Chapter 3

Novel Formulation of Environmentally Friendly Oil Based Drilling Mud

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Additional information is available at the end of the chapter

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1. Introduction

The term drilling fluids or drilling muds generally applies to fluids used to help maintain well control and remove drill cuttings (rock fragments from underground geological formations) from holes drilled in the earth. Drilling fluids are fluids used in petroleum drilling operations. These fluids are a mixture of clays, chemicals, water, oils. These fluids are used in a borehole during drilling operations for[1]:

- Hole cleaning
- Pressure control
- Cooling and lubrication of the bit
- Corrosion control (especially for oil-based muds)
- Formation damage control
- Wellbore stability maintenance
- Transmission of hydraulic energy to BHA (Bottom Hole Assembly)
- Aid in cementing operations
- Minimize environmental impact
- Inhibit gas hydrate formation in the well.
- Avoid loss of circulation and seal permeable formations.

Considering each of the uses, the primary use of drilling fluids is to conduct rock cuttings within the well. If these cuttings are not transported up the annulus between the drillstring and wellbore efficiently, the drill string will become stuck in the wellbore. The mud must be designed such that it can, carry the cuttings to surface while circulating, suspend the cuttings while not circulating, and drop the cuttings out of suspension at surface[1-5].

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The hydrostatic pressure exerted by the mud column must be high enough to prevent an influx of formation fluids into the wellbore, but the pressure should not be too high, as it may fracture the formation. The instability caused by the pressure differential between the borehole and the pore pressure can be overcome by increasing the mud weight. The hydration of the clays can only be overcome by using non water-based muds, or partially addressed by treating the mud with chemicals which will reduce the ability of the water in the mud to hydrate the clays in the formation. These muds are known as inhibited muds. While drilling, the rock cutting procedure generates a lot of heat which can cause the bits, and the entire BHA (Bottom Hole Assembly) wear out and fail, and the drilling muds help in cooling and lubricating the BHA. These fluids also help in powering the bottom hole tools. In cementing operations, drilling fluids are used to push and pump the cement slurry down the casing and up the annular space around the casing string in the hole.

The drilling fluid must be selected and or designed so that the physical and chemical properties of the fluid allow these functions to be fulfilled. However, when selecting the fluid, consideration must also be given to[5-6]:

- The environmental impact of using the fluid
- The cost of the fluid
- The impact of the fluid on production from the reservoir

2. Classification of drilling fluids

Drilling fluids are classified according to the continuous phase[1,3]

- The WBM (Water Based Muds), with water as the continuous phase.
- The OBM (Oil Based Muds), with oil as their continuous phase.
- The Pneumatic fluids (with gases or gas-liquid mixtures as their continuous phase)

This chapter narrows our focus to oil based drilling fluids (OBM).

In general, OBM are drilling fluids which have oil as their dominant or continuous phase. A typical OBM has the following composition:

Clays and sand about 3%, Salt about 4%, Barite 9%, Water 30%, Oil 50-80%.

OBM have a whole lot of advantages over the conventional WBM. This is due to the various desirable rheological properties that oils exhibit. Since the 1930s, it has been recognized that better productivity is achieved by using oil rather than water as the drilling fluid. Since the oil is native to the formation it will not damage the pay zone by filtration to the same extent as would a foreign fluid such as water. We shall outline some of the desirable properties of oil based muds, which include[4]:

1. **Shale Stability: OBM** are most suited for drilling shaly formations. Since oil is the continuous phase & water is dispersed in it, this case results in non-reactive interactions with shale beds.
2. **Penetration Rates: OBM** usually allow for increased penetration rates.

3. **Temperature:** OBM can be used to drill formations where BHT (Bottom Hole Temperatures) exceed water based mud tolerances. Sometimes up to over 1000 degrees rankine.
4. **Lubricity:** OBM produce thin mud cakes, and the friction between the pipe and the well bore is minimized, thus reducing the pipe differential sticking. Especially suitable for highly deviated and horizontal wells.
5. Ability to drill low pore pressured formations is accomplished, since the mud weight can be maintained at a weight less than that of water (as low as 7.5 ppg).
6. **Corrosion control:** Corrosion of pipes is reduced since oil, being the external phase coats the pipe. This is due to the fact that oils are non conductive, thermally stable, and more often, do not permit microbial growth.
7. OBM can be re used, and can also be stored for a long period of time since microbial activity is suppressed.

The basic kind of oil used in formulating OBM is the diesel oil, which has been in existence for a long time, but over the years, diesel oil based muds have posed various environmental problems.

Water-based muds (WBMs) are usually the mud of choice in most drilling operation carried out in sandstone reservoir, however some unconventional drilling situations such as deeper wells, high temperature/pressure formation, deepwater reservoir, alternative shale-sand reservoir and shale resource reservoir require use of other mud systems such as oil based mud to provide acceptable drilling performance[5-8].

OBM is needed where WBM cannot be used especially in hot environment and salt beds where formation compositions can be dissolved in WBM. OBM have oil as their base and therefore more expensive and require more stringent pollution control measures than WBM.

It is imperative to propagate the use of environmentally friendly and biodegradable sources of oil to formulate our OBM, thereby making it less expensive and environmentally safe and equally carry out the basic functions of the drilling mud such as maintenance of hydrostatic pressure, removal of cuttings, cooling and lubricating the drill string and also to keep newly drilled borehole open until cementing is carried out.

2.1. Background

Environmental problems associated with complex drilling fluids in general, and oil-based mud (OBM) in particular, are among the major concerns of world communities. Among others are the problems faced by some host communities in the Niger Delta region of Nigeria. For this reason, the Environmental Protection Agency (EPA) and other regulatory bodies are imposing increasingly stringent regulations to ensure the use of environmentally friendly muds[7-8].

Throughout the 1970s and 1980s, the EPA and other regulatory bodies imposed environmental laws and regulations affecting all aspects of petroleum-related operations from exploration, production and refining to distribution. In particular, there has been increasing pressure on oil and gas industry stakeholders to find environmentally acceptable alternatives to OBMs. This has been reflected in the introduction of new legislation by government agencies in almost every part of the world.

The researches and surveys conducted came up with possibilities of having environmentally friendly oil based mud. Stakeholders in the oil and gas industry have been tasked with the challenge of finding a solution to this problem by formulating optimum drilling fluids and also reduce the handling costs and negative environmental effects of the conventional diesel oil based drilling fluid. An optimum drilling fluid is one which removes the rock cuttings from the bottom of the borehole and carries them to the surface, hold cuttings and weight materials in suspension when circulation is stopped (e.g during shut in), and also maintain pressure. An optimum drilling fluid also does this at minimum handling costs, bearing in mind the HSE (Health, Safety, Environment) policy in mind[6].

In response to the harmful effects of diesel oil on the environment and on the ozone layer (as a result of the emission of greenhouse gases), researches and surveys have gone on in the past two to three decades, and have come up with mud formulations based on the use of plant oils as diesel substitutes. Over the years, plant oils have become increasingly popular in the raw materials market for diesel substitutes. The most popular being: Rapeseed oil, Jatropha oil, Mahua oil, Cottonseed oil, Sesame oil, Soya bean oil, palm oil etc. This brings about the importance of agro allied intervention in the energy industry. Hence, the contribution of non-edible oils such as jatropha oil, canola oil, algae oil, moringa seed oil and Soapnut will be significant as a plant oil source for diesel substitute production.

This chapter describes the formulation of environmental friendly oil based mud (using plant oil such as jatropha oil, algae oil and moringa seed oil) that can carry out the same functions as diesel oil based drilling fluid and equally meet up with the HSE (Health, Safety and Environment) standards. Mud tests have been carried out at standard conditions on each plant oil sample so as to ascertain the rheological properties of the drilling fluid formulations. The conventional diesel oil based mud would serve as control.

2.2. Motivation

Drilling mud is in varying degrees of toxicity. It is difficult and expensive to dispose it in an environmentally friendly manner. Protection of the environment from pollutants has become a serious task. In most countries like Nigeria, the drilling fluids industries have had numerous restrictions placed on some materials they use and the methods of their disposal. Now, at the beginning of the 1990's, the restrictions are becoming more stringent and restraints are becoming worldwide issues. Products that have been particularly affected by restrictions are oil and oil-based mud. These fluids have been the mud of choice for many environments because of their better qualities. Initially, the toxicity of oil-based fluids was reduced by the replacement of diesel oil with low-aromatic mineral oils. In most countries today, oil-based mud may be used but not discharged in offshore or inland waters. Potential liability, latent cost, and negative publicity associated with an oil-mud spill are economic concerns. Consequently, there is an urgent need for the drilling fluids industry to provide alternatives to oil-based mud.

2.3. Methodology of the study

Four different mud samples were mixed, and the base fluid was varied. The base fluids were algae, moringa, diesel and jathropha oils used in formulating the muds in an oil water ratio of 70:30, where diesel based mud served as the control.

The following equipment and materials were used to carry out the experiment:

Materials	Equipment
1. Pulverized bentonite	1. Weighing balance
2. Barite	2. Retort
3. Diesel oil	3. Halminton Beach Mixer
4. Canola oil	4. Condenser
5. Castor oil	5. Mud balance
6. Jatropha seeds	6. Round bottom flask
7. Water	7. Rotary viscometer
8. n-hexane	8. Resistivity meter
9. Filter paper	9. API filter press
10. Threads	10. pH meter
11. Universal pH paper strips	11. Soxhlet extractor
12. Algae	12. Heating mantle
	13. Vernier Caliper
	14. Reagent bottles

Table 1. Materials and Apparatus required

2.4. Experimental procedure

The plant seeds (jatropha, moringa and algae) were collected from the western part of Nigeria, peeled and dried in an oven at about 55^{O}C for seventy minutes. The dried seeds were then de-hulled, to remove the kernels. The brownish inner parts of the kernels were ground in a blender (to increase the surface area for the reaction).

2.5. Extraction

The method employed in this study is solvent extraction. Solvent extraction is a process which involves extracting oil from oil-bearing materials by treating it with a low boiling point solvent as opposed to extracting the oils by mechanical pressing methods (such as expellers, hydraulic presses, etc.). The solvent extraction method recovers almost all the oils and leaves behind only 0.5% to 0.7% residual oil in the raw material. Here the equipment used was the Soxhlet extractor. A Soxhlet extractor is a piece of laboratory apparatus invented in 1879 by Franz von Soxhlet. It was originally designed for the extraction of a lipid from a solid material.

Figure 1. Soxhlet extractor assembly.

The extraction procedure is given below:

1. 50g of crushed plant seeds were measured out, and tied in filter papers.
2. The sample was loaded into the main chamber of the Soxhlet extractor and poured in about 300ml of n-Hexane through the main chamber.
3. The chamber is fitted into a flask containing 300ml of n-Hexane.
4. The heating mantle was turned on and the system was left to heat at 70° C. The solvent was heated to reflux. The solvent vapour travelled up a distillation arm, and flooded into the chamber housing the solid wrapped in filter papers. The condenser condensed the solvent vapour, and the vapour dripped back down into the chamber housing the solid material.
5. Then at a certain level, the siphon emptied the liquid into the flask.
6. This cycle was repeated until the sample in the chamber changed colour to a considerable extent, and collected the fluid mixture in glass reagent bottles.
7. The mixture was separated via the use of simple distillation, as shown in the set up in Fig. 2.
8. The distillation took place at 70°C; the hexane was recovered and re-used while the oil was stored.

Figure 2. Set-up for distillation.

3. Mud preparation

The densities of the various base fluids (water, algae oil, moringa oil, jatropha oil and diesel) were measured using the mud balance shown in diagram 3

1. Using the weighing balance, the various quantities of materials as shown in Table 2 below were measured.
2. The quantities of water and oil were measured using measuring beakers.
3. Using the Hamilton Beach Mixer, the measured materials were thoroughly mixed until a homogenous mixture was obtained.
4. The mud samples were aged for 24 hours.

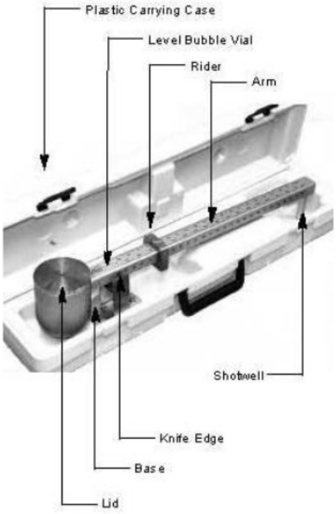

Figure 3. Mud Balance

3.1. Density

1. The aged mud samples were agitated for 2 minutes using the Hamilton Beach Mixer.
2. The clean, dry mud balance cup was filled to the top with the newly agitated mud.
3. The lid was placed on the cup and the balance was washed and wiped clean of overflowing mud while covering the hole in the lid.
4. The balance was placed on a knife edge and the rider moved along the arm until the cup and arm were balanced as indicated by the bubble.
5. The mud weight was read at the edge of the rider towards the mud cup as indicated by the arrow on the rider and was recorded.
6. Steps 2 to 5 were repeated for the other samples.

3.2. Viscosity

7. The mud was poured into the mud cup of the rotary viscometer shown in Diagram 4, and the rotor sleeve was immersed exactly to the fill line on the sleeve by raising the platform. The lock knot on the platform was tightened.
8. The power switch located on the back panel of the viscometer was turned on.
9. The speed selector knob was first rotated to the stir setting, to stir the mud for a few seconds, and it was rotated at 600RPM, waiting for the dial to reach a steady reading, the 600 RPM reading was recorded.
10. The above process was repeated for 300 RPM, 200 RPM, 100 RPM, 60 RPM, 30 RPM and 6 RPM.
11. Steps 7 to 10 were repeated for other samples.

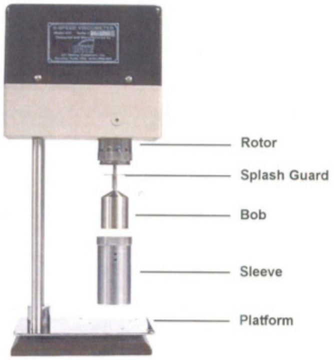

Figure 4. Rotational Viscometer

3.3. Gel strength

12. The speed selector knob was then rotated to to stir the mud sample for a few seconds, then it was rotated to gel setting and the power was immediately shut off.

13. As soon as the sleeve stopped rotating, the power was turned on after 10 seconds and 10 minutes respectively. The maximum dial was recorded for each case.
14. Steps 12 and 13 were repeated for other samples.

3.4. Mud filtration properties

15. The assembly is as shown in fig 5
16. Each part of the cell was cleaned, dried and the rubber gaskets were checked.
17. The cell was assembled as follows: base cap, rubber gasket, screen, filter paper, rubber gasket, and cell body.

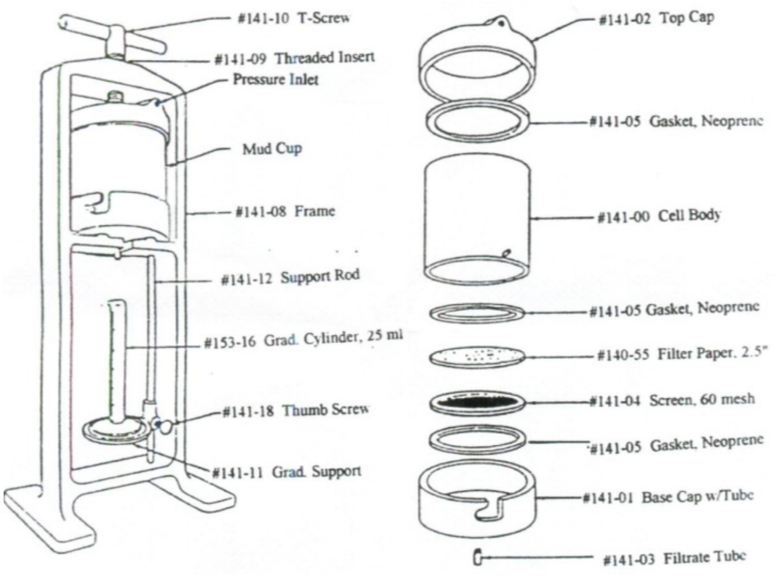

Figure 5. API Filter Press

18. A freshly stirred sample of mud was poured into the cell to within 0.5 inch (13 millimeters) to the top in order to minimize contamination of the filtrate. The top cap was checked to ensure that the rubber gasket was in place and seated all the way around and complete the assembly. The cell assembly was placed into the frame and secured with the T-screw.
19. A clean dry graduated glass cylinder was placed under the filtrate exit tube.
20. The regulator T-screw was turned counter-clockwise until the screw was in the right position and the diaphragm pressure was relieved. The safety bleeder valve on the regulator was put in the closed position.
21. The air hose was connected to the designated pressure source. The valve on the pressure source was opened to initiate pressurization into the air hose. The regulator was adjusted by turning the T-screw clockwise so that a pressure was applied to the cell in 30 seconds or less. The test period begins at the time of initial pressurization.

22. At the end of 30 minutes the volume of filtrate collected was measured. The air flow through the pressure regulator was shut off by turning the T-screw in a counter-clockwise direction. The valve on the pressure source was then closed and the relief valve was carefully opened.
23. The assembly was then dismantled, and the mud was removed from the cup.
24. The filter cake was measured using a vernier caliper, and the measurements were recorded.
25. The above procedures were carried out for the other mud samples.

3.5. Hydrogen ion concentration (pH)- Colorimetric paper method

26. A short strip of pH paper was placed on the surface of the sample.
27. After the color of the test paper stabilized, the color of the upper side of the paper, which had not contacted the mud, was matched against the standard color chart on the side of the dispenser.
28. Steps 26 and 27 were carried out on other samples.

4. Toxicity test

29. After the oil based mud samples have been formulated, each is then tested on a growing plant (that is on beans seedling), to see the effects on the plant growth and the living organisms in the soil. Bean seed was planted and exposed to 100ml of three different mud samples, with the following base fluids; diesel, canola and jatropha, the growth rate was measured, and the number of days of survival.

4.1. Results of density measurements

The results as obtained from measurements of density using the mud balance are contained in Table 2 below.

SAMPLE	MEASURED DENSITY (ppg)	CALCULATED DENSITY (ppg)	ERROR	Barite (g)
Diesel	8.26	8.261	0.01	119.1
Algae	7.81	7.815	0.005	126.5
Jatropha	8.32	8.326	0.06	154.5
Moringa	8.30	8.307	0.007	149.3
Canola	8.47	8.470	0	150.6

Table 2. Mud density values

Mud density ϱ is calculated using eqn $\rho_m = \frac{M_{Ben} + M_{Oil} + M_{Water}}{V_{Ben} + V_{Oil} + V_{Water}}$

e.g for Jatropha

$$\rho_{m,J} = \frac{0.110231 + 0.38040768 + 0.76742464}{0.0924608 + 0.0528344 + 0.005079769585} = 8.326 \text{ ppg}$$

From the above table, the error differences between the calculated and measured densities all lie below 0.1, thus the readings obtained using the mud balance have a high accuracy. It also showed that the denser the base oil, the higher the amount of barite needed to build.

4.2. Viscosity and gel strength results

Viscosity readings obtained from the experiment carried out on the rotary viscometer are contained in Table 3.

The dial reading values (in lb/100ft^2) are tabulated against the viscometer speeds in RPM.

Viscosity values are calculated with equations

Apparent viscosity= Dial Reading at 600RPM (θ_{600})/2

Dial speed (RPM)	Diesel	Algae	Jatropha	Moringa	Canola
600	185	122	154	169	128
300	170	114	133	158	120
200	169	96	124	149	115
100	163	88	114	143	114
60	152	82	107	140	113
30	143	74	98	136	111
6	122	62	92	120	110
3	81	55	76	79	60

Table 3. Viscometer Readings for Diesel, Jatropha and Canola OBM's

Rheological Properties	Diesel	Algae	Jatropha	Moringa	Canola
Plastic Viscosity	15	8	21	11	8
Apparent Viscosity	92.5	61	77	84.5	64
Gel Strength	50/51	52/43	54/55	52/53	60/72

Table 4. Plastic Viscosities, Apparent Viscosities, Gel Strength,

Diesel OBM had the highest apparent viscosity, followed by Moringa, then Jatropha, Canola and algae OBM's

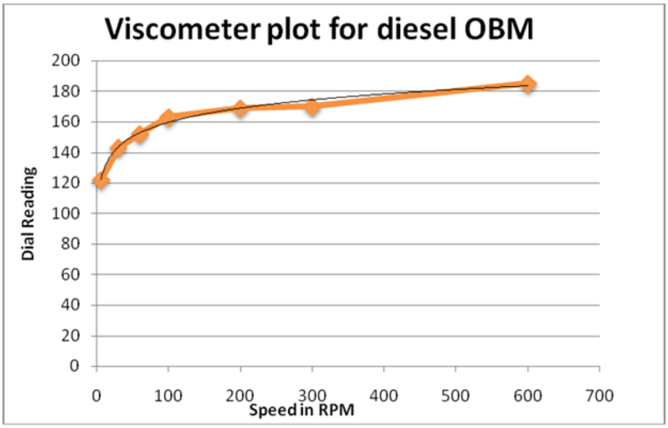

Figure 6. Viscometer Plot for Diesel OBM

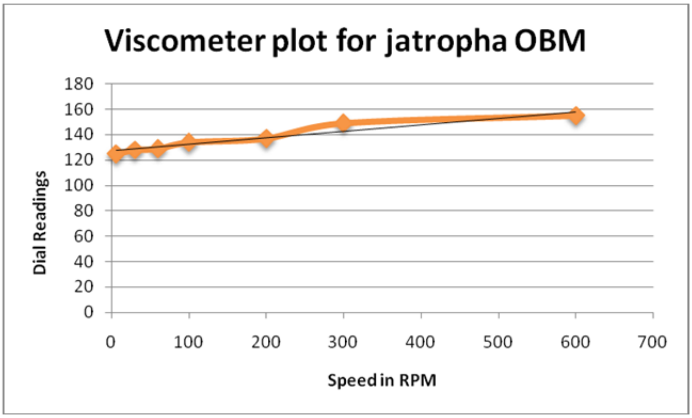

Figure 7. Viscometer Plot for Jatropha OBM

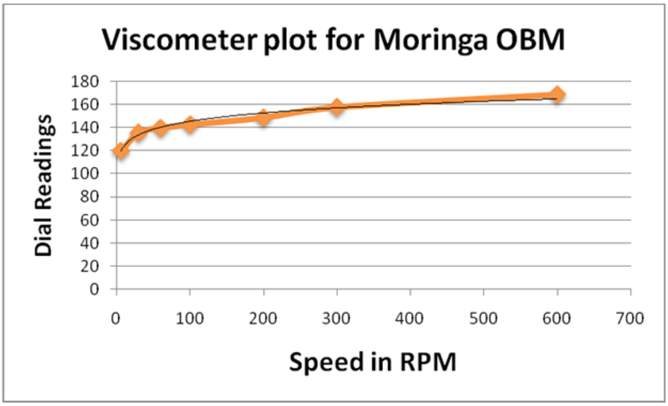

Figure 8. Viscometer Plot for Moringa OBM

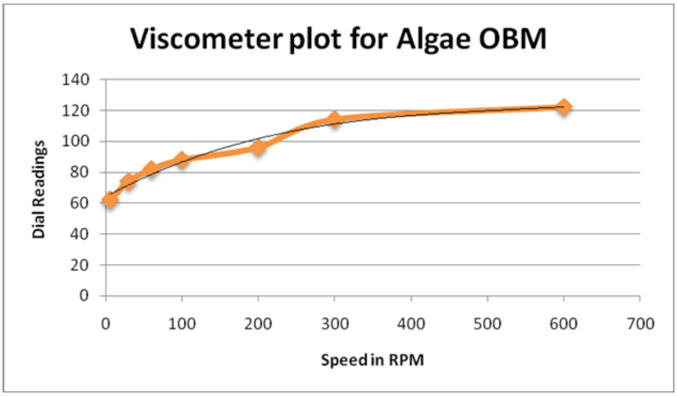

Figure 9. Viscometer Plot for algae OBM

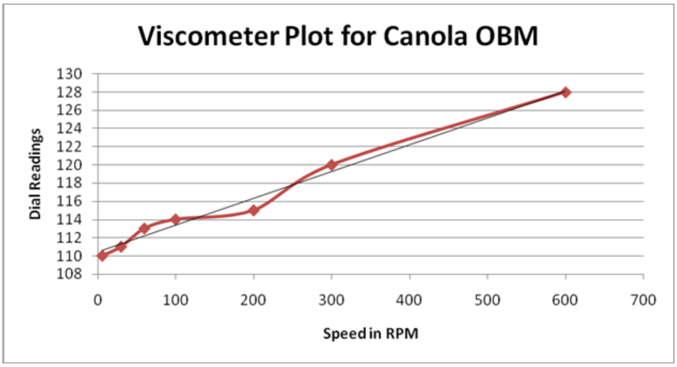

Figure 10. Viscometer Plot for Canola OBM

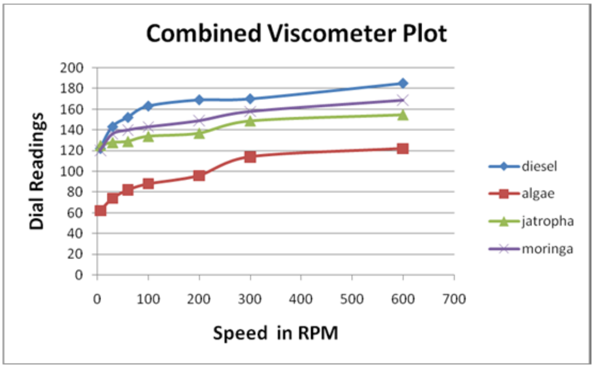

Figure 11. Combined viscometer plot for Diesel, Algae, and jatropha OBM's

It can be seen that the plots on Figures 6 to 11, generated from the dial readings of all the mud samples are similar to the Bingham plastic model. This goes to prove that the muds have similar rheological behaviour.

However, not all the lines of the plot are as straight as the Bingham plastic model. This can be explained by a number of factors such as: possible presence of contaminants, and the possibility of behaving like a different model such as Herschel Bulkley.

A Bingham plastic fluid will not flow until the shear stress τ exceeds a certain minimum value τ_y known as the yield point[9] (Bourgoyne et al 1991). After the yield has been exceeded, the changes in shear stress are proportional to changes in shear rate and the constant of proportionality is known as the plastic viscosity μ_p.

From Figures, the yield points of the different muds can be read off. The respective yield points are the intercepts on the vertical (shear stress) axes.

For reduced friction during drilling, algae OBM gives the best results, followed by Jatropha OBM then moringa OBM.

This means Diesel OBM offers the greatest resistance to fluid flow. Algae, Jatropha, Moringa and Canola OBM's pose better prospects in the sense that their lower viscosities will mean less resistance to fluid flow. This will in turn lead to reduced wear in the drill string[10].

4.3. Mud filtration results

The filtration tests were carried out at 350 kPa due to the low level of the gas in the cylinder.

The mud cakes obtained from the API filter press exhibited a slick, soft texture.

From Table 5 and Figures 12 to 15, we can infer that Diesel OBM had the highest rate of filtration and spurt loss. Comparing this to a drilling scenario, this means that the mud cake from Diesel OBM is the most porous, and the thickest.

From these inferences, we can see that Algae, Jatropha, Moringa and Canola OBM's are better in filtration properties than Diesel OBM as inferred from thickness and filtration volumes.

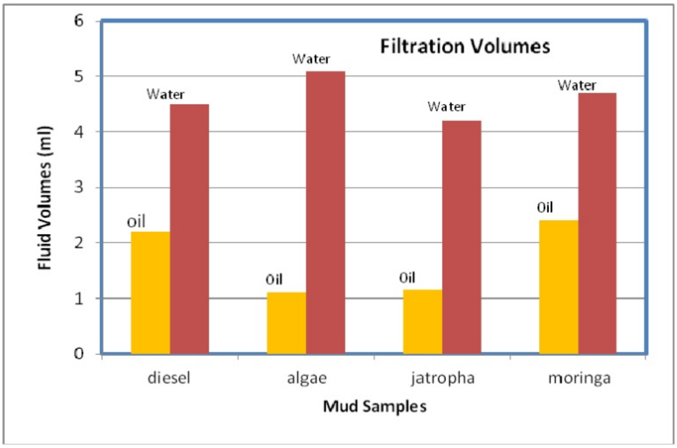

Figure 12. Filtration Volumes for Diesel, Algae, Jatropha and Moringa OBM's

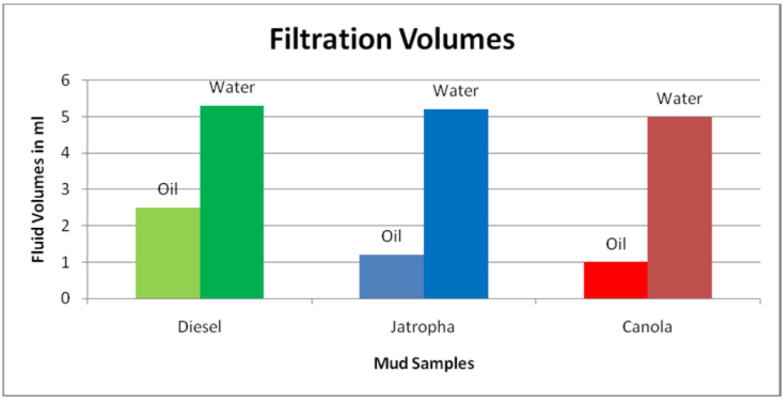

Figure 13. Filtration Volumes for Diesel, Jatropha and Canola OBM's

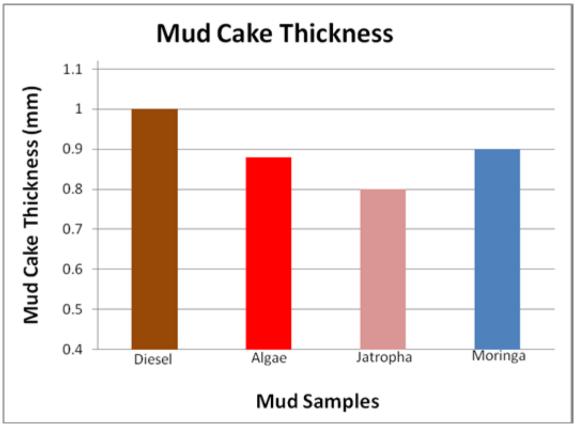

Figure 14. Mud Cake Thicknesses for Diesel, Algae, Canola OBM's

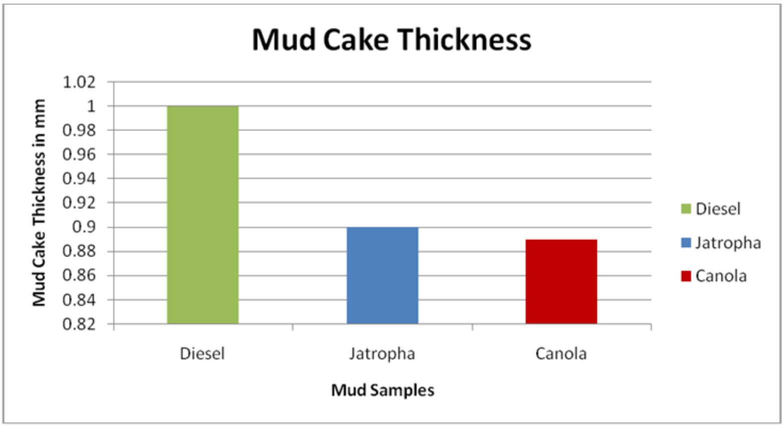

Figure 15. Mud Cake Thicknesses for Diesel, Jatropha and Canola OBM's

Filtration Properties	DIESEL	ALGAE	JATROPHA	MORINGA	Canola
Total Fluid Volume	6.9ml	6.2ml	6.3ml	7.2ml	6.0 ml
Oil volume	2.3ml	1.1ml	1.1ml	2.5ml	1.0 ml
Water Volume	4.6ml	5.1ml	4.2ml	4.7ml	4.3 ml
Cake Thickness	1.0mm	0.9mm	0.8mm	0.9mm	0.78mm

Table 5. Mud Filtration Results

Problems caused as a result of excessive thickness include[4]:

i. Tight spots in the hole that cause excessive drag.
ii. Increased surges and swabbing due to reduced annular clearance.
iii. Differential sticking of the drillstring due to increased contact area and rapid development of sticking forces caused by higher filtration rate.
iv. Primary cementing difficulties due to inadequate displacement of filter cake.
v. Increased difficulty in running casing.

The problems as a result of excessive filtration volumes include[4]:

i. Formation damage due to filtrate and solids invasion. Damaged zone too deep to be remedied by perforation or acidization. Damage may be precipitation of insoluble compounds, changes in wettability, and changes in relative permeability to oil or gas, formation plugging with fines or solids, and swelling of in-situ clays.
ii. Invalid formation-fluid sampling test. Formation-fluid flow tests may give results for the filtrate rather than for the reservoir fluids.
iii. Formation-evaluation difficulties caused by excessive filtrate invasion, poor transmission of electrical properties through thick cakes, and potential mechanical problems running and retrieving logging tools.
iv. Erroneous properties measured by logging tools (measuring filtrate altered properties rather than reservoir fluid properties).
v. Oil and gas zones may be overlooked because the filtrate is flushing hydrocarbons away from the wellbore, making detection more difficult.

4.4. Hydrogen ion potential results

Drilling muds are always treated to be alkaline (i.e., a $pH > 7$). The pH will affect viscosity, bentonite is least affected if the pH is in the range of 7 to 9.5. Above this, the viscosity will increase and may give viscosities that are out of proportion for good drilling properties. For minimizing shale problems, a pH of 8.5 to 9.5 appears to give the best hole stability and control over mud properties. A high pH (10+) appears to cause shale problems.

The corrosion of metal is increased if it comes into contact with an acidic fluid. From this point of view, the higher pH would be desirable to protect pipe and casing (Baker Hughes, 1995).

The pH values of all the samples meet a few of the requirements stated but Diesel OBM with a pH of less than 8.5 does not meet with specification. Algae, Jatropha, Moringa and Canola OBM's show better results since their pH values fall within this range.

Type of Oil	DIESEL	ALGAE	JATROPHA	MORINGA
pH Value	8	9	8.5	9

Table 6. pH Values

4.5. Results of cuttings carrying index

Only three drilling-fluid parameters are controllable to enhance moving drilled solids from the wellbore:Apparent Viscosity (AV) density (mud weight [MW]), and viscosity. Cuttings Carrying Index (CCI) is a measure of a drilling fluid's ability to conduct drilled cuttings in the hole. Higher CCI's, mean better hole cleaning capacities.

From the Table, we can see that Jatropha OBM showed best results for CCI iterations.

	Diesel	Jatropha	Canola
CCI	15.901	19.067	17.846

Table 7. Cuttings Carrying Indices (CCI's)

4.6. Pressure loss modeling results

The Bingham plastic model is the standard viscosity model used throughout the industry, and it can be made to fit high shear- rate viscosity data reasonably well, and is generally associated with the viscosity of the base fluid and the number, size, and shape of solids in the slurry, while yield stress is associated with the tendency of components to build a shear-resistant.

	Diesel	Jatropha	Canola
Drill Pipe	829	277.39	250.65
Drill Collar	177.35	173.75	157.0
Drill Collar (Open)	161.35	158.15	142.9
Drill Pipe (Open)	14.1	13.81	12.48
Drill Pipe (Cased)	9.28	9.10	8.22
Total	1191.98	706.45	571.25

Table 8. Bingham Plastic Pressure Losses in Psi

It can be seen from the table that Jatropha and Canola OBM's gave better pressure loss results than Diesel OBM as a result of lower plastic viscosities, and hence should be encouraged for use during drilling activities.

4.7. Result of the toxicity measurements

Samples of 100ml of each of the selected oils were exposed to both corn seeds and bean seed and the no of days which the crop survived are as indicated in Figure 16. The growth rate was also measured i.e the new length of the plant was measured at regular time intervals. For the graph of toxicity of diesel based mud the reduced growth rate indicates when the leaves began to yellow, and the zero static values indicate when the plant died.

From the results indicated by the figure 16, it can be concluded that jatropha oil has less harmful effect on plant growth compared to canola and diesel. Bean seeds were planted and after one week, they were both exposed to 100ml of both jathropha formulated mud and diesel formulated mud. The seeds exposed to jatropha survived for 18 days, while that exposed to diesel mud survived for 6 days and then withered. When the soil was checked, there was no sign of any living organisms in diesel mud sample while that of the jatropha mud, there were signs of some living organisms such as earth worms, and other little insects. This shows that jatropha mud sample is environmentally safer for both plants and micro animals than diesel mud sample.

From the figure 17, it can be seen that the seeds exposed to jatropha had the highest number of days of survival which indicates its lower toxicity while that of diesel had the lowest days of survival which indicates its high toxicity. The toxicity of diesel can be traced to high aromatic hydrocarbon content. Therefore, replacements for diesel should either eliminate or minimize the aromatic contents thereby making the material non toxic or less toxic. Biodegradation and bioaccumulation however depend on the chemistry of the molecular character of the base fluids used. In general, green material i.e plant materials containing oxygen within their structure degrade easier.

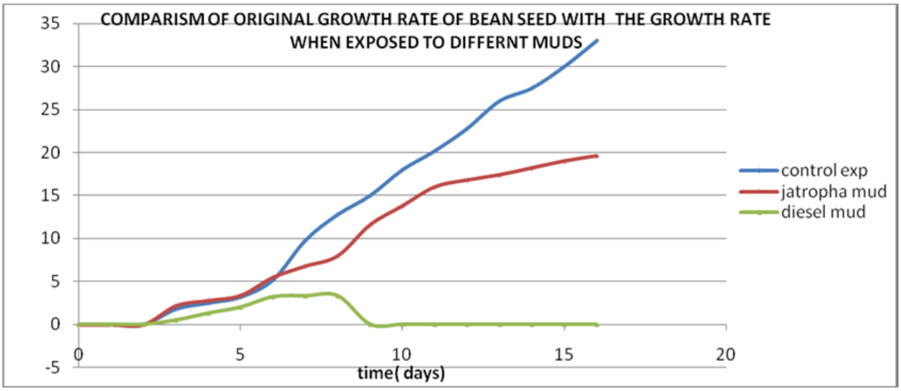

Figure 16. Comparison of Growth Rate Curve of Different Mud Types

4.8. Results of density variation with temperature

Densities were measured for the various samples at temperatures ranging from 30^{O}C to 80^{O}C and are summarized in Table 9.

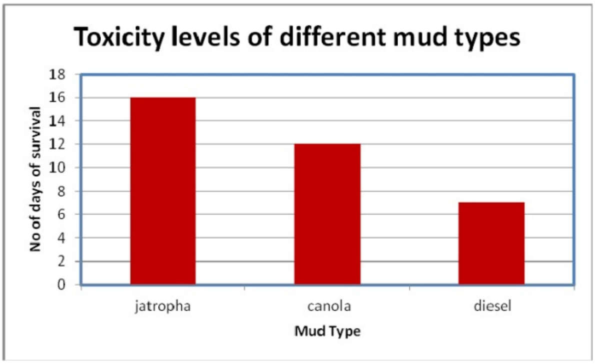

Figure 17. Toxicity of different mud types

Temperature	Diesel	Jatropha	Canola
30ºC	10	10	10
40ºC	10.1	10.05	10.05
50ºC	10.17	10.1	10.05
60ºC	10.2	10.15	10.1
70ºC	10.2	10.15	10.15
80ºC	10.25	10.2	10.17

Table 9. Density Changes in ppg at Varying Temperatures.

The mud samples were heated at constant pressure, and in an open system, hence the density increment.

At temperatures of 60ºC and 70ºC, the densities of Diesel and Jatropha OBM's were constant, while that happened with Canola OBM at a lower range of 40ºC and 50ºC. This is shown in Figure 18. This could be due to the differences in temperature and heat energy required to dissipate bonds, which vary with fluid properties (i.e the continuous phases).

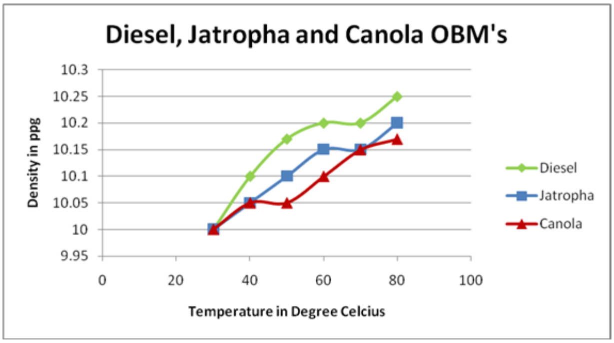

Figure 18. Density against Temperature (Diesel, Jatropha and Canola OBM's)

After the results were recorded, extrapolations were made and hypothetical values were derived for temperatures as high as 320^{O}C, to enhance the prediction using Artificial Neural Network (ANN).

These values are summarized Tables 10 to 12

	Diesel	**Jatropha**	**Canola**
30^{O}C	10	10	10
40^{O}C	10.1	10.05	10.05
50^{O}C	10.17	10.1	10.05
60^{O}C	10.2	10.15	10.1
70^{O}C	10.2	10.15	10.15
80^{O}C	10.25	10.2	10.17
90^{O}C	10.31133	10.24333	10.20667
100^{O}C	10.35648	10.2819	10.24095
110^{O}C	10.40162	10.32048	10.27524
120^{O}C	10.44676	10.35905	10.30952
130^{O}C	10.4919	10.39762	10.34381
140^{O}C	10.53705	10.43619	10.3781
150^{O}C	10.58219	10.47476	10.41238
160^{O}C	10.62733	10.51333	10.44667
170^{O}C	10.67248	10.5519	10.48095
180^{O}C	10.71762	10.59048	10.51524
190^{O}C	10.76276	10.62905	10.54952
200^{O}C	10.8079	10.66762	10.58381
210^{O}C	10.85305	10.70619	10.6181
220^{O}C	10.89819	10.74476	10.65238
230^{O}C	10.94333	10.78333	10.68667
240^{O}C	10.98848	10.8219	10.72095
250^{O}C	11.03362	10.86048	10.75524
260^{O}C	11.07876	10.89905	10.78952
270^{O}C	11.1239	10.93762	10.82381
280^{O}C	11.16905	10.97619	10.8581
290^{O}C	11.21419	11.01476	10.89238
300^{O}C	11.25933	11.05333	10.92667
310^{O}C	11.30448	11.0919	10.96095
320^{O}C	11.34962	11.13048	10.99524

Table 10. Hypothetical Temperature-Density Values (extrapolated from regression analysis).

4.9. Results of neural networking

From the Artificial Neural Network Toolbox in the MATLAB 2008a, the following results were obtained:

60% of the data were used for training the network, 20% for testing, and another 20% for validation.

On training the regression values, returned values are summarized in Table 11

	Diesel	Jatropha	Canola
Training	0.99999	0.99999	0.99995
Testing	0.99725	0.99056	0.99898
Validation	0.99706	0.98201	0.99328
All	0.99852	0.99414	0.99675

Table 11. Regression Values.

Since all regression values are close to unity, this means that the network prediction is a successful one.

The graphs of training, testing and validation are presented below:

The values were returned after performing five iterations for each network. This also goes to say that the Artificial Neural Network, after being trained and simulated, is a viable and feasible instrument for prediction.

Figures 19 to 31 present the plots of Experimental data against Estimated (predicted) data for training, testing and validation processes from MATLAB 2008.

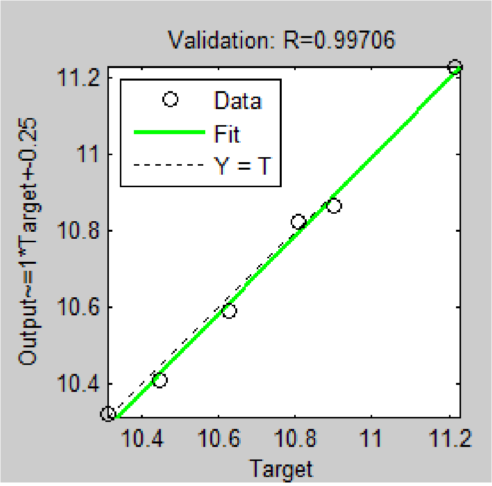

Figure 19. Diesel OBM Validation values

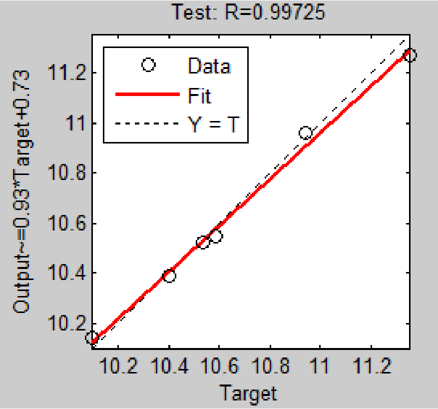

Figure 20. Diesel OBM Test values

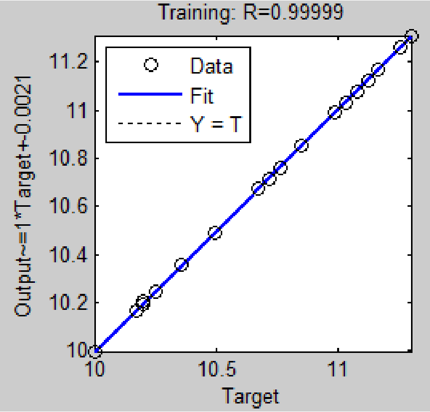

Figure 21. Diesel OBM Training values

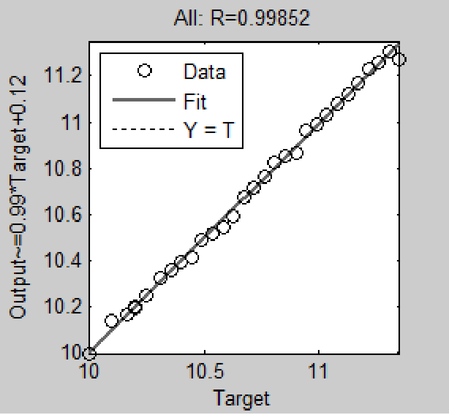

Figure 22. Diesel OBM Overall values

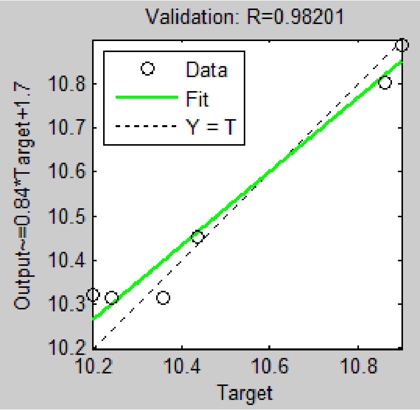

Figure 23. Diesel OBM Overall values

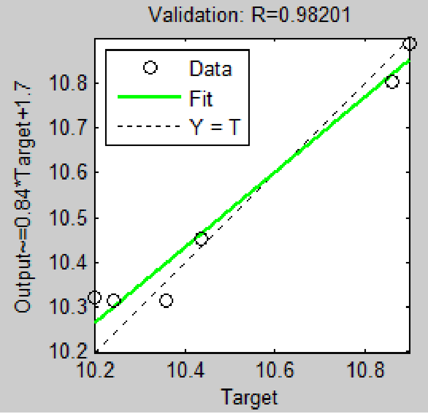

Figure 24. Jatropha OBM Validation values

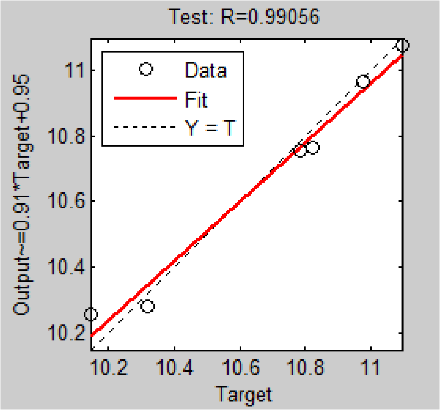

Figure 25. Jatropha OBM Test values

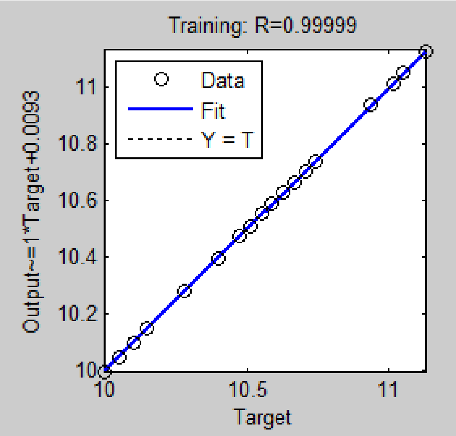

Figure 26. Jatropha OBM Training values

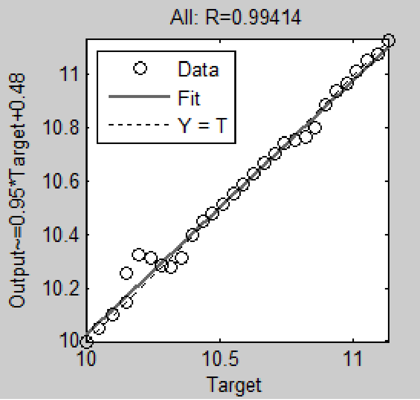

Figure 27. Jatropha OBM Overall values

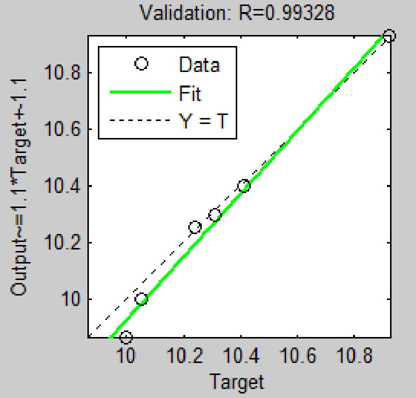

Figure 28. Canola OBM Validation values

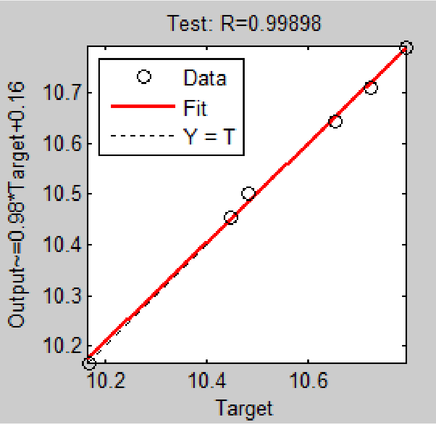

Figure 29. Canola OBM Test values

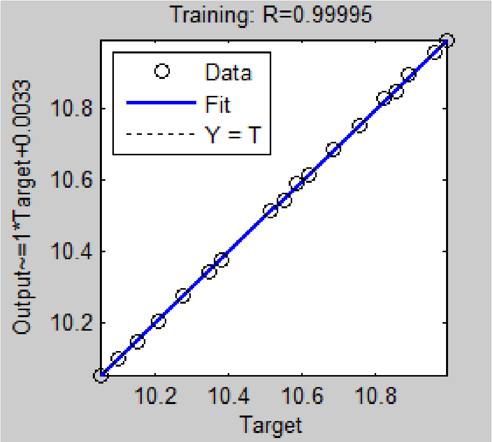

Figure 30. Canola OBM Training values

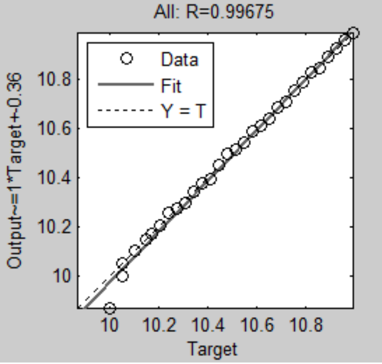

Figure 31. Canola OBM Overall values

We can see from the Figures 19 to 31 that the data points all align closely with the imaginary/arbitrary straight line drawn across. This validates the accuracy of the network predictions and this also gives rise to the high regression values (tending towards unity) presented in Table 11

Errors, estimated values and experimental values are summarized in Tables 12 to 14

Temperature °C	Exp Values	Est Values	Errors
30	10	10.049	0.049
40	10.1	10.1407	0.0407
50	10.17	10.1794	0.0094
60	10.2	10.2022	0.0022
70	10.2	10.2236	0.0236
80	10.25	10.24	-0.01
90	10.31133	10.287	-0.02433
100	10.35648	10.3579	0.001424
110	10.40162	10.3904	-0.01122
120	10.44676	10.4222	-0.02456
130	10.4919	10.4835	-0.0084
140	10.53705	10.5204	-0.01665
150	10.58219	10.5455	-0.03669
160	10.62733	10.6133	-0.01403
170	10.67248	10.687	0.014524
180	10.71762	10.7202	0.002581
190	10.76276	10.7714	0.008638
200	10.8079	10.8335	0.025595
210	10.85305	10.8611	0.008052
220	10.89819	10.8991	0.00091
230	10.94333	10.9623	0.018967
240	10.98848	10.9955	0.007024
250	11.03362	11.0273	-0.00632
260	11.07876	11.085	0.006238
270	11.1239	11.1195	-0.0044
280	11.16905	11.1474	-0.02165
290	11.21419	11.2049	-0.00929
300	11.25933	11.2432	-0.01613
310	11.30448	11.2545	-0.04998
320	11.34962	11.2674	-0.08222

Table 12. Errors, Experimental Values, and Estimated Values for Diesel OBM

Temperature °C	Exp Values	Est Values	Errors
30	10	10	0
40	10.05	10.05	0
50	10.1	10.0998	-0.0002
60	10.15	10.1485	-0.0015

Temperature °C	Exp Values	Est Values	Errors
70	10.15	10.2556	0.1056
80	10.2	10.3232	0.1232
90	10.24333	10.3143	0.070967
100	10.2819	10.2851	0.003195
110	10.32048	10.281	-0.03948
120	10.35905	10.3147	-0.04435
130	10.39762	10.3985	0.000881
140	10.43619	10.4526	0.01641
150	10.47476	10.4769	0.002138
160	10.51333	10.5126	-0.00073
170	10.5519	10.5544	0.002495
180	10.59048	10.5884	-0.00208
190	10.62905	10.63	0.000952
200	10.66762	10.6665	-0.00112
210	10.70619	10.7025	-0.00369
220	10.74476	10.741	-0.00376
230	10.78333	10.7559	-0.02743
240	10.8219	10.7655	-0.0564
250	10.86048	10.803	-0.05748
260	10.89905	10.8872	-0.01185
270	10.93762	10.9375	-0.00012
280	10.97619	10.9644	-0.01179
290	11.01476	11.0148	3.81E-05
300	11.05333	11.0533	-3.3E-05
310	11.0919	11.0747	-0.0172
320	11.13048	11.1305	2.38E-05

Table 13. Errors, Experimental Values, and Estimated Values for Jatropha OBM

Temperature °C	Exp Values	Est Values	Errors
30	10	9.8841	-0.1159
40	10.05	10.0044	-0.0456
50	10.05	10.048	-0.002
60	10.1	10.0925	-0.0075
70	10.15	10.1449	-0.0051
80	10.17	10.1681	-0.0019
90	10.20667	10.1987	-0.00797
100	10.24095	10.2489	0.007948
110	10.27524	10.2745	-0.00074
120	10.30952	10.2972	-0.01232
130	10.34381	10.3445	0.00069
140	10.3781	10.377	-0.0011
150	10.41238	10.4003	-0.01208
160	10.44667	10.4539	0.007233

Temperature °C	Exp Values	Est Values	Errors
170	10.48095	10.4994	0.018448
180	10.51524	10.519	0.003762
190	10.54952	10.5537	0.004176
200	10.58381	10.5952	0.01139
210	10.6181	10.6145	-0.0036
220	10.65238	10.6444	-0.00798
230	10.68667	10.6888	0.002133
240	10.72095	10.7105	-0.01045
250	10.75524	10.7365	-0.01874
260	10.78952	10.7895	-2.4E-05
270	10.82381	10.8224	-0.00141
280	10.8581	10.8465	-0.0116
290	10.89238	10.8971	0.004719
300	10.92667	10.9337	0.007033
310	10.96095	10.945	-0.01595
320	10.99524	10.9562	-0.03904

Table 14. Errors, Experimental Values, and Estimated Values for Canola OBM

The minute errors encountered in the predictions further justify the claim that the ANN is a trust worthy prediction tool.

The Experimental outputs were then plotted against their corresponding temperature values, and also fitted into the polynomial trend line of order 2.

The Equations derived are[7]:

Diesel OBM:

$$\rho = -4 \times 10^{-7} T^2 + 0.004T + 9.915 \tag{1}$$

Jatropha OBM:

$$\rho = 7 \times 10^{-7} T^2 + 0.003T + 9.994 \tag{2}$$

Canola OBM:

$$\rho = -2 \times 10^{-6} T^2 + 0.004T + 9.827 \tag{3}$$

Also by comparing the networks created with that of Osman and Aggour[12] (2003), we can see that this work is technically viable in predicting mud densities at varying temperatures as the network developed in the course of this project showed regression values close to those proposed by Osman and Aggour[12].

Errors, percentage errors and average errors as compared with Osman and Aggour[12] are relatively lower, thus guaranteeing the accuracy of the newly modeled network.

Table 15 shows the regression values of Osman and Aggour for oil based mud density variations with temperature and pressure[12].

Training	Testing	Validation	All
0.99978	0.99962	0.99979	0.9998

Table 15. Table Showing the Regression Values from Osman and Aggour[12]

Temperature	Diesel	Jatropha	Canola
30	0.49	0	1.159
40	0.40297	0	0.453731
50	0.092429	0.00198	0.0199
60	0.021569	0.014778	0.074257
70	0.231373	1.040394	0.050246
80	0.097561	1.207843	0.018682
90	0.235986	0.692808	0.078054
100	0.013748	0.031076	0.077606
110	0.107859	0.382504	0.007183
120	0.235115	0.428105	0.119538
130	0.080107	0.008473	0.006675
140	0.157991	0.157237	0.010553
150	0.346719	0.020412	0.116025
160	0.132049	0.006975	0.069241
170	0.136087	0.023647	0.176011
180	0.024081	0.019604	0.035776
190	0.080259	0.00896	0.039587
200	0.23682	0.01049	0.107622
210	0.074195	0.03447	0.03386
220	0.008346	0.035012	0.074922
230	0.173317	0.254405	0.019963
240	0.06392	0.521209	0.097495
250	0.057271	0.529223	0.174223
260	0.056307	0.108703	0.000221
270	0.039597	0.001088	0.013022
280	0.193818	0.107419	0.106789
290	0.082846	0.000346	0.043324
300	0.143289	0.000302	0.064369
310	0.442092	0.155111	0.145538
320	0.724421	0.000214	0.355045

Table 16. Table of the Relative Deviations

Table 17 compares the Average Absolute Percent Error abbreviation (AAPE), Maximum Average relative deviation (Ei) and Minimum E_i for Diesel, Jatropha and Canola OBM's as well as the values from Osman and Aggour.

	Diesel	Jatropha	Canola	Osman et al
Minimum E_i	0.008346	0.000214	0.000221	0.102269
Maximum E_i	0.724421	1.207834	1.159	1.221067
AAPE	0.172738	0.193426	0.124949	0.36037

Table 17. Table Comparing Maximum Ei, Minimum Ei, and AAPE

5. Conclusion

The lower viscosities of jatropha, moringa and canola oil based mud (OBM's) make them very attractive prospects in drilling activities.

The results of the tests carried out indicate that jatropha, moringa and canola OBM's have great chances of being among the technically viable replacements of diesel OBM's. The results also show that additive chemistry must be employed in the mud formulation, to make them more technically feasible. In addition, the following conclusions were drawn:

1. From the viscosity test results, it can be inferred that the plastic viscosity of jatropha OBM can be further stepped down by adding an adequate concentration of thinner. This method can also be used to reduce the gel strengths of jatropha, moringa and canola OBM's.
2. The formulated drilling fluids exhibited Bingham plastic behavior, and from the pressure loss modeling, canola OBM gave the best results, and next was jatropha OBM.
3. The tests of temperature effects on density: The densities increased and became constant at some point, and began increasing again (these temperature points of constant density varied for the different samples). The diesel OBM showed the highest variation range, while the canola OBM showed the lowest.
4. Artificial Neural Network works well for prediction of scientific parameters, due to minimized errors returned.

6. Limitations

1. The temperature-density tests were carried out at surface conditions under an open system and at a constant pressure due to the absence of a pressure unit thus, the equations developed are not guaranteed for down-hole circulating conditions.
2. During the temperature-density tests, it was observed that some of the mud particles settled at the base of the containing vessel, and this reduced the accuracy of the readings.
3. The accuracy of the temperature-density readings is also reduced because of the use of an analogue mud balance (calibrated to the nearest 0.1 ppg).
4. The mud samples were aged for only 24 hours, hence the feasibility of older muds may not be guaranteed.

7. Recommendations

1. This work should further be tested and investigated for the effect of temperature on other properties of the formulated drilling fluids.

2. The temperature-density tests should also be carried out at varying pressures, to simulate downhole conditions.

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