50/50 Oil-Water Ratio Invert Emulsion Drilling Mud Using Vegetable Oil as Continuous Phase

P. C. Ihenacho, M. Burby, G. G. Nasr, G. C. Enyi

***Abstract*—**Formulation of a low oil-water ratio drilling mud with vegetable oil continuous phase without adversely affecting the mud rheology and stability has been a major challenge. A low oil-water ratio is beneficial in producing low fluid loss which is essential for wellbore stability. This study examined the possibility of 50/50 oil-water ratio invert emulsion drilling mud using a vegetable oil continuous phase. Jatropha oil was used as continuous phase. 12 ml of egg yolk which was separated from the albumen was added as the primary emulsifier additive. The rheological, stability and filtration properties were examined. The plastic viscosity and yield point were found to be 36cp and 17 Ib/100 ft^2 respectively. The electrical stability at 48.9ºC was 353v and the 30 minutes fluid loss was 6ml. The results compared favourably with a similar formulation using 70/30 oil - water ratio giving plastic viscosity of 31cp, yield point of 17 Ib/100 ft^2, electrical stability value of 480v and 12ml for the 30 minutes fluid loss.

This study indicates that with a good mud composition using guided empiricism, 50/50 oil-water ratio invert emulsion drilling mud is feasible with a vegetable oil continuous phase. The choice of egg yolk as emulsifier additive is for compatibility with the vegetable oil and environmental concern. The high water content with no fluid loss additive will also minimise the cost of mud formulation.

***Keywords*—**Environmental compatibility, low cost of mud formulation, low fluid loss, wellbore stability.

I. INTRODUCTION

SUCCESSFUL drilling and completion of oil and gas wells to a considerable extent depend on the properties of the drilling fluids. The fluids are supposed to perform certain functions such as maintenance of wellbore stability, minimise fluid loss, lubricate and cool drill bit, clean and transport cuttings out of the wellbore. The choice of fluid depends mainly on the formation lithology, temperature and pressure, cost and logistics, environmental and health considerations. Invert emulsion fluids are usually preferred for drilling highly technical and challenging formations like shale. This is due to the fluids suitable properties such as improved wellbore stability, high lubricity, penetration rate, and greater cleaning abilities with less viscosity. The enhanced shale inhibition ability of invert emulsion fluids is of particular importance in shale formations for multi-stage fracking. Invert emulsion mud was defined by [7] as oil based drilling mud to which water is added to. According to [9] while drilling through shale, the water activity of the invert emulsion fluid is maintained at a lower level than the water activity of the shale thus creating an osmotic pressure that drives the flow of water from the shale to the invert emulsion fluid thereby preventing shale hydration. These properties may help to reduce operation cost; however, the use of potentially hazardous base fluids and chemicals like diesel pose several environmental issues associated with the disposal and hazards to personnel. The uncontrolled release of these fluids can result in the contamination of surrounding areas, including sources of drinking water, and can negatively impact natural habitat. Therefore, the current trend is towards development of environmentally friendly oil-based drilling fluids using alternative base oils to diesel while maintaining high technical performance. Over the years several plant oils have become increasingly popular in the raw materials market as diesel substitutes [6]. The most popular is Rapeseed oil, Mahua oil, Cottonseed oil, Sesame oil, Soya bean oil, palm oil, Canola oil, Moringa seed oil, Soapnut and Jatropha because of their low toxicity. In their study, [6] confirmed that Jatropha oil exhibited lower toxicity compared to canola and diesel oils. However, there have been conflicting issues with the vegetable oils in maintaining the mud technical properties like good rheology, high stability and low fluid loss.

It is always a challenge to reduce the oil-water ratio (OWR) during the formulation of mud system. So far the industry was not able to reduce the OWR in their formulation beyond 85/15. This is a major gap in the previous works in the subject area toward the development of sustainable oil-based mud (OBM) systems using non-toxic, edible vegetable oils [4]. Vegetable oils are highly viscous and a low oil- water ratio will mean a very high viscous mud. Brine has a high density and a mixture of salts. Hence, the more the amount of brine internal phase added to a viscous vegetable oil the more complex the entire nature of the mud system becomes. A low /water ratio (e.g. 60/40) is beneficial in producing low fluid loss although mud rheology will need to be considered [5]. Therefore, this study examined the possibility of a reduced oil-water ratio invert emulsion system with a vegetable oil continuous phase. This will reduce cost of formulation because the more water in the mud system the cheaper the cost of formulation. With a reduced OWR, the fluid loss will be low which is beneficial for wellbore stability and low oil retention on cuttings which makes for easy cuttings treatment and disposal. In a preliminary test result of vegetable oil-based mud, [1] stated that Duratone used as Fluid-loss control additive in mineral oil-based muds is not suitable for vegetable oil-based mud; hence the need for a suitable fluid loss additive for vegetable oil- based muds. While the industry works on a

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suitable fluid loss additive for vegetable oil, a low OWR such as 50/50 will give a low fluid loss. This study has formulated the mud without a fluid loss additive. While considering low OWR with a vegetable oil continuous phase [3], [4] emphasised the need for careful selection of additives for vegetable oil-based mud stating that additives that will function in base-oil from hydrocarbon or synthetic source may not be functioning well in vegetable grade oil-base medium. Therefore, this study has used egg yolk as an emulsifier additive for compatibility and environmental concern.

A low OWR is beneficial for low fluid loss. This study examined the possibility of 50/50 oil-water ratio invert emulsion drilling mud with a vegetable oil continuous phase.

II. Materials and Method

An invert emulsion mud consisting of 350ml of oil-water ratio 50/50 using Jatropha oil as the continuous phase and egg yolk as emulsifier was formulated. Hen egg yolk was carefully separated from the albumen (egg white) by rolling it on a filter paper to remove adhering fragments of the albumen and allowed to flow into a suitable plastic container. The densities of the base oil (Jatropha) and water were measured using the mud balance. Using a beaker, 175 ml of Jatropha oil and 175ml of water were measured. The weighing balance was used to measure the required quantities of calcium chloride and bentonite as shown in the mud composition in Table I. The calcium chloride was added to the beaker of water. Using the Hamilton Beach mixer, the measured materials were thoroughly mixed, adding 12ml of egg yolk dropwise while mixing for 60 minutes.

The weight of the formulated mud was measured using the mud balance. The mud balance was thoroughly cleaned and dried to avoid any irregularities in the reading. While in the upright position; the cup was filled with the mud to the brim and covered with the lid firmly seated while allowing some of the mud to expel through the vent to release any trapped air or gas. The outside of the cup was wiped and dried of any mud. The beam was placed on the base support and balanced by moving the rider along the graduated scale until balance was achieved when the bubble got under the centreline. At this point the mud weight was read in pounds per gallon (ppg). The mud weight was 8.1ppg.

The electrical stability of an oil-based drilling mud is a property related to its emulsion stability and oil-wetting capability. The electrical stability test was carried out using the Fann electrical stability tester shown in Fig. 1. The test was conducted at the recommended test temperature of 48.9ºC and later at 120ºC to check any variation at elevated temperature. The electrode probe was thoroughly cleaned, wiped and swirled in the base oil used for the mud formulation, cleaned and dried. The mud sample was placed in a glass beaker and maintained at the test temperature. The sample was hand-stirred using the electrode probe for 10 seconds to ensure uniform composition and temperature of the sample. The electrode probe was positioned not to touch the bottom or sides of the container and the electrode surfaces completely covered by the sample. The test button was pushed and released for the automatic voltage ramp. The electrode probe was never moved during the measurement. At the stop of the ramp indicating voltage breakdown, the electrical stability reading was taken in volts. The test was repeated and the average of the readings was recorded as the electrical stability of the Invert emulsion mud as shown in Table II.

The filtration property was checked using the high temperature high pressure (HTHP) filter press shown in Fig. 2 at 120ºC and 500psi. The filtrate was collected at the end of 30mins as shown in Table III.

The rheological property (Plastic viscosity, Yield point and apparent viscosities) of the formulated mud sample was also examined after aging for 16 hours. The 8-speed viscometer was used for the measurement at the following dial settings 600, 300, 200, 100, 60, 30, 6, and 3 in rotation per minute (RPM) as shown in Table IV. The mud was allowed to gel for 10 seconds and 10 minutes respectively. The plastic viscosity, apparent viscosity and yield point were evaluated using the following relationships:

$$\text{Plastic viscosity (PV)} = \text{dial reading for 600 rpm} - \text{dial reading for 300 rpm} \quad (1)$$

$$\text{Yield point (YP)} = \text{dial reading for 300rpm} - \text{PV} \quad (2)$$

$$\text{Apparent Viscosity (AV)} = \text{600rpm} / 2 \quad (3)$$

The PV and AV were measured in centipoise (cP) while the yield point was measured in (Ib/100 ft^2).

A repeat mud formulation was done with oil-water ratio of 70/30 increasing the bentonite to 10g and reducing the emulsifier to 8ml while other components remain unchanged. Similar tests were conducted to compare the rheological, emulsion stability and filtration properties of 50/50 oil-water ratio mud.

All tests were conducted according to [2].

III. Results and Discussion

The mud weight measured at 32ºC was 8.1ppg for oil-water ratio of 50/50 and 70/30. Mud weight is an important property as it helps to maintain hydrostatic pressure, suspend cuttings and better cleaning of the bore hole. The electrical stability values of the 50/50 and 70/30 OWR muds at various temperatures shown in Table II were within the range of electrical stability for a stable mud. At 48.9ºC the electrical stability values were 353v and 480v for the mud of 50/50 and 70/30 OWR muds respectively. According to [8], the estimated electrical stability for oil-based mud of mud weight of 8-10 ppg of OWR 65/35-75/25 is 200-300 volts. The electrical stability of an oil-based drilling mud is a property related to its emulsion stability and oil-wetting capability. The emulsion should be stable enough to incorporate additional water volume if down hole water flow is encountered. The 50/50 OWR mud had a lower fluid loss of 6ml compared to12ml of the 70/30 OWR mud as shown in Table III. The rheological behaviour of the 50/50 and 70/30 OWR muds at different viscometer readings are shown in Table IV. Higher water content clearly improves the fluid loss, though the viscosity of the system may be high, hence the quantity of the viscosifier used for the mud of 50/50 oil-water ratio was 3g of bentonite.

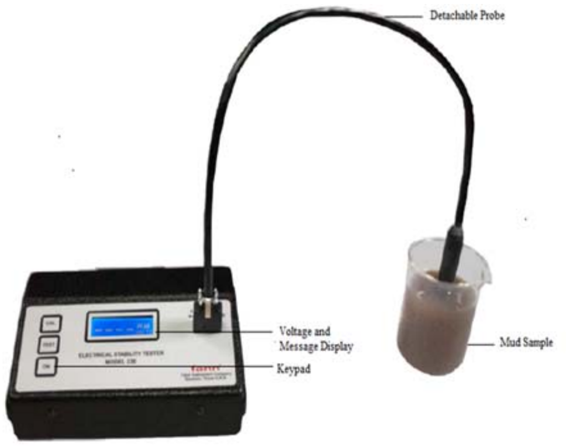

Fig. 1 Electrical Stability Tester

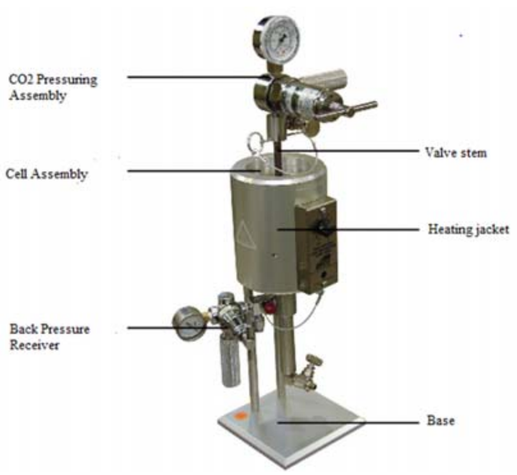

Fig. 2 High Temperature-High Pressure (HTHP) Filter Press

Fig. 3 compares the electrical stability of the 50/50 and 70/30 OWR muds. The electrical stability of the 50/50 OWR mud compared favourably with 70/30 OWR mud without much variation. At 48.9ºC the electrical stability values were 353v and 480v for the 50/50 and 70/30 oil-water ratio muds respectively. However, the electrical stability of the 50/50 OWR mud decreased to 258V at 120ºC. In the same order the electrical stability of the 70/30 OWR mud decreased to 393V. This decrease in electrical stability at increased temperature is associated with drilling fluids with oleic phase. The electrical stability of an oil-based drilling mud is a property related to its emulsion stability and oil-wetting capability. Fig. 4 compares the viscosities of the 50/50 and 70/30 OWR mud samples. There is no significant variation in the viscosities of the 50/50 and 70/30 OWR muds. From Table IV, the plastic viscosity of the 50/50 OWR mud is 36cp and a yield point of 17 Ib/100 ft^2 while the 70/30 OWR mud had plastic viscosity of 31cp and yield point of 17 Ib/100 ft^2. The 10 seconds and 10 minutes gel strength of the 50/50 OWR mud was 3 and 4 Ib/100 ft^2 while that of 70/30 OWR mud was 6 and 7 Ib/100 ft^2 respectively. The 30 minutes fluid loss for the 50/50OWR mud was 6ml and that of 70/30 was 12ml as shown in Fig. 5. There was no fluid loss additive in the mud formulation. These results have shown that with a good composition, a 50/50 OWR invert emulsion mud with vegetable oil continuous phase is feasible. Despite the higher water content, the electrical stability, rheological behaviour of the 50/50 OWR mud compared favourably with usual 70/30 OWR mud while achieving a low fluid loss which is essential for wellbore stability.

TABLE I
MUD COMPOSITION

Component	Quantity	
	50/50 OWR Mud	70/30 OWR Mud
Base oil (Jatropha oil)	175ml	245ml
Water	175ml	105ml
Bentonite	3g	10g
Egg yolk emulsifier	12ml	8ml
Calcium Chloride	4g	4g
Lime (Calcium Oxide)	3g	3g

TABLE II
ELECTRICAL STABILITY VALUES OF 50/50 AND 70/30 OWR MUDS

Temperature (ºC)	Electrical Stability(V) 50/50 OWR Mud	Electrical Stability(V) 70/30 OWR Mud
48.9	353	480
120	258	393

TABLE III
FLUID LOSS OF 50/50 AND 70/30 OWR MUDS AT 120ºC AND 500 PSI

Fluid loss (ml)	50/50 OWR Mud	70/30 OWR Mud
30mins	6	12

IV. CONCLUSION

Based on the results from this study, the following conclusions are drawn:

The variation in the electrical stability values of the 50/50 and 70/30 OWR muds was minimal. There was also no significant viscosity variation of the two samples despite the higher water content of the 50/50 OWR mud. The higher water content in the 50/50 OWR means less retention of oil on the cuttings which means less treatment of the cuttings before disposal, also reducing cost of disposal and less impact on the environment. The mud system was formulated without a wetting agent and fluid loss additive; this reduces cost of formulation. The use of egg yolk as emulsifier is for compatibility with the vegetable oil continuous phase and the call for non-toxic additives. The fluid loss of 6ml of the 50/50 OWR ratio is beneficial for well bore stability.

Generally, with a good composition using guided empiricism, 50/50 OWR invert emulsion mud is feasible with a vegetable oil continuous phase. This is technically viable in reduction of fluid loss for enhanced wellbore stability. Less oil retention on cuttings will reduce cost of disposal and environmental impact. The high water content with no fluid loss additive also means less cost of mud formulation.

TABLE IV
RHEOLOGICAL BEHAVIOUR AT DIFFERENT VISCOMETER READINGS FOR 50/50 AND 70/30 OWR MUDS

Dial Setting (RPM)	Mud Type	
	50/50 OWR Mud	70/30 OWR Mud
600	89	79
300	53	48
200	38	40
100	23	26
60	15	16
30	9	11
6	3	9
3	2	6
Gel Strength,10seconds (Ib/100 ft^2)	3	6
Gel Strength,10 minutes (Ib/100 ft^2	4	7
Apparent Viscosity (cP)	44.5	39.5
Plastic Viscosity(cP)	36	31
Yield Point (Ib/100 ft^2)	17	17

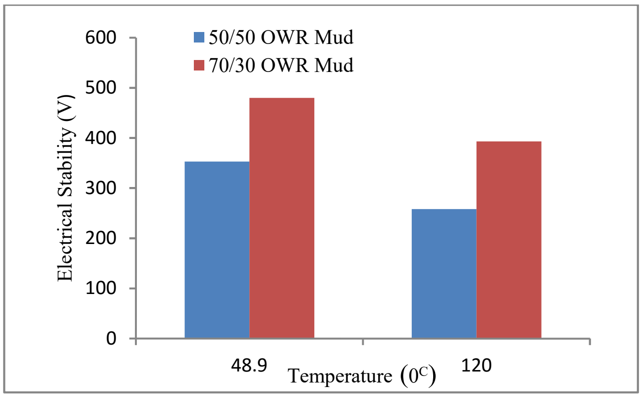

Fig. 3 Comparative Analysis of the Electrical Stability of 50/50 and 70/30 OWR Muds

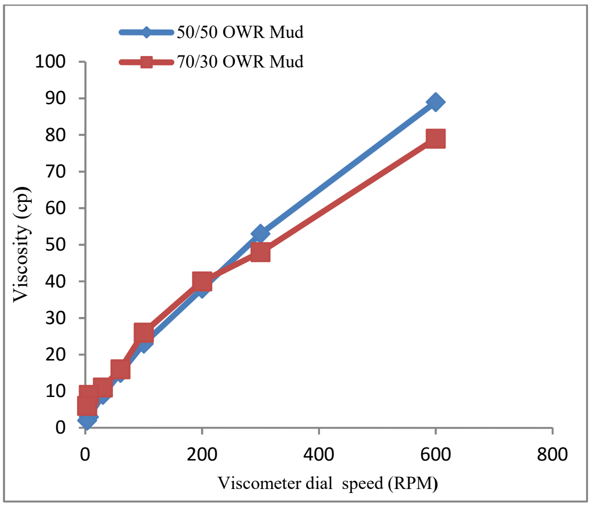

Fig. 4 Comparative Analysis of the Viscosities 50/50 and 70/30 OWR Muds

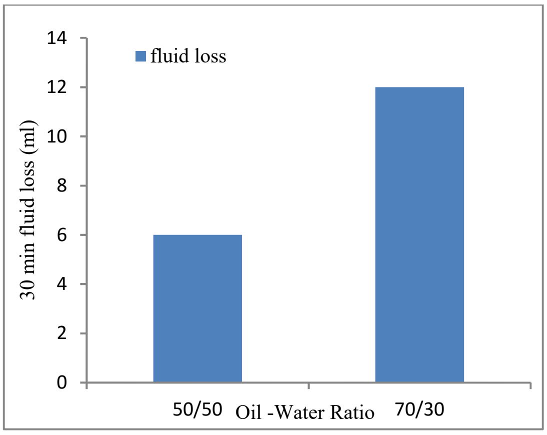

Fig. 5 Comparative Analysis of the Fluid loss of 50/50 and 70/30 OWR Muds

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