of the formulated muds

while Paradril® SOBM exhibited the lowest rate of filtration with thinner filter cake. High filtered volume is associated with thick filter cake because the cake is formed by deposition of clay particles on the walls of the hole during loss of water to the formation. So the higher the filtered volume, the thicker the filter cake and the less efficient the drilling mud. A thick cake reduces the effective diameter of the hole and increases the contact area between the tube and the cake leading to increased risk of stuck tubes (Amorin et al., 2011). Based on this result, drilling mud formulated from re-refined used lubricating oil will not be an effective fluid for drilling purposes.

Electrical stability (ES) is a vital property of oil based mud (OBM) and synthetic oil based mud (SOBM). The ES represents the stability of emulsions formed by oil and water during the formulation. A low ES mud is not conductive and therefore cannot transfer power. A good drilling mud should have an ES of between 700 and 900 V under circulation. However, an ES range of 300 to 400V is considered ideal for newly formulated mud as well as mud in storage. From the results of the ES test presented in Table 2, drilling mud formulated from the four base oils used in this study meet the specification for stable fluid, however, mud formulated from re-refined used lubricating oil exhibited the least ES value of 480 V and as such is the least stable of the formulations. The low ES value of the re-refined used lubricating oil based mud may be as a result of the low resistivity of the re-refined used oil. The resistivity of this base oil may have been reduced due to the rigorous re-processing steps it was subjected to prior to its use for the formulation. For re-refined used lubricating oil based mud emulsion to be stable there will be need to add water and salt to the formulation, which will invariably affect the effectiveness of the mud.

The toxicity test conducted by spilling equal volume of the four formulated muds on young cassava plants show that re-refined used lubricating oil mud is the most toxic of the formulations. Cassava plant spilled with re-refined used lubricating oil based mud first showed evidence of withering after 3 days and finally died after 5 days. Cassava plants spilled with mud formulated from Paradril®, Emcaid® and Ty-Chem-Low Tox® synthetic base oils survived for 15, 10 and 12 days respectively (Figure 4). From this result it is clear that SOBM is more environmental friendly than re-refined used lubricating oil based mud. In a similar study, Fadairo et al. (2012) observed that jatropha oil based mud spilled on growing bean seedling was able to survive for 16 days before it eventually died while the same quantity of diesel oil based mud spilled on the same bean seedling survived for only 7 days before dying. Re-refined used lubricating oil based mud is therefore more toxic than all other types of base oil used for formulating drilling mud – even diesel. Toxicity of drilling mud is a function of the aromatic content of the base oil. An environmental friendly drilling mud is one with negligible carcinogenic poly-aromatic compounds. This explains why vegetable base oil mud are ecologically and environmentally friendly as seen from the drilling mud produced from the other three synthetic base oils. Though extraction of the re-refined used lubricating oil with an aromatic selective solvent (N-methylpyrolidone (NMP)) is aimed at reducing the aromatic content of the re-refined oil to non detectable level, the toxicity result shows that the re-refined used lubricating oil based mud may still contain high concentration of aromatic compounds and this may have been responsible for its high toxic nature. Based on this result, re-refined used lubricating oil does not meet the environmental conditions for the formulation of an efficient and ecologically safe oil based drilling mud.

Conclusion

The possibility of using re-refined used lubricating oil as base oil for the formulation of drilling mud had been investigated. From the results, it is clear that re-refined used lubricating oil is not a viable option neither for diesel oil based mud nor for synthetic oil based mud. Re-refined used lubricating oil based mud is very toxic and therefore fails the environmental requirement as outlined for efficient drilling mud by the Nigerian Government. The cost index for re-refined used lubricating oil based mud may also be higher than those of the synthetic oil based mud due to the combined cost of refining and extraction. As a result, re-refined used lubricating oil may not be a viable alternative to vegetable oil and other synthetic oils for the formulation of drilling mud.

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