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Rheological Properties of Oil Based Mud and Optimization of Hole Cleaning Using Low Viscosity and High Viscosity Oil Based Mud

Imad Biboye Eseimokumoh[1], Oguta Eniye[2], Toun-Aregha Nelson Preye[3], Igbagara Woyintonye[4]

[1,2,3,4,]Department of Chemical and Petroleum Engineering, Niger Delta University, PMB 071, Wilberforce Island, Bayelsa State, Nigeria.

Corresponding author: imadeseimokumoh@gmail.com

Abstract:

The type of drilling mud selected has a great role to play in the success of any rotary drilling process. The main function of drilling mud is to remove cuttings during the drilling process. Viscosity is the most needed property of the drilling mud that helps it to perform its task. This property helps the mud to be effective in well cleaning and also assist in suspending drilling cuttings in the hole when circulation of the fluid is put on hold. Monitoring and continuously adjusting the viscosity of the drilling fluid is important. Rheological tests were conducted to determine the plastic viscosity, yield point, gel strength among others. This will help to develop concise understanding to be able to modify these fluids to suit varying conditions that may be encountered during operations for better drilling practices. Results from this investigation showed that, increasing the wellbore flow rate would increase the Cutting Carrying Index. Oil Based Mud samples with higher viscosities tend to have more gel strengths and can also have a good hole cleaning efficiency at an average flow rate.

Keywords — **Drilling Fluid, Rheology, Oil Based Mud (OBM), Viscosifier, Low Viscosity Mud (LVM), High Viscosity mud (HVM)**

I. INTRODUCTION

In the oil and gas industry a lot of activities are carried out with fluids. These fluids could be used for drilling and transporting drilled cuttings to the surface (drilling mud) or well completion (completion fluids; brine), these fluids could also be the well effluent such as produced water, crude oil and natural gas. Therefore, it is important to understand the principles that govern the behaviour of these fluids, their properties and the conditions suitable for using or transporting these fluids. The rheological properties can be extremely influenced or changed by increasing temperature and pressure in deep drilling wells [2]. The Egyptian and Chinese used water as the first drilling fluid.

The drilling fluids can provide gravitational pressure during drilling operations which helps to prevent reservoir fluids from infiltrating the uncased area of the well, thereby, ensuring that the cleanliness and temperature of the drill bit during drilling operations are maintained. Prevention of formation damage and corrosion are the basic criteria for selecting the drilling fluid used for a particular job. The main requirement of any drilling fluid is its ability to remove cuttings from the wellbore or bottom-hole to the surface [1].

Good hole cleaning means the efficient and effective carrying of drilled solid from the bottom hole to the surface. This will help for unhindered movement of tubular and drill strings. Poor hole cleaning leads to a number of drilling problems such as stuck pipe, high rotary torque, break down of formation, slow rate of bit penetration and loss of circulation [6]. These drilling problems will lead to higher drilling cost. Cutting bed is formed as hole angle increases causing drilling cuttings to settle by the force of gravity along the bottom of the well [5]. Drilling fluid can be Pneumatic (air/gas based), Oil based or Water based depending on the flow properties of the fluid based on the applied force. In the petroleum industry various researches has been carried out on the measurement and identification of fluid properties. Also, these fluids have been grouped based on their behaviour and relevance to the production and exploration of petroleum all over the world. Our understanding of the characteristics of the fluid gives insight on the suitable conditions for its use, mode of storage, maximum and minimum pressure and temperature to be applied and the problems that may arise from handling such fluids. This is why rheology is considered in the oil and gas industry. Rheology shows the properties of fluid under flow conditions, the changes that these fluids may undergo and the ability of such a fluid to return to its original state after experiencing such changes. Hence, understanding the concepts of rheology is key to Improving engineering practices in the oil and gas industry.

1.1 Properties of Drilling Fluid

- Rheology
- Density
- pH
- Sand Content
- Filtration Property

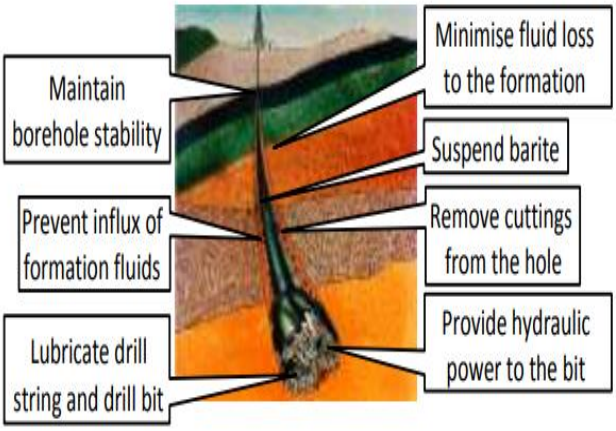

Fig. 1 Main functions of drilling fluids

1.2 Functions of Drilling Fluid

As schematically depicted in **Fig. 1** above, drilling fluids have the following main functions:

- Control subsurface pressures, maintaining well control.
- Remove drill cutting from beneath the bit and circulate them to the surface.
- Maintain wellbore stability, mechanically and chemically.
- Transmit hydraulic energy to the drill bit and downhole tool.
- Cooling and lubricating the drill string and bit.
- Allow adequate formation evaluation.
- Providing a wellbore that is complete to produce hydrocarbons.
- Suspending or minimizing the setting of drill cuttings or weighting materials such as barite, micromax, ilmenite, and hematite when circulation is stopped.
- Form a low Permeability, thin and tough filter cake across permeable formations.

1.3 Types of Drilling Fluids

There are 3 basic types of drilling fluids, namely;

- Pneumatic (air/gas) based mud
- Water Based Mud
- Oil Based Mud

Pneumatic (air/gas) Based; Are employed in drilling depleted zones or areas with abnormally low pressures within the pore spaces of the rock formation. During the drilling of such formations, the pneumatic fluids are converted to liquid-based fluids and this increases the probability of damaging productive zones. Pneumatic wells are not effective for very deep wells below 10000ft due to the fact that the volume of air or gas required to lift drill cuttings from the wellbore could be greater than what the surface equipment can handle.

Water Based Mud: Are subdivided into inhibitive, non-inhibitive and polymer fluids depending on their impact on clay swelling. Clay swelling is a damage of the formation caused by the reduction of formation permeability arising from the change in clay equilibrium. When water-base filtrates from stimulation fluids, completion, drilling activities, work over filter through the reservoir, the clay equilibrium is altered [3]. Water based muds are divided into: inhibitive fluids, non-inhibitive and polymer fluids [4]. The inhibitive fluids have an appreciable impact on clay swelling due to the presence of cations such as Sodium (Na+), Calcium (Ca++) and Potassium (K+). Water based muds are the most preferable drilling muds because they are easy to formulate, low cost of maintenance and has the ability to outwit most of the challenges associated with drilling activities [3].

Oil Based Muds:

Oil-based drilling fluid formulations usually contains emulsifiers, lime, brine, fluid loss controller, viscosifier, and weighting agent [8]. When shales are problematic, and there are highly deviated holes, oil based fluids are primarily used in the drilling operation because of their ability to reduce friction and prevent hydration of clays [3]. Oil based muds are chosen due to their ability to resist contaminants such as anhydrite, salt, carbon dioxide and hydrogen sulphide gases. Recently, due to the environmental concern associated with the use of oil based fluids, their use is either restricted or prohibited to certain locations.

1.4 Rheology

In 1920, the term rheology was coined by a professor at Lafayette College, Eugene C. Bingham, from a suggestion by a colleague, Markus Reiner. Rheology is defined by the English dictionary as a branch of physics that studies the deformation and flow of matter. Rheology is considered when fluid is involved and flow is possible. The concepts related with rheology is based on the changes the fluid undergoes and the ease of motion during flow.

1.4.1 Concepts and Measurements of Rheological Properties

1.4.2 Viscosity

Viscosity is a quantity that expresses the magnitude of internal friction in a fluid. It is measured by the force per unit area resisting uniform flow, and it is the measurement of at which fluids flow.

Measurements

In the industry, viscosity is measured using a viscometer and the unit of measurement is in centipoise (cp)

Types of Viscometer

i. Rotational Viscometer
ii. Turning fork vibrational viscometer
iii. Glass capillary viscometer
iv. Viscosity Cup
v. Falling ball viscometer

Another instrument that can be used to measure viscosity is a **CONSISTOMETER**

1.4.3 Apparent Viscosity

This is the **viscosity of a fluid measured at a given shear rate at a fixed temperature**. It can be calculated mathematically using the equation;

$\mu_a = [Ø_{600}/ 2]$ ----------i Where; μ_a=apparent viscosity

$Ø_{600}$=dial reading at 600RPM

1.4.4 Plastic Viscosity

The resistance to the flow of a fluid is called plastic viscosity. Due to interaction between solids within the drilling mud, mechanical friction can cause plastic viscosity in wells. Increasing the *plastic viscosity* means that drilled solids are increasing in the drilling mud.

This can be calculated mathematically using; PV = $Ø_{600}$ - $Ø_{300}$ ii

Where; μ_p=plastic viscosity, $Ø_{600}$=dial reading at 600RPM, $Ø_{300}$=dial reading at 300RPM.

1.4.5 Yield Point

Yield Point (YP) is the attractive force among colloidal particles in Drilling mud. YP is the shear stress at zero shear rate. From the Fann viscometer (readings at low rpm), yield point is best estimated using low shear rate readings [7]. The YP shows the ability of the drilling mud to carry cuttings to the surface at dynamic condition. Its unit is $lb/100ft^2$.

YP= $Ø_{300}$- PV...................................iii

Where $Ø_{300}$ = Dial Reading at 300RPM, PV= plastic viscosity

1.4.6 Gelation or Gel Strength

Gelation is the phenomenon whereby fluid is able to suspend weighted matter or materials. It can be referred to as the carrying capacity of the fluid. For drilling fluid, gelation is the ability of drilling mud to suspend drilled cuttings in the wellbore during a downtime. Losing the gel strength will accumulate more drilled cuttings downhole leading to sticking of the drill string. Mitigating this problem takes a long time and will increase the total cost of the drilling operation [7]. A device called viscometer is used to measure Gel strength. When the rotational viscometer is turned at a low rotor speed i.e. 3 rpm after the mud has remained static for some period of time (10 seconds, 10 minutes, or 30 minutes), the gel strength is obtained by noting the maximum dial deflection.

II. METHODOLOGY

2.1 Test Procedures:

OBM samples are prepared through mixing all of the components using the Electric blender. The materials have to be mixed in following a set sequence. After the mixing time which is 10 to 15 minutes, the resulting mud sample has a volume of 1 lab barrel or 350ml. The procedures are as follows;

i.) Required amount of base oil (Diesel) which is approximately 262.5ml is added to the blender, then the blender was turned on.

ii.) 6.5ml of the primary emulsifier (invermul) is added into the blender using a syringe.

iii.) 5g of filtration control agent (duratone) is added to the mixture.

iv.) 5g of lime was then added to the mixture.

v.) 10g of Calcium Chloride (dissolved in the quantity of the water measured) is added to the mixture

vi.) 17.5g of drilling clay (bentonite) is then added to the mixture.

vii.) 48g of weighing material (barite) is then added for the desired density and allowed to blend for some minutes to form a good emulsion

2.1.1: *Rheology Test*

Materials used: different concentrations of formulated drilling mud.

Equipment: Rotational viscometer

Test procedures:

i. Formulated drilling mud was used to fill the test cup to the scribed line.

ii. The leg lock unit nut was loosened to raise the viscometer assemble

iii. The test cup was placed on the viscometer stand and adjusted with the stand until the rotor sleeve was immersed in the formulated drilling mud at the scribe-line

iv. The viscometer stand was held in position by tightening the lock screw on the left leg of the equipment

v. The mud was stirred for 10seconds at 600rpm

vi. The red knob on the equipment was pressed and the dial reading at 600rpm was taken.

vii. The readings were allowed to stabilize

viii. The dial reading was recorded

ix. The same procedures were repeated for other samples at rotational speeds of 300, 200, 100, 6 and 3 rpm respectively.

III. MODELING AND ANALYSIS

3.1 Materials and Equipments Used in Investigation

The table below shows the materials and equipments used for the analysis of the experiment.

Table 1: Materials Used

Sequence	Materials	Function	Concentration
1.	Base Oil (Diesel)	Solvent	262.5ml
2.	INVERMUL	Primary Emulsifier	6.5ml
3.	Lime	Activator for Primary Emulsifier and PH control agent	5g
4.	Duratone	Filtration Control Agent	5g
5.	$CaCl_2$	Reduce water activity	10g
6.	Geltone II	Organophilic Viscosifier	6.5g
7.	Bentonite	Drilling mud	17.5g
8.	Barite	Weighing Agent	48g
9.	Brine /Water	Prevent shales from Hydrating	87.5ml

Table 2: Equipments Used

Sequence	Equipment/Apparatus	Function
1	Electronic Weighing Balance	
2	Blender	
3	Mud Balance	
4	Rheometer	

Fig. 2 Electric Weighing Balance Fig. 3 Blender

Fig. 4 Mud Balance

Fig. 5 Rheometer

Fig. 6 PH paper

Fig. 7 Bentonite clay

Fig. 8 Barite

Fig. 9 Reference drilling mud

Fig. 10 Calcium chloride

Fig. 11 Geltone

Fig. 12 LIME

Table 3: Drilling Fluid Requirements for a Standard Oil Based Mud

Requirements	Description
Density	12-14 ppg
Oil-Water Ratio	75/25 or 80/20
Reading at 600rpm	65<
YP	15-30
Gel strength	Progressive over time
HPHT Fluid loss	>10

IV. RESULTS AND DISCUSSION

4.1 Results and Discussions

Table 4: Low Viscosity and High Viscosity Mud Result Samples

RP	LVM-2	BASEMUD	HVM-2	REF.MUD
600RPM	34	47	80	77
300RPM	22	29	52	46
200RPM	16	22	45	34
100RPM	11	14	34	20
6RPM	4	6	19	4
3RPM	3	5	17	2
GEL10'/10"	3,3	5,7	8,12	9,14
MUDWEIGHT (PPG)	8.2	8.5	8.7	8.7
PH	8	10.5	12	10
APPRENT VISCOSITY	17	23.5	40	38.5
PLASTIC VISCOSITY	12	18	28	31
YIELDPOINT	10	11	24	15
FLUID BEHVIOUR INDEX(n)	0.62804	0.69662	0.62150	0.74324
FLUID CONSISTIENCY INDEX(k)	223.7860	192.34051	550.9798	228.1235
FLOWRATE(GPM)	450	450	450	450
ANNULAR VELOCITY	70.9938	70.9938	70.9938	70.9938
CCI	0.3257	0.5919	0.9095	0.5241

4.1.1 Discussion of Results:

After the base mud samples have been prepared, we hereby prepare two other samples of oil based muds using the same proportion of materials used in preparing the based mud, labeling them LVM and HVM which indicates Low viscosity Mud and High Viscosity Muds Respectively.

We hereby reduced the fluid viscosity by addition of 4ml of diesel to the LVM sample then agitating the fluid with the electric blender and increased the fluid viscosity by addition of 4 grams of viscosifier, geltone to the HVM sample and also agitating with the electric blender for 2 to 3 minutes.

The REF. Mud values indicates a Reference standard drilling Oil based mud from the field in PTI'S Exploration Laboratory in which we also used for our experiment.

The Rheological properties which includes Reading at 600rpm, 300rpm, 200rpm 100rpm, 6rpm, 3rpm, Gel strength at 10 seconds and 10 minutes of the samples of LVM,Base Mud, HVM and REF. Mud was determined using a **Rotational Viscometer**. Investigating hole cleaning optimization using low and high viscosity drilling mud can be further explained from the results gotten.

Apparent viscosity, $u_a = \frac{Ø_{600}}{2}$

Plastic Viscosity, PV = $Ø_{600} - Ø_{300}$

Yield point, YP= $Ø_{300}$ - PV

Fluid Behaviour index, $n = 3.322\log(\frac{2PV+YP}{PV+YP})$

Fluid consistency index, $k = 511^{1-n}(PV + YP)$

Where; $Ø_{600}$ = Reading at 600rpm and $Ø_{300}$ = Reading at 300rpm

Assume flow rate is constant at 450gpm, with hole diameter of 15 inches and pipe diameter of 8 inches, therefore the constant Annular velocity will be ;

$$\text{Annular Velocity} = \frac{25.4q}{d_h^2 - d_p^2}$$

Where; $d_h = \textit{Hole diameter and } d_p = \textit{pipe diameter}$

Therefore, $AV = \frac{25.4 \times 450}{15^2 - 8^2} = 70.9938 \text{ft/min}$

Robinson's Model

From Robinson 1993 model shown in equation iv below

$CCI = \frac{K(AV)(MW)}{400000}$ ……………………………. iv

Where;

CCI= carrying cutting index

K= fluid consistency index

n= flow behaviour index

MW= mud weight

400000 is a constant derived by Robinson for cutting bed erosion in the annulus.

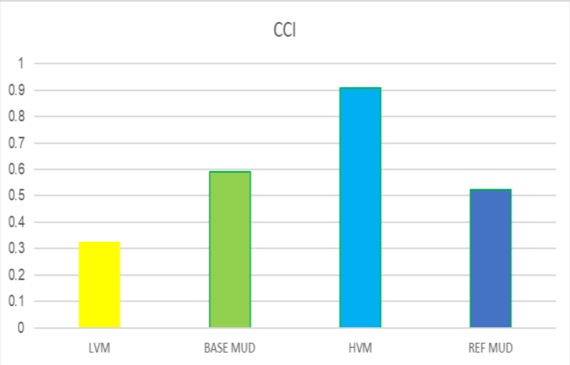

Fig. 13 A Bar Chart showing the Cutting Carrying Index of the Oil Based Mud samples.

According to Robertson (1993) Model, If Cutting Carrying index (CCI) is equal to 0.5 or less, the hole cleaning is poor, but if the CCI is 1 or more then the hole cleaning is good. From the experiment, the CCI for the Low viscosity mud (LVM) is 0.3257 which indicates that the LVM sample will not be efficient in an hole cleaning operation since its CCI is less than 0.5.

The CCI for the Base Mud and REF. Mud from the experiment is 0.5919 and 0.5241, which indicates that the hole cleaning for the base mud is still poor.

The CCI for the High Viscosity Mud is 0.9095, which is not up to the standard value for a good hole cleaning drilling mud but can be considered for drilling operation because it is a fraction away from 1.

V. CONCLUSION

From this study, the following conclusions can be drawn;

i. To ensure optimum hole cleaning during drilling operations, the LVM and Base Mud needs to be circulated down the drill bit at high flow rates (turbulent flow rates) to achieve excellent hole cleaning while HVM need to be circulated at a low flow rate (laminar flow rate) to achieve maximum hole cleaning down the well bore.

ii. To increase the CCI of the LVM samples and Base Mud Samples, there need to be an increase in flow rate(q) and Fluid Consistency Index(K) which is a factor of the fluid’s viscosity.

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