FORMULATION AND CHARACTERIZATION OF DRILLING FLUIDS FROM POLYMER AND LOCAL CLAY

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DECLARATION

I hereby declare that this thesis titled '**FORMULATION AND CHARACTERIZATION OF DRILLING FLUIDS FROM POLYMER AND LOCAL CLAY**' is a record of my own research findings. It has not been presented partially or wholly on any previous work for the award of any degree. Any quotations and sources of information are acknowledged by means of reference.
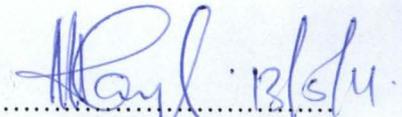
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CERTIFICATION

This thesis titled "**FORMULATION AND CHARACTERIZATION OF DRILLING FLUIDS FROM POLYMER AND LOCAL CLAY**" by MUHAMMAD, RABIU LAWAL (M.ENG/SEET/2006/1523) meets the regulations governing the award of the degree of Master of Engineering of Federal University of Technology, Minna and is approved for its contribution to scientific knowledge and literary presentation.

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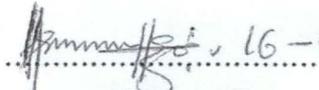
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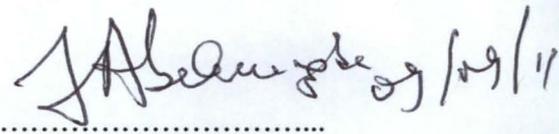
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DEDICATION

Praise be to Almighty Allah for the life He bestowed upon me and for giving me the opportunity to undertake this master's programme. I dedicate this work to His Servant whom He chose to be my Father, Late Alhaji Muhammad Lawal Murshid.

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ABSTRACT

The formulation and characterization of local clay, beneficiated with polymer was investigated. Firstly, the clay samples were collected and characterized as non-hydrated clay after processing it to 75 micron size. The effects of various polymer used were determined. Using ten different compositions the clays were formulated with Sodium Carboxyl methyl cellulose (SCMC) with/without Lignosulphonate were investigated. Further Formulations were carried out using BSM clay based on results obtained from above formulation, using Polyanionic Cellulose (DRISPAC) and Hydroxyl ethyl Cellulose (HEC) at clay concentrations of 17.5g, 21.0g and 24.5g. The results revealed the addition of SCMC and with/without Lignosulphonate produce an unsatisfactory result with BSM clay having better results compared to MTB clay. Further beneficiation at different concentrations of clay sample, starting with 0.5g of polymer was investigated. The used of 2.5g of Polyanionic Cellulose (DRISPAC) with the local clay gave a satisfactory result than 2.0g of Hydroxyl ethyl Cellulose (HEC) because of its lower gel strength despite the fact that all other parameters satisfactorily attained the API standard. Both investigation involving DRISPAC and HEC record a satisfactory values for both power index (n) and characteristic factor (k).

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CHAPTER ONE

1.0 INTRODUCTION

Drilling fluids are generally termed 'blood' of all drilling operations and the petroleum industry especially has continued to make increasing use of these fluids. Drilling fluid or mud is a vital component in the rotary drilling process. Most of the problems encountered during the drilling of a well can be directly or indirectly attributed to the quality and efficiency of the mud. Due to the complexities of treating, monitoring and conditioning of the mud, an operating company will usually hire a service company to provide a drilling fluid specialist (mud engineer) on the rig. The cost of the mud and the chemical additives may fairly be high, although this may seem expensive, the consequences of not maintaining good mud properties may prove much more expensive in terms of drilling problems of which it can accounts for about 10 - 20% of total operating cost. To minimize the cost as well as improve on the performance and safety, other generic types of these fluids, for example polymer drilling fluids- are continuously being developed mainly to meet the increasing challenges of deeper well drilling/completion especially in high temperature and pressure environment, increasing use of advanced wells (multilateral and horizontal wells) and stiff environmental regulations (Bleier *et al.*, 1993).

Historically, either water based muds (WBMs) or Oil based muds (OBMs) have been used for drilling operations all over the world. The performance of many water based muds makes them to be particularly deficient in drilling deep, high angle, extended reach wells or in high temperatures and pressures. Oil based muds are therefore being used in large numbers to overcome these deficiencies. As the operating companies make aggressive moves towards the exploration/development in the deeper waters, the use of OBMs has increased tremendously. Although wells drilled with OBMs produce lower waste volumes, the

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Environmental Protection Agencies worldwide and in particular the country of production have stiff guidelines on the release of free oil and drill cuttings discharges and wastes on site. This has led to the development of a variety of potentially low-toxic, biodegradable synthetic based muds (SBMs) and a variety of pseudo-oil based muds (POBM) which theoretically offer better pollution prevention potential over oil based muds (Max *et al.,* 1996).

In offshore drilling operations, more care is given to choice of drilling fluid to be used, pollution control is very important and the water based mud becomes inevitable choice due its properties which seems to solve many, if not, all of the problems of drilling in offshore. Bentonite mud can achieve some of the properties, but a bentonite/polymer mud will surely give more due to the introduction of polymer which serves as fluid loss control agent (Mansour *et al.,* 2009).

For these systems, the definition of the optimum operating conditions for completing oil wells nowadays depends largely on the understanding of the complex fluid mechanics of drilling fluids or mud. A good knowledge of the fluid rheological behavior is fundamental to this understanding most especially with respect to:

- The formulation of the fluid recipe (concentration and type of chemical additives for optimum fluids formulation) and how it affects its behavior;
- Accurate prediction of pressure drop and the energy requirement, i.e. pump horsepower requirement, etc. Need proper pumps to push the fluid around the wellbore without actually overloading your surface equipment;
- Design for optimum hydraulic and operating conditions such as pump rate - effective hole cleaning and stability, fluid displacement strategies for cement-mud displacement, and their effects on different tools;

• phase separation mechanism and settling behavior of solids – fluid-particle interaction, solids' control, wellbore clean-up. All of these affect how the fluids will react with the wellbore;

• Particle suspension and transport properties, including cuttings and milled swarfs;

• Phase behavior – for underbalanced drilling.

These factors must be considered well in advance before the actual drilling programme. Without fluids we would have no drilling operations. Fluids that are used can be gas, a mixture of gas and liquid or just liquid. Laser drilling, using combinations of beams, is technically possible but in practical terms is difficult to achieve. At present there are no drilling operations that do not involve fluids (Bleier *et al.*, 1991).

1.1   Aim and Objectives

This project is aimed at formulation and consequently characterization of the polymer formulated drilling mud samples through the study of the rheological properties as well as comparing them with the available standards and Bentonite clay so as to ascertain their efficiency. This aim can be achieved through the realization of the following objectives:

- Collection and Processing of local clay samples.

- Formulation of the drilling mud using , Fresh water, sodium hydroxide, Lignosulphonate (Q-BROXIN), sodium carboxyl methyl cellulose (SCMC), Hydroxyl ethyl cellulose (HEC) and Polyanionic cellulose (DRISPAC)

- Characterization of the formulated drilling mud, from the properties resulted from analysis carried out.

The above objectives are aimed at realizing a drilling fluid that will give better rheological properties and also be in line with all environmental regulations for drilling in

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offshore and also to determine how the properties of local clay will be blended with the controlling fluid loss of polymer.

1.2   Approach

The work involves two processes, namely formulation and characterization of the developed mud samples in offshore drilling operations.

The processes of formulating the polymer drilling mud will involve a mixture of local clay samples and polymer, often known as bentonite/polymer mud.

Scores of samples of the drilling mud will be prepared with varying quantity of the materials/additives. The materials will include bentonite, Local clay samples, Fresh water, sodium hydroxide, Lignosulphonate (Q-BROXIN), sodium carboxyl methyl cellulose (SCMC), Hydroxyl ethyl cellulose (HEC) and Polyanionic cellulose (DRISPAC). Each of the material mentioned above does control some properties of mud and varying them means changing in some of the properties of the fluid. Finally, in characterization of the developed mud samples, such properties like density, viscosity, filtrations properties, and e.t.c. will be measured. The measured parameters will be compared with the standard mud properties so as to ascertain their conformity.

1.3   Justification

Due to strict stiff environmental regulations on drilling activities in many countries especially Nigeria to prevent environmental pollutions, the use of water based mud is highly recommended. However the use of bentonite/polymer mud gives better viscosity control, higher solids tolerance and better filtration control in offshore drilling and as such is more environmentally friendly.

The method of development of the present mud samples discussed above, which will involve the low solid organic polymer combined with filtration properties of bentonite will surely yield excellent characteristics for offshore drilling operations. Potassium ions in the mixture will be small and will readily plug the clay lattice thereby preventing it from escaping into the sea water; sodium carboxyl methyl cellulose (SCMC), Hydroxyl ethyl cellulose (HEC) and Polyanionic cellulose (DRISPAC) will all control the fluid loss and all these will result in excellent drilling operation with minimal environmental pollution.

1.4 Study Constraints

For any study or research work, the researcher is always limited by some factors. This study is not an exception hence its constraints include; lack of sponsorship, equipment, published books, recent journals, etc.

CHAPTER TWO

2.0 REVIEW OF LITERATURE

2.1 Drilling Operations

Drilling is the technological process of realizing a well bore (the hole) by means of a drilling rig and other equipment. To realize a well bore it is necessary to dislocate rocks which are laid out in stratigraphic columns below the earth's crust and to evacuate the dislocate rocks (detritus) to the surface from different depths (Katz, et al., 1959).

The idea of drilling wells with a rotary rig instead of the chisel-like bit used in 1500s was successfully used in1865.

By 1901, the famous Texas well, was drilled with a rotary rig, this was due to the fact that rotary drilling process provide very deep holes, thousands of feet. As the pipe with the rig is rotated, rock cuttings, debris are formed and the issue becomes how to remove the unwanted cuttings and debris out of the hole. Also considered was the heat generated at the drilling bit head. All these led to the use of a circulating fluid called 'mud' which served to correct the outlined problems, of lubricity and heat transfer as well as the removal of the unwanted cuttings (Rogers, 1980).

2.1.1 Drilling Applications.

Considerable quantities of useful substances are extracted from the interior of the earth's crust through wells. Also through wells, a direct investigation of rock contents from the earth's crust is carried out.

Rogers, 1980, the domain of drilling application is diversified and multiple. Some principal applications of drilling are as follows:

(i) Extraction of petroleum gas

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(ii) Geological prospecting and exploration for new reserves of useful substances or for the delimitation of existing reserves.

(iii)Execution of mines in ore and coal mining industries for:

(a)   Ventilation

(b)   Water drainage

(c)   For lowering props and timber into mines for firefighting purposes.

(iv)Exploitation or extraction of water from water beds for industrial use, agriculture (irrigation), and for human consumption etc.

(v) Ground or soil investigation prior to building, road, bridge, tunnels, barrages, dams, railways etc.

(vi)Consolidation of rocks in case of surface or underground construction e.g. well sites, underground trains etc.

(vii)   For prospecting and recovering medicinal mineral waters for medical purposes.

(viii)   For recovery of brines containing various salts such as sodium chloride, sodium bromide and sodium iodine for chemical industries.

Above all, the most important and widest application of drilling is for prospecting, exploration and exploitation of oil and gas reservoirs. The greatest number of wells and the deepest wells are found in the petroleum industry.

2.2 Drilling Concept, History and Development

Drilling has been in practice since the entiquities, for example in the Egypt the cradle of modern civilization, amongst the initial preparatory works for the construction of pyramids, bore holes were made with the help of instruments from bronze with diamond inserts. Also in China (1700 BC) wells were drilled up to 500m for the extraction of brine

from where salt was obtained by evaporation. The Chinese drill stem in those days comprised of bamboo sticks and the method of drilling was percultant and manual.

The first well drilled for the exploration of oil and gas was supposedly known to have been in Russia (Bibi Eibat neat Baku) in 1848 using percursion drilling method and later in 1859 the historic oil well (colonel Drake Well) was drilled in the United States near Titus ville, Pennyslvania. The total depth was 59feet. it struck oil at 59.5feet and percursion drilling method was employed. Since then other drilling methods have been introduced. These include: cable tool drilling, rotary drilling, and turbine drilling.

Due to the continuous development in drilling technology, new methods are now being tried experimentally. They are based especially on the basic principles of rock composition and machines.

Examples of modern drilling techniques based on principles of rock dislocation and evacuation are:

- Drilling with explosives
- Flame drilling
- Electric arc drilling
- Plasma jet
- Laser beams
- Erosion drilling
- Form drilling
- Air drilling

2.2.1 Genesis of Drilling Fluid

The information available from the early history of drilling fluid was very obscure; hence the genesis of drilling fluid (mud) could only reveal very little information on this material. The early wells drilled by the rotary method apparently used only whatever mud formations available.

During this period the physical properties of drilling mud posed serious problems to the drillers, these problems included mud weight, fluid or water loss, viscosity, filtration and filter cake formation etc. and then there were no purchase of admixtures for control of the physical properties. The art of mud handling consisted of modifying, through the use of water which was first performed by a French Engineer Fauvelle in 1845. Water was pumped down a hollow boring rod, while drilling water well for the purpose of bringing cuttings to the surface. This breakthrough by Fauvelle posed a challenge to scientist and also stirred up more academic interest (Rogers, 1980).

However some years latter Pollard and Heggen developed an improvement in cable tool drilling to prevent the excessive waste of gas which was occurring as a result of drilling gas wells by the percussion method. After their discovery they defined the term Mud-Laden Fluid as (A mixture of water with any clay which will remain suspended in water for a considerable time) the discovery by Pollard and Heggen became a spring board for several other discoveries and definitions of drilling mud (Rogers, 1980).

Nevertheless, the modern history of drilling fluid started in 1921 with the first attempts to control mud properties through the use of additives by means of weighting drilling fluid to prevent wells from blowing out from high gas pressures; this was done by maintaining the hydrostatic head at a rate higher than the formation pressure.

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2.2.2 Drilling Fluids

Drilling fluid are mixtures of clay, usually bentonite, and water used primarily in oil, gas and water drilling operations to carry cuttings to the surface as well as to lubricate and cool the drilling bit.

The drilling fluid is related either directly or indirectly to almost every drilling problem. This is not to say that the drilling fluid is the cause or solution of all drilling problems, but it is a tool that can often be used to alleviate a problem situation. Many have thought that a magic additive for example polymer would solve all of their problems and that the drilling fluid could somehow make up for poor drilling practices. This is simply not the case. It is a part of the drilling process and should be used to complement all other facets of the operation. Selection and application of the drilling fluid are the key factors in the success of any drilling operation (Bourgoyne *et al.*, 1986).

In planning a mud program, the selection of a mud that will minimize the amount of lost time in the drilling operation is very important. Such a mud will usually be economical regardless of its cost per barrel.

Generally, a good drilling fluid contains a minimum number of additives. This allows easier maintenance and control of properties. It is desirable to have a mud system that is flexible. After selection of a suitable mud program, consideration should be given to its implementation. The performance of a drilling fluid is determined more by engineering than by the products used (Bleier *et al.*, 1991).

For proper understanding of the term drilling fluid, its composition and classification, it is necessary here that a clearer definition of the words "drilling" and "fluid" be made. Drilling as the word implies is a technological process of realizing a well bore by means of machines, thus dislocating rocks which are laid out in stratigraphic columns beneath the earth's crust and evacuating the cuttings to the surface.

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FLUID: A fluid is a substance which may flow; that is, its constituent particles may continuously change their positions relative to one another. Moreover, it offers no lasting resistance to the displacement, however, great, of one layer over another. This means that, if the fluid is at rest, no shear force (i.e. a force tangential to the surface on which it acts) can exist in it (Al-Otaibi *et al.,* 1999).

In the light of the above definition, in the drilling operation by the rotary method which is now essentially the best drilling procedure used in the petroleum industry, a fluid is maintained in the hole at all times. During actual drilling the fluid is circulated continuously to remove cuttings and the removal of cuttings is readily facilitated by a fluid with a viscosity greater than that of water. At the same time the drilling mud must be pumpable and its viscosity characteristics must be subject to some control.

The drilling fluid should be marked by thixotropic behaviour; that is, it should have gel strength. This attribute is necessary so that the cuttings do not settle to the bottom of the hole.

2.2.3 General Classification of Fluids

Fluids have been classified into two general classes:

(1)   Newtonian

(2)   Non-Newtonian

NEWTONIAN FLUIDS: These follow Newton's law of viscous resistance. For these fluids, Shear stress is directly proportional to the shear rate at a constant temperature and pressure. Such fluids immediately start to move, when a force in excess of zero is applied to them.

NON-NEWTONIAN FLUIDS: The fluids deviate from Newton's law of viscous resistance because they do not show a direct proportionality between shear stress and shear rate. For non-Newtonian fluids the ratio of shear stress to shear rate is called "apparent viscosity instead of viscosity, non Newtonian fluids can further be classified into four major categories:

(1)   Those fluids whose properties are independent of time

(2)   Those fluids whose properties are dependent upon time

(3)   Those fluids which exhibit many characteristics of a solid

(4)   Complex fluids

The time independent non-Newtonian fluids have been subdivided into three classes:

(a)   Bingham plastic

(b)   Pseudopalstic

(c)   Dilatant

Only the above three are of interest in drilling fluid technology. Drilling fluid behavior can be predicted with accuracy sufficient for practical purposes by one or more models. Flow models usually visualized by means of consistency curves, which are plots either of flow pressure versus flow rate, or of shear stress versus shear rate.

2.3. Drilling Fluids Technology

Technology is the application of both scientific knowledge and engineering principles to a specific industrial development. Drilling fluid technology involves the sciences of Geology, Chemistry, Physics, and the skills and application of Engineering. Its goals are the utilization of available equipment and materials to attain at lowest cost the desired objectives

of earth excavation. Drilling fluid technology is not aimed at the design of an ideal drilling fluid only, but at the achievement of real end product with successful completion of each borehole with minimum overall expenditure.

Drilling fluids technology has developed as a significant economic contribution to the production of oil and gas sector. Both the introduction of new drilling fluid products and the development of better practices in their application arose because there were problems to be solved. Such problems as how to reduce waste of natural resources, how to improve safety in drilling, and how to lower costs through time and materials savings have led to the recognition of the drilling fluid as a vital factor in the success of many drilling operations (Rogers, 1980).

Drilling fluids are dynamic, constantly changing in response to changing conditions as the well is being drilled and down-hole pressures and temperatures increase from 300 - 1500psi, and 149 - 232°C respectively. Usually at this point, another fluid with required properties is employed due to the changes (Rogers, 1980).

A drilling fluid controls the subsurface pressure of the well by its hydrostatic pressure. Hydrostatic pressure is the force exerted by a fluid column and depends on the mud density and true vertical depth (TVD).

Borehole instability is a natural function of unequal mechanical stresses and physico-chemical interactions and pressures created when support in material and surfaces are exposed in the process of drilling a well. The drilling fluid must overcome both the tendency for the hole to collapse from mechanical failure and/or from chemical interaction of the formation with the drilling fluid. The Earth's pressure gradient is 0.465 psi/ft. which is equivalent to the height of a column of fluid with a density of 8.94 ppg, and is approximately the density of seawater.

2.4. Functions of Drilling Fluids

Many requirements are placed on the drilling fluids. Historically, the first purpose was to serve as vehicles for the removal of cuttings from the bore hole. Nowadays, the diverse applications of drilling fluids make it difficult for the assignment of specific functions.

The list of functions of drilling mud below is an indication of the complex nature of the role of drilling fluids in the drilling operation. It is obvious that compromises will always be necessary when designing a fluid to carry out these functions, which in some cases require fluids of opposite properties. The most important functions in a particular drilling operation should be given the most weight in design of the drilling fluid (Max *et al.,* 1996).

Many of these functions are controlled by more than one mud property and should be thoroughly discussed.

There are a number of functions a drilling fluid performs; the more basic ones are listed below:

1. Balance formation pressure

2. Carry or removal of cuttings and sloughing from hole bottom to the surface..

3. Clean beneath the bit

4. Cool and lubricate bit and drill string

5. Suspension of cuttings and weighing materials during circulation break

6. Seal permeable formations and maximize penetration rates.

7. Stabilize borehole

8. Corrosion control

In addition to these functions, there are several other functions with which the drilling fluid is associated with, namely:

1. Formation evaluation

2. Completion operations

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3.   Production operations

In performing the above listed functions drilling fluids:

• must maintain stability of properties under the operating conditions of temperature and pressure;

• must not generate any secondary reaction which could lead to precipitation;

• must not react with the formation;

• must not damage the formation either through plugging by solids, bacterial deterioration, etc.

(a) To remove drill cuttings

As the bit penetrates the formation, the rock cuttings drilled must be removed; otherwise the drilling efficiency will decrease. In removing the drill cuttings there are three separate operations:

i)   Lifting the cuttings to surface while circulating

ii)   Suspension of cuttings while not circulating

iii)   Dropping out of cuttings on surface

The mud properties must be carefully engineered to fulfill these requirements. The lifting capacity depends on the annular velocity, density and viscosity, Suspension depends on a gelling thixotropic effect, which develops after circulation is stopped. Using mechanical devices such as shale shakers, desanders, and desilters achieve removing the solid material from the mud at surface. It is not economically feasible to remove all solids before recirculating the mud. However, the more effective the solids removal the less chemical treatment and dilution is subsequently required.

If drilling and circulation are interrupted, if this occurs there needs to be some mechanism of halting cutting settlement. The ability to suspend cuttings in this scenario is a function of gel strength and is a key property of drilling fluids. In air or gas drilling there will

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be no gelling and all cuttings will settle out if pumping is interrupted. Hence air is not normally considered a proper drilling fluid.

A drilling fluid will contain gel forming particles (clays) which, when allowed to settle, form a network mesh, or gel structure, which tends to "solidify" the fluid. This is termed a thixotrophic property and is reversible. Gel strength is a function of the fluid's reversible gel structure and is regarded as a static property of the fluid. It indicates the ability of a fluid to suspend cuttings and also the ease with which the gel can be broken. Gel strength generally increases with time from the break in circulation (Figure 2.2) (SITP, 2000).
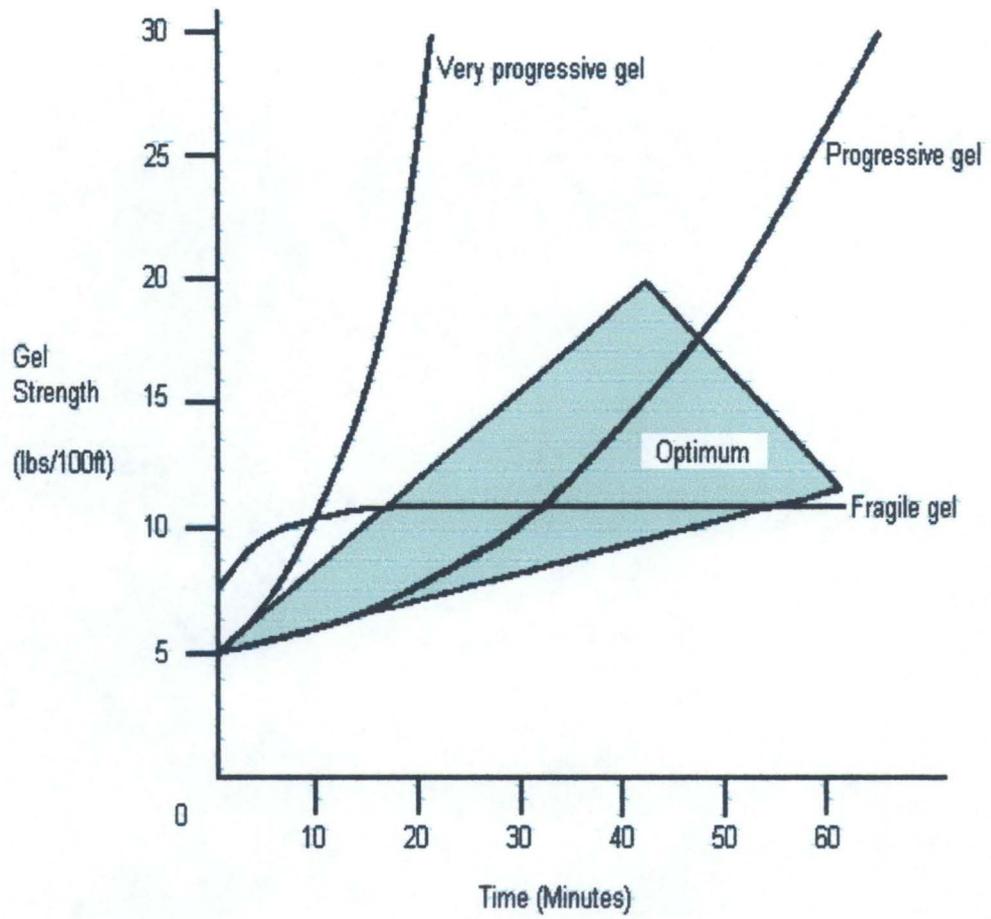
Figure 2.1: Illustration of time dependent of gel properties (SITP, 2000).

(b) Control formation pressures

The hydrostatic mud pressure must be sufficient to prevent an influx of formation fluids into the wellbore; the mud density is the controlling factor;

$$HP = 0.052 \times MW \times TVW \tag{1}$$

Where,

HP = Hydrostatic pressure (psi)

MW = Mud weight (ppg)

TVW = True vertical weight (ft)

By increasing the mud weight however increases the risk of formation breakdown and loss circulation, and the rate of penetration will decrease. The mud weight must be selected very carefully to meet specific requirements. Barite is added as a weighting material due to its high specific gravity (S.G. = 4.2) (SITP, 2000).

Permeable formations contain fluids that may be under considerable pressure due to the overburden and matrix stress caused by tectonic forces. A major function of the drilling fluid is to impose level of control over the formation. Control of these pressures, and hence influx of formation fluids to the wellbore, must be maintained through the hydrostatic pressure of the fluid column. Measures of control vary, they may be in overbalance, balance or underbalanced, the important point being that the level of control is known. Mud density must always be monitored during drilling for this reason.

The flow properties are also important in terms of bottom hole circulating pressure or equivalent circulating density (ECD). The pressure applied to the formation during circulation is greater than pure hydrostatic pressure of the fluid column due to annular frictional losses. The imposed control pressure must not exceed the formation fracture pressure.

Failure to control formation pressure will lead to a kick or uncontrolled influx of formation fluid into the wellbore, which will in turn lead to a blowout if control is not regained. Drilling deals with potentially dangerous systems but also have the equipment to deal with them. Blow out preventers are always used. However, in a worst case scenario, blowouts can occur within the rock itself if formation fluids find their way into other layers of rock and eventually to the surface. Gas can easily permeate through cracks and fissures. This can result in fracturing within the rock (termed an underground blowout). Apart from the fire risk, if this occurs offshore, the quantity of gas can lower the density of the seawater sufficiently to sink a drilling rig.

(c) Maintain wellbore stability

The drilling fluid should deposit a filter cake on the wall of the borehole to consolidate the formation and to prevent formation damage. The filter cake is formed by the hydrostatic pressure forcing the liquid part of the mud filtrate into the formation, leaving some solid material on the side of the borehole. A good filter cake must be thin, slick and impermeable. In a permeable zone (e.g. sand), the fluid loss must be controlled, otherwise;

i)   The filter cake will become so thick that it may cause stuck pipe.

ii)   Filtrate entering productive zones may cause damage, which will reduce the formation's productivity.

(d) Cool and lubricate the bit

The combined effects of weight and speed of rotation generate heat at the bit. Unless the bit is cooled it will overheat and quickly wear out. If the mud contains a lubricant such as oil the friction in the bearings will be reduced, this will also reduce the friction between the drill string and the borehole as the hole is being drilled. Not only will this prolong the service

life of the downhole equipment but it will also help to prevent drilling problems such as torque, drag and differential sticking.

By the very nature of rotating and pumping, temperature rises considerably downhole due to friction within the wellbore and at the bit. The drilling fluid absorbs much of this heat and conducts it to the surface. Lubrication of the wellbore is achieved through the filter cake deposit which can minimise the friction effect between the formation and drill string.

In addition, although not always the case, formation and fluid temperatures down hole normally increase with depth due to the natural geothermal gradient. This has become more of a concern in recent years as wells become deeper and as more high pressure - high temperature (HPHT) wells are drilled. High pressures and temperature may lead to more compacted and abrasive formations which are difficult to drill.

The use of specially formulated additives can reduce abrasivity and improve lubricity; these are very important considerations in both highly deviated and extended wells. A number of fluids are in the markets which alter the behaviour of salts and shales. Lubricity is analysed by the API extreme pressure tester

(e) Transmit hydraulic horsepower to bit

For efficient drilling, most of the power delivered by the pumps should be used at the bit. The hydraulic horsepower is transmitted by the drilling fluid and so mud properties such as plastic viscosity, yield point and mud weight are important, the high velocity created by pumping the mud through the bit nozzles provides the turbulence, which cleans the bottom of the hole.

(f) Isolation of Formation Fluids

In conventional overbalance drilling, the hydrostatic pressure of the drilling fluid is greater than the formation pressure. There is therefore a tendency for the drilling fluid to flow into the rock. Fluid losses to the formation must be controlled.

Typical drilling fluids contain solids and liquids, mainly clays and chemicals, which are used to control its properties. Initial fluid losses form a thin layer of filter cake on the walls of the wellbore as the solids do not pass into the rock. This cake minimises subsequent filtrate losses, stabilises the hole wall and protects the formation. Certain problems such as the plugging of pores in the formation or interstitial clay swelling may occur resulting in the need for secondary intervention once drilling is complete. Many formations however do respond well to secondary intervention so initial damage should be minimised. Proper design and control of the filter cake forming properties of the fluid is therefore important. These can be monitored using an API filter press.

Total loss of drilling fluid can occur, termed lost circulation, if the formation is damaged, unstable, or if, for example, caverns are encountered. It is possible to encounter 'thief zones' where fluid loss constantly occurs.

Apart from formation damage, another consequence of fluid loss is differential sticking of the drill string. This occurs when the pipe becomes embedded in the filter cake opposite a permeable zone and is held in place by the over balance within the wellbore. Low water loss muds that form hard, thin, impermeable filter cakes will minimise this problem, whilst oil based muds can virtually eliminate it in many cases.

For underbalanced drilling there is no drilling fluid loss to the formation as hydrostatic pressure is less than formation pressure.

(g) Fluid Displacement Efficiency

Fluid displacement efficiency especially with respect to cement-mud displacement has been found to be a function of factors which are largely dependent to the velocity profile generated. The factors include:

- Fluids density difference;
- Fluid rheological properties;

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- Wellbore geometry especially pipe eccentricity;

- Flow rate;

- Flow regime.

For effective displacement, a flat velocity profile is required either through laminar or turbulent flow. In many instances, laminar plug flow may be preferred as turbulence may create a potential intermixing of cement/mud resulting in potential contamination.

It is illogical to assume that pumping at high rate to achieve turbulence would result in better displacement efficiency and efficient cement-casing-formation bonding. Every instance must be analysed on its merit. One industry reason for pumping in turbulence is the potential for cake erosion. This may not be achievable and could create unwarranted wellbore instability due to high equivalent circulation density (SITP, 2000).

In order to design and maintain a mud to perform a given function, it is necessary to measure the mud properties which control its ability to perform that function. For this reason, measurements are normally made on a variety of mud properties.

Considerable research has been done on how to design, test and correlate these properties with the functions of a mud (James, 1997). Normally, the functions of a mud are carried out in down hole under conditions not easily duplicated in a mud test. Over the years, attempts have been made to either simulate more closely the downhole conditions or to predict the down hole mud properties from surface condition measurements. Measurements of both physical and compositional properties are made in a complete mud check. Some functions are controlled directly by the mud composition, but even those which are correlated with physical properties are controlled by adjusting the mud composition. Since we normally have a multifunctional requirement for a drilling fluid, we need an extensive series of both physical and compositional tests in order to properly monitor a mud system. Properties

should be measured on the mud going in at the suction and on the same mud coming out at the flow line.

In order to effectively control the properties of a mud, we need to know how specific changes in mud composition will affect the properties. There are normally a number of ways that a mud property can be adjusted to a given value. However, we are usually faced with maintaining several properties within acceptable limits. This means that there is one best way to adjust a mud property and still maintain control of the other properties. In order to accomplish this, we must understand the interrelationship between mud composition and mud properties. The liquid and solids content of a mud form the foundation which ultimately determines the performance of the mud. Chemical treatment should be thought of as a means of making small or selective adjustments in mud properties and not as the primary controlling component of a mud. The primary source of controlling the rheological and filtration properties is the control of the amount and type of solids in the fluid. The importance of controlling the solids in a mud cannot be over stressed. This is the basis of all mud treatment, because it is worth to note that presence of undesirable solids in mud increase drilling costs. They cause reduction in penetration rate, promote lost circulation and differential pressure sticking, and cause high mud costs due to treatment and dilution to maintain necessary mud properties.

The normal mud cost for drilling a well is linked very closely to the solids control practice used. In general, the aim is to minimize plastic viscosity for increased penetration rate, provide sufficient yield point or effective annular viscosity to clean the hole without causing unnecessarily high circulating pressures, and provide sufficient gel strength to suspend barite and cuttings. To fulfill these requirements, it is necessary to adjust the flow properties of a mud to handle each situation that is encountered. It is obvious that ideal mud properties for one problem may increase the severity of another. For this reason, there is no

standard recipe for an ideal mud composition. For all except a few special situations, barite and bentonite are the only solids needed to provide the density, viscosity , and fluid loss control requirements of a mud. Formation solids that enter the system from the drilling process provide no function that could not be better satisfied by addition of barite, bentonite, and bentonite/polymer. As a result, elimination of drilled solids is a primary concern. The solids in a mud can be roughly divided into two types, inert and active.

The inert solids are those that have very little tendency to react with each other or to a change in environment. These are non swelling solids which are essentially electrically uncharged and easily dispersed. They consist of such materials as sand, silt, limestone, feldspar, and barite. With the exception of barite, these solids are undesirable in a mud. They increase the plastic viscosity and crowd the system so that more desirable solids cannot be added. They do little to reduce fluid loss and actually cause the filter cake to be thicker. Since they are not hydrated, they cause the filter cake to be dry and brittle with a high coefficient of friction. These are poor qualities to prevent differential pressure sticking (Bleier *et al.,* 1991). As the total volume of solids in suspension is increased, the mechanical resistance to flow is increased. This causes an increase in the plastic viscosity. As the solids become crowded, the plastic viscosity increases quite rapidly. The difference in plastic viscosities between muds containing no drilled solids and 10 percent drilled solids is shown in **Figure 2.3**. This curve assumes completely inert drilled solids. If the drilled solids hydrate and increase in volume, the plastic viscosities will be even greater. This shows the need for maintaining low solids content in a mud.

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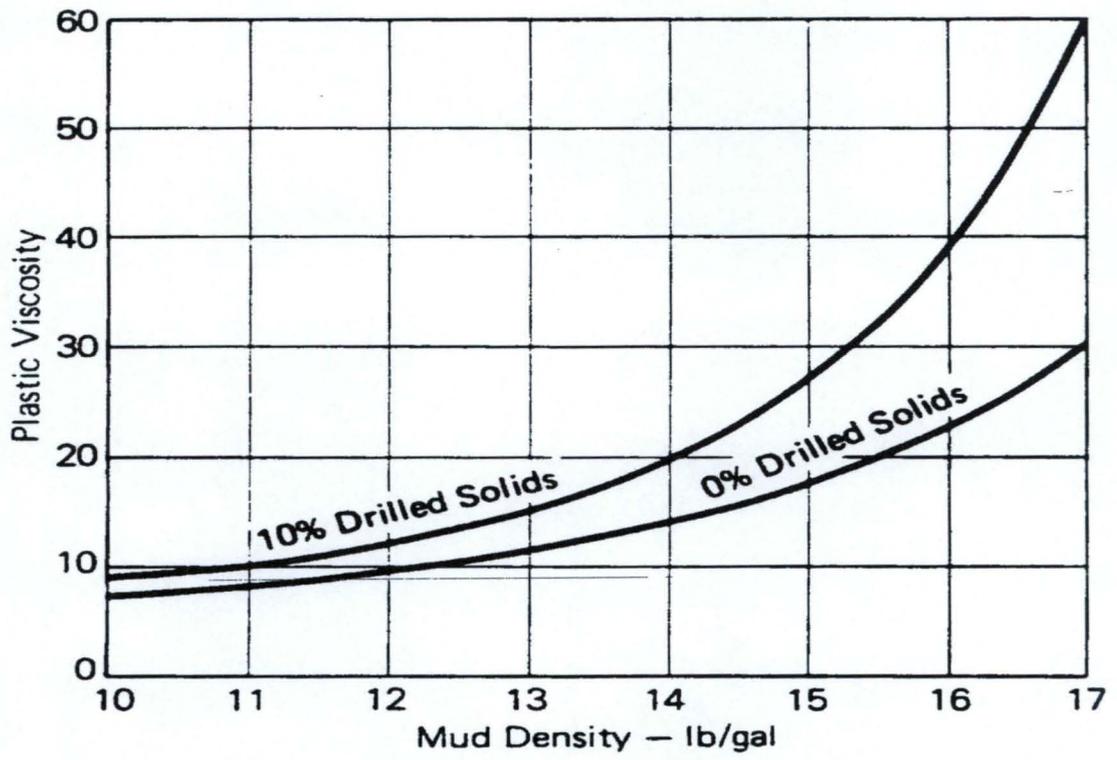
Figure 2.2: Effect of inert drilled solids on plastic viscosity.

2.5 Types of Drilling Fluid.

Drilling fluids may be broadly classified as liquid or gases, although pure gas or gas-liquid mixtures are used, they are not as common as the liquid based systems. For the purpose of this research work we will restrict our discussion to the three main types of mud used, namely, **water based muds**, **oil based muds** and **synthetic based muds** (Bleier *et al.,* 1990).

Figure2.3: A typical Drilling Mud

2.5.1 Water Based Mud:

From Fresh Water to Mud

Fresh water is one of the oldest muds and is generally used with very few additives. The term 'mud' is thought to have been first used when fresh water and surface soil were mixed to develop viscosity properties. Fresh water is often the base for water based muds.

Water based muds are now complex mixtures of solids, liquids and chemicals. There are active solids like bentonite which acts mainly as the dispersed phase providing the main gel structure. Active and inactive additives can be added in various proportions to control the fluid properties. For example,

- Barite is used to increase mud weight; this is an inactive solid;

- Carboxyl-methyl-Cellulose (CMC) a polymer is used to control fluid loss. This is an active additive;

- Lignites can be used to control mud viscosity. This is an active additive;

- Nut plug, byrofibre and Mica, are all loss control materials (LCM) used to prevent and control the total loss of whole mud into the formation. They are inactive.

The chemical additives very often provide the generic names for the different water based muds. Examples are given below:

Inhibited Muds

Inhibited muds are used to minimise formation hydration problems. Added chemicals are used to slow the rate at which water hydrates formation clays or sensitive shales. Hydration causes clays to swell, thereby reducing the structural integrity of the wellbore. This can lead to hole size reduction, sloughing or collapse of the wellbore and increased drilling fluid solid content.

Inhibition can be instigated through the use of calcium hydroxide for example in lime muds, calcium sulphate in gypsum muds or through high concentrations of various salts such as potassium or sodium chlorides.

Sea water muds are commonly used in offshore due to economic reasons. Since sea water contains sodium chloride it naturally inhibits clay hydration. Potassium chloride (KCl) / polymer mud is often used to control water sensitive sloughing shales as the potassium ion is small and readily 'plugs' into the clay lattice.

Alkalinities of inhibited muds are very important and must be monitored closely for the clays and dispersant chemicals to behave in the required manner.

Highly suitable for drilling are formations containing gypsum and hydrites as well as dirty sands (sands with high clay content).

Lignosulphonate (Dispersed) Muds

Dispersed muds such as lignosulphonate mud, contain chemicals that cause the clay platelets to separate within the liquid phase. Dispersed muds tend to have better viscosity control, higher solids' tolerance and better filtration control than non-dispersed systems and are used for drilling high activity clays. Such muds can be made up of water, bentonite, caustic soda, CMC polymer and lignosulphonate. They are suitable for use when:

- High mud weight is needed > 14ppg;
- drilling under moderately high temperature;
- High contamination is expected;
- Low fluid loss is required.

KCl/Polymer (Non Dispersed) Muds

Non dispersed muds normally contain minimal quantities of bentonite and other solids, and no dispersants. Polymers are often used to enhance bentonite properties and to flocculate drilled solids. Close monitoring of solids, alkalinity and bentonite levels is

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important. It's used to drill water sensitive, sloughing shales. Typical compositions can be as follows: Water or brine; potassium chloride; Caustic soda; CMC; Lubricants; bentonite and possibly HEC.

Flocculated Muds

In flocculated muds strong attraction between clay particles causes the platelets to arrange themselves in an edge to face or end to end arrangement. This clay structure is associated with high filtration, viscosity and gel strength. Undesirable flocculation can occur due to mud contaminants. In this case chemicals are added to reduce the edge to face attraction and return the clay to a dispersed or aggregated state.

Salt Saturated Muds, or Brines

These are brine based fluids in which the continuous phase is either, sodium chloride, calcium chloride, calcium bromide, zinc or bromide, etc. and are generally used in situations where high densities and viscosities are not required. They are used extensively in work over and completion activities where a low solids' concentration is desirable. Potassium chloride brine is particularly effective in inhibiting formation hydration. Brines are good for drilling through salt sections where fresh water mud contamination is a major threat.

2.5.2 Oil Based Mud:

These are similar in composition to water based muds except that the continuous phase is oil. There are three types of such muds namely:

- Pure oil based mud;

- Regular emulsion, or water-in-oil – emulsions with oil as continuous phase and water (generally < 5%) as dispersed phase;

• Invert emulsion, or oil-in-water – emulsions with water (generally > 5%) as continuous phase and oil as dispersed phase, generally, water will be contained as a non–continuous phase within the oil. In the case of invert muds, emulsifiers are required to form an oil film

around the water droplets. Water in an invert system helps in filtration control, baryte support, contributes to viscosity and gel strengths and also allows many chemicals to dissolve. Small amounts of extra water may however drastically alter the emulsion and hence change the overall mud properties.

These muds are generally more expensive and require more stringent pollution control than water based muds. Their use is generally restricted to conditions where water based muds are dangerous, technically impossible or uneconomical to use.

These include high pressure and high pressure applications as well as conditions where the formation such as shale, is highly sensitive to water based muds. It is important in the latter case to maintain salinity within the oil above that of the formation. They are particularly popular for drilling advanced wells such as extended reach wells, multilateral and horizontal wells. Sodium silicate muds for example are used for high pressure high temperature (HPHT) reactive shales.

A typical composition can be:

- Diesel as base oil;

- Calcium or sodium chloride;

- Water in dispersed phase;

- Bentonite;

- Typical additives;

- LCM;

- Barytes, etc.

2.5.3 Synthetic Based Mud (SBM):

Diesel oil was originally used as the base for OBM. Because of the environmental effect of oil based muds however, many drilled cuttings have to be processed to clean out the oil before dumping to meet control regulations. This makes its use rather expensive. To

reduce cost and minimise pollution, much more highly refined or synthetic oils are now being developed and used to make what are generally termed synthetic based muds (SBMs). The SBMs are classified according to molecular structure of the synthetic base fluids which can be esters, ethers, etc. They have drilling and operational properties similar to OBMs but have the advantage of being more 'environmentally friendly'. Cuttings from wells using synthetic oils can still be dumped at sea as long as restrictions are followed.

Likewise, so-called pseudo oil based muds are also being developed which are mainly water based systems but possess the merits of oil based muds especially in terms of stability at high temperature and high pressure.
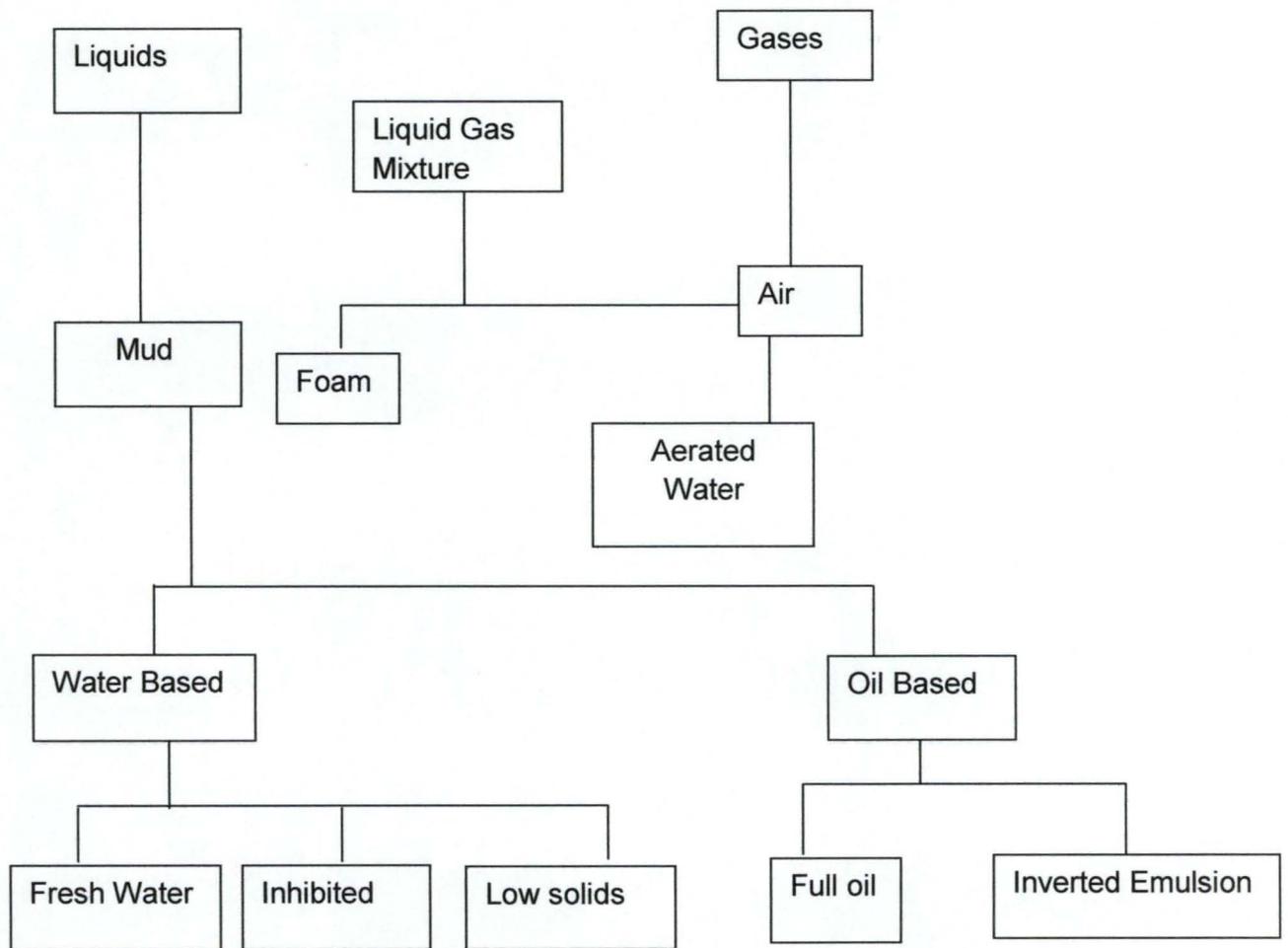
Figure 2.4: Classification of Drilling Fluids.

2.6 Characterization of Water Based Mud.

In order to design and maintain a mud to perform a given function, it is necessary to measure the mud properties which control its ability to perform that function. For this reason, measurements are normally made on a variety of mud properties. Considerable research has been done to design, test and to correlate these tests with the functions of a mud. Over the years, attempts have been made to either simulate more closely the downhole conditions or to predict the downhole mud properties from surface condition measurements. Measurements of both physical and compositional properties are made in a complete mud check. Some functions are controlled directly by the mud composition, but even those which we correlate with physical properties are controlled by adjusting the mud composition. Since we normally have a multifunctional requirement for a drilling fluid, we need an extensive series of both physical and compositional tests in order to properly monitor a mud system. Properties should be measured on the mud going in at the suction and on the same mud coming out at the flow line (Rogers, 1980).

Drilling mud has four basic properties that determine the behavior of mud as a drilling fluid; density, gel strength, filtration and viscosity. Several other properties exist but mostly are dependent on the above mentioned properties above (Rogers, 1980).

2.6.1 Density

The starting point of pressure control is the control of mud density. The weight of a column of mud in the hole is necessary to balance formation pressure is the reference point from which all pressure control calculations are based. The required weight of the mud column establishes the density of the mud for any specific case. Fortunately, density is one of our most accurate measurements. With a simple mud balance it is possible to weigh a mud to the nearest 0.1 lb. / gal, which is equivalent to 5.2 psi per 1000 feets of mud column.

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Density which is defined as weight per unit volume of the drilling mud is commonly reported as kilograms per cubic metre (kg/m^3) as well as pounds per gallon (lb/gal) or pounds per cubic foot (lb/ft^3).

A mud balance is used for measurement of density. This device is easy to use on site as well as in the lab. Configurations vary but all models consist of a container on one side of fixed volume, a fulcrum with spirit level and a sliding weight scale on the other side. Care must be taken when using the balance. The container must be cleaned before use, in order to gain an accurate reading.

The density of any drilling fluid is directly related to the amount and average specific gravity of the solids in the system. The control of density is important in that the hydrostatic pressure exerted by the column of fluid is required to contain formation pressure and aid in keeping the hole open. Degradation of additives affects the density.

2.6.2 Rheological Properties.

Rheological is concerned with the deformation of all forms of matter. The rheologist is interested primarily in the relationship between flow pressure and flow rate, and in the influence thereon of the flow characteristics of the fluid. In essence it deals with the study of the stress-strain true relationship of fluid or any matter.

There are 3 important parameters associated with the rheology of drilling fluid.

1. Viscosity: (a) Apparent

     (b) Plastic

2. Yield point or yield stress

3. Gel strength.

Two of the most important physical properties of drilling fluids are viscosity & gel strength proper control of these properties are essentials for some of the functions earlier stated of drilling fluids.

Viscosity

The viscosity of a fluid is defined as its resistance to flow. A more accurate description is that viscosity is the relationship between the shear stress to shear rate and generally it is used to describe drilling fluid in motion. The appearance (or apparent viscosity) of a high viscosity fluid is sometimes described as "thick" and that of low viscosity as "thin".

The desired viscosity for a particular drilling operation is influenced by several factors, including mud density, hole size, pumping rate, drilling rate, pressure system and requirements, and hole problems. The indicated viscosity as obtained by any instrument is valid only for that rate of shear and will differ to some degree when measured at a different rate of shear.

Two tools are generally used to evaluate these properties:

• Marsh funnel;

• Multi speed viscometer/viscosity-gel (vg) meter/rheometer.

The Marsh funnel test measures the time taken for a fixed volume of fluid to flow through a standard tube section. The applicability of the test is limited as it measures viscosity at one shear rate only. However, due to the simplistic nature and ease with which it can be carried out on site, the Marsh funnel test remains the most useful tool for detection and measurement of change.

A viscometer is used to provide a more detailed analysis of the fluid's viscosity profile. The unit consists of an outer rotating sleeve and an inner bob. Rotation of the sleeve is controlled to evaluate different shear rates. Shear stress is measured by the deflection of a dial attached to the bob which is held in place by a spring of known resistance. The viscometer

give a visual representation of the viscosity profile. This profile can be compared to that required by the drilling programme.

Commonly, readings are only taken at 300rpm and 600rpm. This allows a quick rheological calculation but does necessarily give a good correlation for what can be a very complex fluid system. Much more meaningful information as to which rheological model most closely describes the fluid, and hence its overall behavioural characteristics, can be gained by using a multi-speed viscometer such as Baroid's Fann system. Fann 35 is used for most scenarios whilst Fann 70 is used for HP-HT analysis and can measure under conditions of 20,000psi and 400 °F. Fann 35 has several forms; the most common are 6 and 12 speeds. The 12 speed test gives a much better indication of properties at lower shear rates (Table 2.1).

Table 2.1. Fann 35 Measurement Speeds

6 speed	12 speed
600, 300, 200, 100, 6, 3 (rpm)	600, 300, 200, 180, 100, 90, 60, 30, 6, 3, 1.8 and 0.8 (rpm)

The Plastic Viscosity and Yield Point are calculated from the 600-rpm and 300-rpm dial readings as follows:

$$PV, cP = \frac{600\text{-rpm}}{\text{Dial reading}} - \frac{300\text{-rpm}}{\text{dial reading}} \qquad (2)$$

$$YP, lb/100ft^2 = \frac{300\text{-rpm}}{\text{Dial reading}} - \frac{\text{Plastic}}{\text{Viscosity}} \qquad (3)$$

can be used to measure plastic viscosity and yield point. On site, readings can be plotted to

APPARENT VISCOSITY: This is the effective viscosity at 600 rotations per minute (rpm) divide by 2

PLASTIC VISCOSITY: It is a measure of the internal resistance to fluid flow, expressed in centipoises; it's an indicative of the concentration, shape and size of solids in the fluid yield point or yield stress:

YIELD POINT OR STRESS; It is a measure of the resistance to initial flow or the stress required to start fluid movement. It is measured under flowing conditions. The resistance is due to electrical charges located on or near the surface of solid particles.

If a change in viscosity is noted during drilling, perhaps through the Marsh funnel test, the specific region of variation can easily be identified and remedial measures taken. The mud engineer can test any new formulations prior to bulk alteration of the fluid.

2.6.3 Gel strength (10-sec/10-min)

The Rheometer is used to determine the Gel strength, in lb/100 sq. ft., of a mud. The Gel strength is a function of the inter-particle forces. An initial 10-second gel and a 10-minute gel strength measurement give an indication of the amount of gellation that will occur after circulation ceased and the mud remains static. The more the mud gels during shutdown periods, the more pump pressure will be required to initiate circulation again.

Most drilling muds are either colloids or emulsions which behave as plastic or non-Newtonian fluids. The flow characteristics of these differ from those of Newtonian fluids (i.e. water, light oils, etc.) in that their viscosity is not constant but varied with the rate of shear, therefore the viscosity of plastic fluid will depend on the rate of shear at which the measurements were taken.

2.6.4 Filtration

Evaluation of the filtration and filter cake properties of the drilling fluid is carried out using a filter press. A filter press consists mainly of a cylindrical mud cell with a means of applying pressure at the top and a drain tube at the bottom with a filter paper holder just above. Below this apparatus sits a graduated cylinder. Pressure is normally applied hydraulically or pneumatically. Different arrangements of equipment are available for atmospheric or HPHT environments. The drilling fluid is normally pressurized for 30 minutes. Examination of the filter paper will give an indication as to the physical filter cake properties and thickness, whilst the volume of fluid in the graduated cylinder gives an indication of the fluid loss characteristics.

2.6.5 Liquids and Solid contents.

A retort kit is used to determine the volumes of solid and liquid in the drilling fluid. (Figure 3.6) The fluid is placed in a sealed steel container and heated until the liquid components have completely vapourised. The vapours are condensed in a graduated cylinder whilst both dissolved and suspended solids will remain in the retort.

2.6.6 Sand Content.

Periodic sand content determination of drilling mud is desirable, because excessive sand may result in the deposition of a thick filter cake on the wall of the hole, or may settle in the hole about the tools when circulation is stopped, thus interfering with successful operation of drilling tools or setting of casting. High sand content also may cause excessive abrasion of pump parts and pipe connections.

The sand content of a mud is classed as the volume percent of particles larger than 74 microns. A fixed volume of mud is diluted and shaken in a graduated tube, before being

poured over a 200 mesh sieve. The remaining sand on the sieve is then rinsed and washed back into the graduated tube for a direct reading.

2.7 Drilling Fluid Design.

The design of drilling fluids for optimum results involves the specification of the type of drilling fluid to be used, the specification of fluid density and the desired rheological properties.

Type of Drilling Fluids to Use

This depends largely on the type of formation to be drilled and the expected downhole operating conditions including the potential hazards to be encountered. These will invariably dictate the actual type and composition of the fluid in terms of chemical additives to be used.

Specification of fluid density

One of the primary functions of the drilling fluid is the control of formation through the imposition of hydrostatic pressure on the formation. Thus, the mud must be of sufficient density to meet this basic function. Therefore:

$$0.052 \text{ X } P_M \text{ x } D = P_R + P_{OB} \qquad (4)$$

$$P_M = \text{fluid density}$$

$$P_R = \text{reservoir or pore pressure}$$

$$P_{OB} = \text{overbalance}$$

Usually, a P_{OB} of 200psi is sufficient, but it could be as high as 500psi depending on conditions.

It is important that the imposed pressure must not be more than the maximum allowable pressure which must be a factor less than the formation breakdown pressure. From the above, the mud density required can be computed as follows:

$$P_m = \frac{P_R + P_{OB}}{0.052 \times D} \qquad (5)$$

The main rheological properties are apparent viscosity, Plastic viscosity, gel strength, yield, n and k. The drilling mud must have good suspension and carrying capacities. Therefore optimum combination of these properties is required. These properties are adjustable to suit specific requirements whereas the mud density is largely dependent on the formation pore pressure.

Other relevant properties are as specified in the sections above and can be adjusted to requirements.

High pressure and high temperature are known to have major effects on drilling fluids.

Temperature effects

Generally, water based drilling muds are known to be highly unstable in HP-HT wells with **viscosity** reducing with increase in temperature; barite sag and secondary reactions and breakdown of polymer systems have been known to occur.

Increase in temperature is also known to lead to a decrease in **mud weight** especially for oil-based muds with density at surface being lower at depth than at the surface. This no doubt will have major effect on the bottom hole circulation pressure as the equivalent density would be lower than expected which can result in a potential influx of formation fluid into the wellbore. The effect of **fluid loss** on the other hand is not well known except that the possibility of mud instability can lead to the presence of more and 'more' 'free water' which can result in higher filtrate loss. However, the reduced annular pressure may minimise this loss. Pressure does not appear to have any major effect on the fluid rheological properties but density has been known to decrease with increase in pressure. For oil based muds, temperature has been known to lead to a decrease in viscosity while pressure causes an increase in viscosity.

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Baryte sag, i.e., the settling of solids onto the lower side wall of a deviated hole or to the sump of a vertical hole. Potential avalanche of solids settling will lead to inconsistency with respect to mud weight. Attempting to viscosify the mud may lead to a higher equivalent mud density which may result in fractures and potential lost circulation problem.

Effect of pressure

Increase in pressure generally appears to have an increase in equivalent mud density with depth but probably to a lesser degree. Effect on rheology however is not well defined. While thermal expansion appears to affect the rheological properties, the mud compressibility does not seem to be affected by rheology. However at low shear rate, some mixed effects have been observed with viscosity increasing with increase in pressure. Thus, adequate correction for the fluid properties must be effected when drilling HP-HT wells.

Suggested control

1. To avoid HP-HT problems, it is essential to understand the response of the chosen mud to HP-HT. This includes prediction of down hole mud weight and rheology. This will guide the choice of fluid properties at surface and the mixing formula;

2. Efforts should be made to make the low shear rate rheology as high as possible to suit existing hole conditions;

3. Fluid properties must continuously be monitored and treatment by thinners should be avoided where possible to avoid potential hole problems;

4. Use of small / medium size range of weighting materials in small concentrations may help in minimising barite sag;

5. Excessive mud circulation at low flow rate should be avoided if possible and circulation bottoms-up at each predefined point to reduce heavy mud presence in the annulus should be encouraged;

6. Optimum hydraulics is crucial to a successful drilling of HP/HT wells to avoid problems.

Choice Factors

Some of the practical factors involved in choosing and developing the drilling mud for any well are:

- Formation type – if reactive shales are encountered that calls for the use an inhibitive mud.

- Temperature and pressure range – the stability of mud itself will be a function of these. For example, if the temperature is too high the mud may solidify.

- Rock strength – how much stress can be imposed? Brittle rock systems can be altered by using specific mud additives (surfactants).

- Formation evaluation technique – if a resistivity log is needed, for example, the mud readings must be in the background. If the mud is too resistive the change from a conductive salt containing water zone to a resistive hydrocarbon bearing zone could be masked.

- water source and quality – offshore, sea water is abundant but is the chemistry correct, onshore, consideration may be given to drilling a water well.

- Borehole problems – if lost circulation zones are encountered the mud must be able to accommodate LCM.

- Environmental considerations – this is now becoming an extremely important factor as legislation in many countries is extremely strict. It is almost impossible to use OBM in such areas as India, the Niger Delta, Holland, and the Faroese for example.

- Cost – the ideal solution may be prohibitively expensive so the mud recipe may have to be adapted.

2.8 Drilling Operation Economics.

To optimise drilling operations, we have to specify the yardstick by which performance is measured. The most relevant yardstick is cost per metre or foot drilled.

Overall cost must be looked at since individual cost can be misleading. The rig operating rate represents only a fraction of the overall cost, therefore a cheap rig day rate does not always coincide with a cheap well. Holes are drilled in the ground to provide information (in the form of cores or logs or test information), to provide production of oil and gas or to provide an injection point into a reservoir. These objectives of the well should never be forgotten during the drilling operation. To optimise drilling economics, we must achieve the objectives of the well as economically as possible. To do this, we must understand the cost allocations and proportions in drilling operations and use our technology to fine-tune these to reduce expenditure without affecting safety or efficiency (Bleier *et al.*, 1990).

Most service companies will be pleased to provide figures for drilling budgets and talking to them serves a secondary purpose of updating one's knowledge of the demand for certain services and any new deals or equipment that is available. The Time Depth Graph created for the Drilling Programme provides an estimate of the days to be spent on the well. By costing in the charges for these days, the budget begins to take form. It is difficult to fix charges such as coring on an exploration well with the limited knowledge available regarding formations to be drilled, so some assumptions must be made. Similarly for the testing programme and completion programme some assumptions must be made too (SITP, 2000).

To meet environmental regulations, drilling fluids must not pose a threat to personnel or the environment. The use of oil based muds presents the greatest problem. Their use is banned in some areas of the world with tight restrictions on the level of use and dumping of cuttings in others. It may be required for example to transport all cuttings to the shore for cleaning. Environmental pressures are increasing constantly and present new challenges in drilling fluid design. This of course leads to cost increases (SITP, 2000).

2.9 Polymer Chemistry

Polymer is a large molecule composed of relatively small molecules called monomers (8% units) bonded together. The molecular weight of polymers range from 10^4 - 10^7, a few thousands to several million molecular weight units. Polymers can have thousands of repeating units. The lower molecular weight polymers serve as Deflocculants; whereas, the high molecular weight molecules serve as viscosifiers and flocculants. The two major mechanisms for manufacturing polymers are condensation, which alters the makeup of the repeating units, and addition which utilizes the presence of a double bond in the reacting unit to form a long chain. The addition process will generally yield higher molecular weight polymers than will condensation. The condensation process produces a polymer in which the repeating units contain fewer atoms than the monomers from which they were formed. Frequently, water is formed as a by-product of the process. The process requires two or more compounds which react chemically and does not depend upon the presence of a double bond for propagation of the chain (SITP, 2000).

This mechanism is susceptible to interruption by impurities or any outside influence which would reduce the efficiency of the process.

Many commercially available polymers are not readily soluble in water. This is an undesirable property for drilling fluid chemicals. Fortunately, many of the polymers available have been chemically treated in order to make them water-soluble. The solubility of these polyelectrolytes will be affected by the chemical make-up of the drilling fluid, pH, salts and presence of divalent cations, etc.

2.9.1 Polymer Types

Each type of polymer has its own characteristics in terms of how it functions in a particular type of drilling fluid. Selection of the correct type of polymer is therefore critical to

good performance. Listed below are the general types of polymers commonly used in drilling fluid formulations (Mansour *et al.*, 2009).

Polyacrylate, Polyacrylamide, and Partially Hydrolyzed Polyacrylamide (PHPA)

Acrylonitrile is polymerized to form polyacrylonitrile which is then partially hydrolyzed to form acrylamide and acrylic acid groups along the polymer chain (**Figure 2.5**). These polymers are referred to as PHPA, (partially hydrolyzed polyacrylamide), and are used as clay extenders, flocculants, and encapsulating colloids.

$$n(CH_2 = CH) \longrightarrow \left[CH_2 - CH \right]_n \xrightarrow[\text{alkali}]{\text{Hydrolysis}}$$

$$\begin{array}{cc} | & | \\ CN & CN \end{array}$$

**Acrylonitrile
(Monomer)**

Polyacrylonitrile (Polymer)

PHPA Polymer
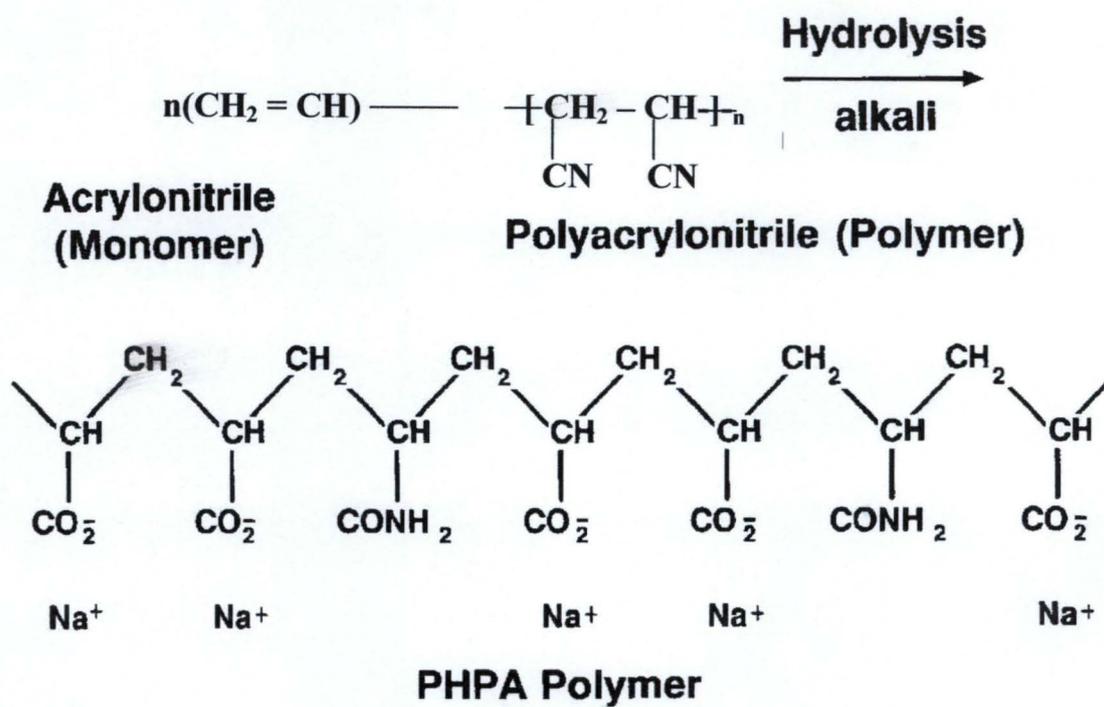
Figure 2.5: Structure of partially hydrolyzed polyacrylamide Polymer

Cellulose Derivatives

A number of different polymers exist which have cellulose as a base. They vary in: **(1)** degree of substitution (DS), **(2)** degree of polymerization (DP), **(3)** type of substitution, and **(4)** extent of purification (salt removal). Their properties and abilities can widely differ. The cellulose molecule is modified by reacting with an acid, then an oxidizing group, and then, an anionic radical is attached to the existing hydroxyl group (Ujma *et al.*, 1989).

- **Carboxymethyl Cellulose (CMC).**

When cellulose is reacted with sodium monochloroacetate, a sodium methylacetate group is substituted on one of the three hydroxyl groups (Figure **2.7**). The degree of substitution (DS) refers to the number of hydroxyl groups upon which substitution takes place divided by the number of repeating units in the molecule (**Figure 2.8**). The degree of substitution will range from zero to a maximum of three. Generally, CMCs will have a DS in the range of 0.4 to 0.8 with 0.45 being required for solubility. The degree of polymerization (DP) will range from 500 to 5000. The polymers with the greater DP will impart more viscosity to the fluid.

High DS on the other hand, will permit more tolerance to salts and cation contamination. Thermal degradation accelerates above 250°F.

- **Polyanionic Cellulose (PAC).**

Polyanionic cellulose is similar to CMC but generally has a DS of about 1.0. The PAC materials generally are more expensive than CMC due to higher processing costs, but show a greater tolerance to hardness and chlorides. PAC begins to thermally degrade at 250°F.

- **Hydroxyethylcellulose (HEC).**

HEC is formed by causticizing cellulose and reacting it with ethylene oxide which replaces one or more of the hydroxyl groups present on the cellulose molecule (**Figure 2.8**). Although HEC is nonionic, it is still water soluble due to the hydroxyl groups.

HEC imparts high viscosity to water or brines but exhibits no gel strengths. It is susceptible to degradation through shear or heat and has a maximum thermal stability of about 225°F.
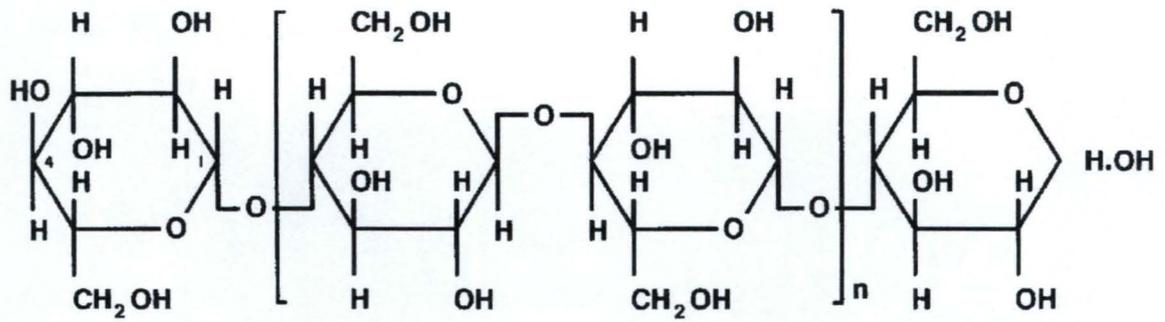
Figure 2.6: Cellulose Structure.

D.S. of 1.0
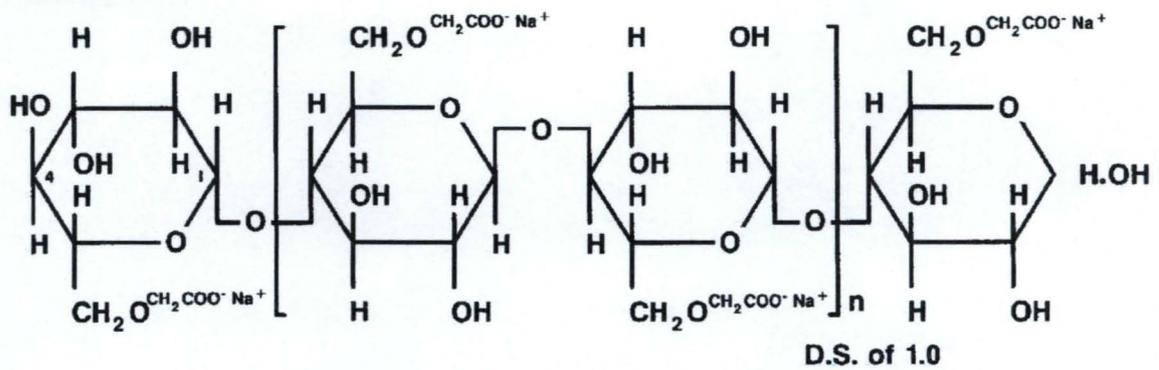
Figure 2.7: Carboxymethyl Cellulose structure.

Hydroxyethylcellulose
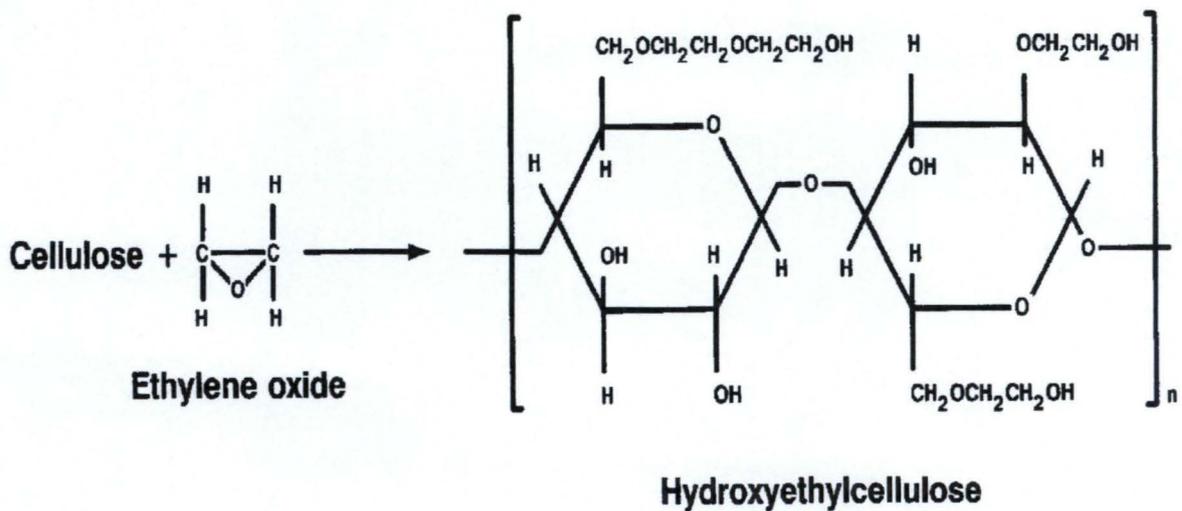
Figure 2.8: Hydroxyethylcellulose Structure.

2.9.2 Polymer Uses.

Some of the major uses of polymers in drilling fluids are:

• Viscosity

• Bentonite Extension

• Deflocculation

• Filtration Control

• Shale Stabilization

- **Viscosity**

These are high molecular weight polymers, usually branched, and water soluble. Viscosity is due to interactions between: (1) polymer molecules and water, (2) polymers themselves, and (3) polymers and solids.

- **Bentonite Extension**

The bentonite extenders work by cross-linking bentonite particles to increase the physical interaction between particles. There is a narrow band of concentrations which allow this cross-linking to occur, but above which a viscosity decrease may occur.

- **Flocculation**

Flocculants are high molecular weight, long chain, anionic molecules which bridge between individual solids causing them to form an aggregate. The aggregates will settle or centrifuge readily for removal.

It is possible to have either total or selective flocculation. Selective flocculation removes some of the drill solids.

- **Deflocculation**

Anionic polymers act as deflocculants by absorbing onto the edges of the clay particles and neutralizing existing charges. Polymer deflocculants are shorter molecules with a greater change in density. These characteristics facilitate adsorption onto the clay particle

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without causing cross-linking. These polymers are sensitive to divalent cations and are less effective when hardness exceeds about 400 mg/l.

- **Filtration Control**

Starches, CMCs, PACs, and hydrolyzed polyacrylates are effective filtration control agents. Filtration control may be provided due to a physical plugging action by the polymer or by viscosifying the liquid phase of the drilling fluid. Anionic polymers control filtration by viscosifying the water phase to restrict fluid flow through the filter cake. Nonionic materials such as the starches, some anionic materials such as PAC and CMC, work by hydrating and swelling and physically plugging pores in the filter cake.

- **Shale Stabilization**

Shale stabilization is provided through polymer attachment to the positively charged sites on the edge of clay particles in shales. This attachment minimizes water invasion into the clay particle and reduces hydration and dispersion. These polymers have been used with success in conjunction with salt and potassium-based muds for an added inhibition.

2.9.3 Filtration Control Additives.

In the oil industry, there is a wide spectrum of products used for filtration control. To lessen the confusion, only the broad classifications will be discussed, and the discussion will be limited to generic names. Their application depends on the type of mud being used and on the chemical and physical environments encountered.

- **Bentonites**

The primary fluid-loss control agents for water-based muds are clay-type solids. Since these solids are colloidal in nature, they provide viscosity as well as filtration control. The ability of bentonite to reduce filtration can be attributed to (Dairanieh *et al*, 1988).

• Small particle size

• Slat plate-like shape

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• Ability to hydrate and compress under pressure

Insufficient bentonite in a mud causes increased filtrate loss, particularly at increased temperature and pressure. Sodium montmorillonite clays are used mostly in freshwater mud systems; however, they are occasionally used in saltwater muds.

- **Lignins and Tannins**

These include sulfonated tannins, quebracho, lignosulfonates, lignites and lignite derivatives. The mechanisms by which they work is by thinning the clays (adsorbing on the positive edges of the clay platelets, which leads to repulsion among the platelets), plus plugging action of the particles themselves.

These additives improve the distribution of solids within the drilling fluid by deflocculating solids such as bentonite and through the colloidal nature of the chemical, skewing the particle size distribution to lower valves.

- **Starches**

Most starch products are used in salt and saturated saltwater environments. Most of the starches used in the domestic oil industry are made from corn or potatoes. The starch grains are separated from the vegetable and specially processed so that they will rapidly and efficiently swell and gelatinize to reduce filtration loss. The sponge-like pegs also fit into the tiny openings left in the filter cake and lower fluid loss by a plugging action. Biocide is recommended when bacterial degradation is a concern (Dairanieh *et al*, 1988).

- **Sodium Carboxymethyl Cellulose (SCMC)**

SCMC is an organic colloid used for filtration control. This material is available in several grades, each varying in viscosity and filtration control qualities. The three grades are commonly called high-viscosity SCMC, medium or regular-viscosity SCMC, and low-viscosity SCMC. The choice of SCMC depends upon the properties desired for the drilling fluid. When viscosity increase and filtration control are both desired, high or medium SCMC

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should be used. When no viscosity increase is needed and a decrease in filtrate loss is required, low-viscosity SCMC is adequate.

- **Polyanionic Cellulose (PAC)**

PAC materials are organic filtration control agents similar to SCMC, but generally of higher purity and quality. This material can be used in both freshwater and saltwater environments. PACs are generally more calcium tolerant than are the SCMCs.

- **Sodium Polyacrylates (SPA)**

SPAs are polymers that are available in various ranges of molecular weight and offer high temperature stability. SPAs of low molecular weight are deflocculants for clays and are used to improve fluid loss control by that mechanism. SPAs of very high molecular weight are effective for fluid loss control by increasing the viscosity of the filtrate and by plugging in the cake. They are sensitive to calcium ions, especially at high molecular weight. Derivatives of SPA which are less sensitive to ionic content are available as proprietary thinners and fluid loss additives.

2.10 Clay Chemistry

Clays are minerals which in the presence of water and agitation will absorb water and break up into colloidal-sized particles. Each particle is only a few microns in thickness and consists of two or more discrete layers. The degree to which the clays dissociate is governed by the clay type, exchangeable cations associated with the clay, and the electrolytic make-up of the water.

Clays are hydrous aluminum silicates composed of alternating layers of alumina and silica. Silica is a tetrahedral structure with a silicon atom surrounded by four oxygen atoms at equal distance from each other. The silica tetrahedrons are joined in a hexagonal structure which is replicated to form a sheet (**Figure 2.9**). The tips of all tetrahedrons point in the same directions and their bases are all the same plane (Grim, 1992).

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Alumina has an octahedral structure consisting of an aluminum atom with six oxygen atoms arranged in an octahedron around it. These aluminas octahedral are then joined in a structure which is replicated to form a sheet or layer. The structure is the same as the mineral gibbsite $[Al_2(OH)_6]$ (**Figure 2.10**).

These sheets of alumina and silica alternate to form the various clays. The clays we are most concerned with are either two-layer or three-layer clays. Most of the clays we encounter either as drill solids or as commercial clays have a platelike shape. The particles may be several microns wide, but only a few Angstroms thick. Since a micron (micrometer) is 1×10^{-6} m and an Angstrom (Å) is 1×10^{-10} m, a clay particle will be roughly 10,000 times wider than its thickness. It is this form, in the case of bentonite, which makes it beneficial in reducing filtrate loss (Grim, 1992).

The principal clays are:

• Kaolinites

• Illites

• Chlorites

• Smectites

• Attapulgite and Sepiolite

○ Oxygen
● Silicon
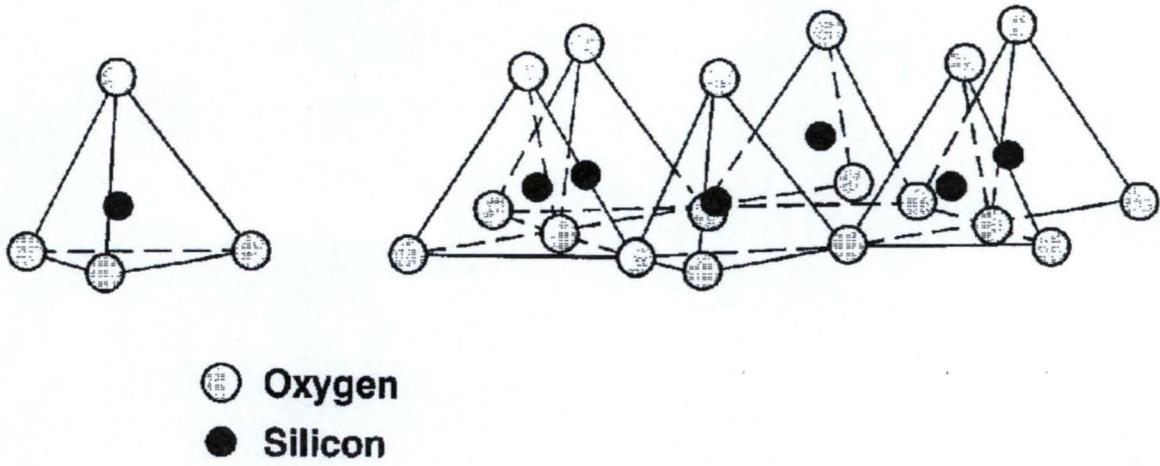
Figure 2.9: Clay Structure

● Hydroxyl Ion
○ Aluminum
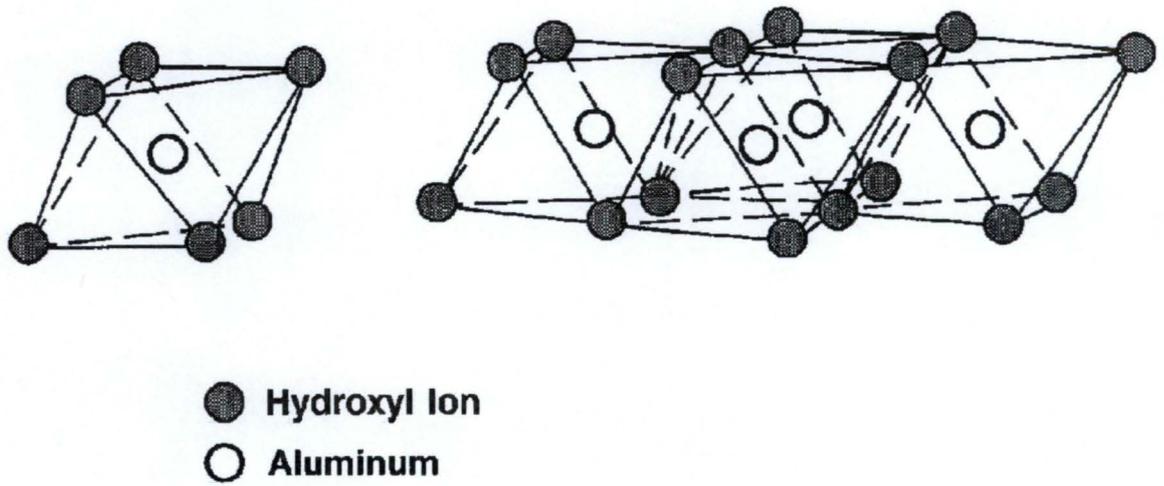
Figure 2.10: Alumina Structure showing Aluminium and Hydroxyl ion pairing

- **Kaolinites**

Kaolinites are two-layer clay composed of a tetrahedral silica sheet and an octahedral alumina sheet (**Figure 2.11**). The silica sheet is oriented so that the tips of the tetrahedral are in the same plane as the oxygen or hydroxyl groups on the alumina sheet. The kaolinite particles are held together by hydrogen bonding and the spacing between layers is about 2.76 Å. The hydrogen bonding is strong enough to exclude water from the clay surface; consequently, kaolinites are considered non-swelling clays.

The cation exchange capacity of Kaolinites is typically 3-15 mill equivalents (meq)/100 g.

- **Illites**

Illites are hydrous micas three layer clays which structurally resemble montmorillonites. Illites have no expanding lattice; therefore, no water can penetrate between the layers. They are composed of an alumina octahedral layer sandwiched by two silica tetrahedral layers (**Figure 2.12**). Some of the silicon atoms in the illite structure are replaced by aluminum atoms. The resulting charge discrepancy is balanced by the association of potassium ions between layers. In some illites the substitution of silicon by aluminum may be lower and the potassium may be replaced by divalent cations such as calcium or magnesium. In these cases the illites may exhibit swelling tendencies similar to montmorillonites. The cation exchange capacity of illites is 10-40 meq/100 g.

| ⊚ Oxygen | ⬤ Hydroxyl Ion |
| ● Silicon | ○ Aluminum |

Figure 2.11: Kaolites Structure
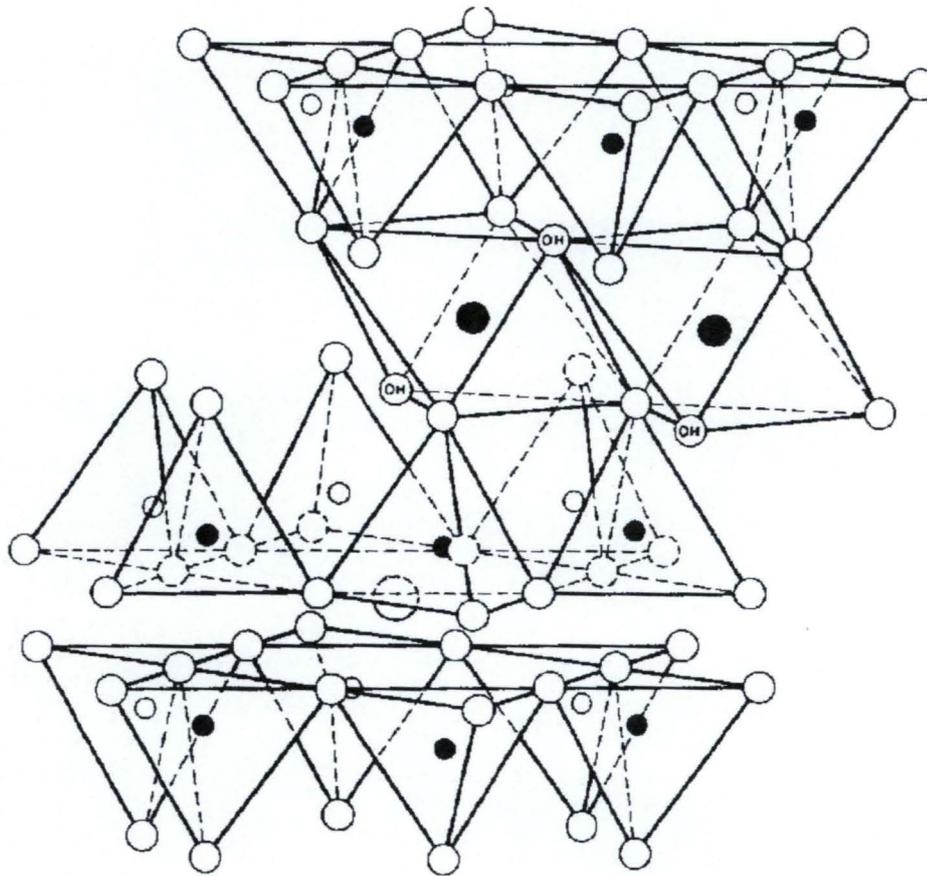
○ Oxygens, (OH) Hydroxyls, ● Aluminum, ○ Potassium
○ and ● Silicons (one fourth replaced by aluminums)

Figure 2.12: Illite Structure.

- **Chlorites**

Chlorites are three-layer clays separated by a layer of brucite (**Figure 2.13**). There is a strong bonding between layers and for this reason chlorite is a non-swelling clay. The cation exchange capacity for chlorites is 10-40 meq/100 g.

- **Smectites (Montmorillonites)**

Smectites are a family of three-layer clays of which montmorillonites are members. They consist of an alumina octahedral layer sandwiched between two silica tetrahedral layers (**Figure 2.14**).

The aluminum atoms in the central layer may be replaced by magnesium or iron atoms causing a charge imbalance. This imbalance is countered by the association of positive cations at the particle surface. These cations may be monovalent, sodium for example (**Figure 2.15**), or divalent such as calcium.
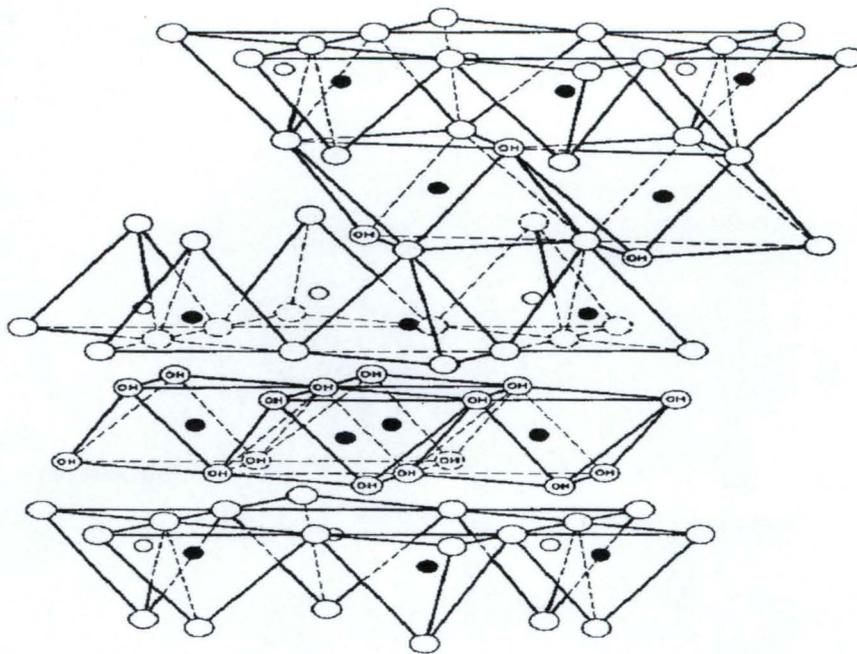
Figure 2.13: Chlorites Structure

Exchangeable Cations
n H₂O
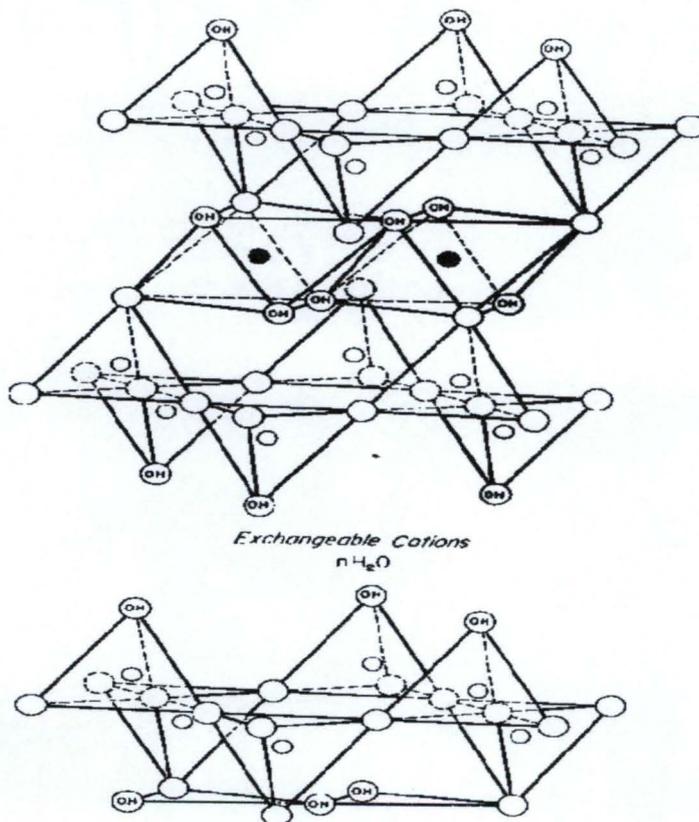
Figure 2.14: Smectites (Montmorillonites) Structure showing the exchangeable ions
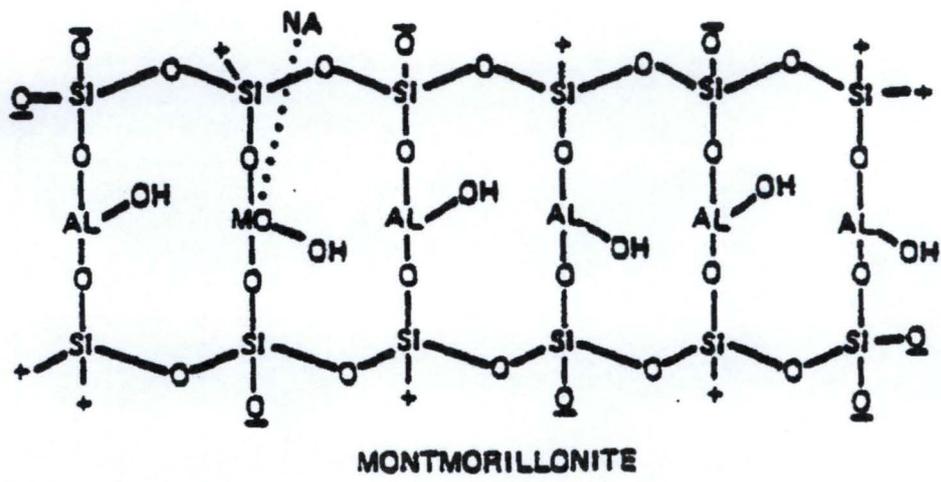
MONTMORILLONITE

Figure 2.15: Structure of Smectites

The character of the exchangeable cation influences the extent to which the montmorillonites will swell. The divalent cations, because of the extra charge, tend to associate with adjacent particles and consequently, restrict swelling of the clay. For this reason calcium montmorillonite is a poorer viscosifier than sodium montmorillonite. Due to their structure, the bonds between particles are weaker than other clays which add to the ability of the montmorillonite to hydrate. This is the principal reason sodium montmorillonite is the most common commercial clay. The cation exchange capacity for smectites is 60-150 meq/100g.

- **Attapulgite and Sepiolite**

Two other commercial clays, attapulgite and sepiolite, are used in special situations in which montmorillonite will not perform. These clays differ in structure from the more common clays in that they are elongated rod-shaped particles. Although there is water associated with these clays, they do not hydrate. These clays viscosify by shearing which causes fracturing along the axis of the rods and exposes charges which cause the rods to attract each other. Since these clays are shear dependent, they are as effective in saltwater as in freshwater. Sepiolite has the added advantage of being very temperature stable and because they yield through shearing, little or no viscosity increase will be seen in the pits since the shearing of the hopper and mixers is usually insufficient to cause the clay to yield. It may take several trips through the bit before maximum benefit is obtained from the clay. For this reason, it is easy to overtreat with these clays in an effort to raise the viscosity of the mud. These clays provide little filtration control because of their shape. It is usually necessary to add filtration control agents when using these clays.

2.10.1 Clay Properties.

Clays are too small to be seen by optical methods and require electron-beam microscopes for study of size and shape. In general, individual layered clays are from 7 to 21

Å thick, but 1000 to 100,000 Å in their width and length. (A 44 micron-325 mesh silt particle is 440,000 Å). Having this small size and relatively large surface area, gives layered clays (such as bentonites) unique behavior when they are dispersed into water. Being highly charged as well, their behavior is more pronounced in terms of clay-clay particle interactions. Surface area that can be created by clay dispersion is very large, about 200 m^2/g. The size and shape of clays allows them to be useful in building viscosity (when highly flocculated) or in building a tightly packed filter cake (when not dispersed or when deflocculated by a thinner) (Grim, 1992).

Polymer chains are extremely long when compared to clay particle dimensions. When high molecular weight (several million) polymer chains become linked with multitudes of clay particles in a water system, there is a combined effect that creates highly viscous, but shear-thinning, rheology.

- **Cation Exchange**

In the active clays, magnesium ions (Mg++) may be substituted into the octahedral matrix for aluminum ions (Al+++). This substitution leaves the clay particle with a net negative charge which must be balanced.

This balancing of charge takes place in the form of cations which are adsorbed onto the surface of the clay platelets. These cations are loosely associated with the clay and may be displaced or exchanged by other cations. The quantity of cations available for exchange is referred to as the cation exchange capacity and is reported in milliequivalents per 100 g of shale. The strength, or ability of cations to exchange, varies. A cation will tend to displace any of those to its right at equal molar concentration (Grim, 1992).

2.10.2 Commercial Bentonite.

Commercial bentonites used in drilling muds are naturally occurring clays and are mined in many areas of the world. They contain the clay mineral smectite and may contain accessory minerals such as quartz, mica, feldspar and calcite.

- **Drilling Fluid Bentonites**

Smectites are three-layer swelling clays of which the most predominant form is calcium, but sodium is also present. Smectites have the ability to swell (hydrate) in the presence of water, these bentonites are used to viscosify drilling fluids. Sodium bentonite, found exclusively in the northwestern part of the United States, is the most widely sought-after bentonite because its hydrational ability is considerably greater than that of calcium bentonite. Hence, the name "premium bentonite" is given to sodium bentonite. Because operational need for using bentonite varies around the globe, API established specifications to cover sodium and calcium bentonites (API, 1990).

API, 1990, currently there are three API bentonites available. They are listed in order of degree of chemical treatment (**beneficiation**):

• API Nontreated Bentonite (no treatment)

• API Bentonite (some treatment level)

• API OCMA Grade Bentonite (high treatment level)

Beneficiation is a process where chemicals are added to a low-quality clay to improve its performance. Soda ash is added for peptization (**Figure 2.16**) and polymers are added to improve rheology and filtration control. All of this is done to make the clay pass API viscosity specifications.

Bentonites that have been treated may exhibit poor performance in five respects:

1) Intolerance to hardness ions,

2) Incompatibility with other polymers in a mud,

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3) Low thermal stability,

4) Limited shelf life, and

5) Polymer structure breakdown as it passes through the bit.

For some drilling operations, API or OCMA bentonite may be economical and not create problems. However, based on the five items above, their performance in many of the mud systems currently in use can be unpredictable and increase bentonite consumption.
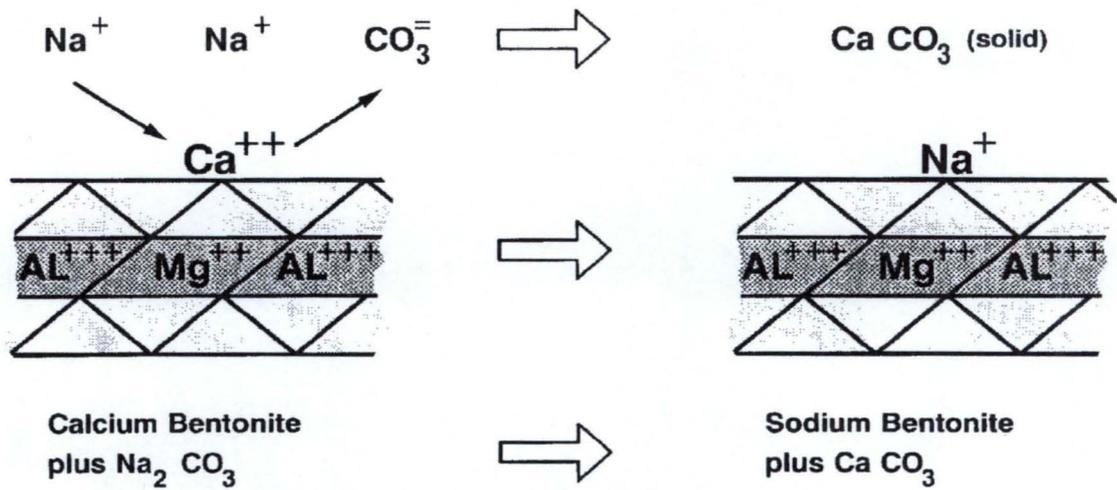
Figure 2.16: Beneficiation of Calcium Bentonite to Sodium Bentonite.

2.10.3 API Bentonites.

- **API Non-treated Bentonite**

API non-treated bentonite is a premium quality material without any chemical additives for beneficiation. Being premium clays, they bring a premium price; however, they can be cost effective in terms of predictable performance and lower usage.

- **API Bentonite**

API Bentonite is generally predominantly sodium bentonite; however, some degree of beneficiation is allowed under certain specifications for this material. The YP/PV ratio specification (3 maximum) limits this amount of beneficiation. Hence, API bentonite, under many conditions, performs similarly to the nontreated bentonite.

- **API OCMA Grade Bentonite**

API OCMA Grade Bentonite is predominantly a calcium bentonite and as such, cannot meet specifications of either of the other two API-grade bentonites. Even with less stringent performance requirements, OCMA grade bentonites require high levels of chemical treatment (beneficiation) which is reflected by the high YP/PV ratio (6 maximum) allowable. However, API OCMA grade bentonite is used in many areas where the drilling fluid will not encounter excessive temperature nor contamination, and where suspension and hole cleaning are the primary requirements.

The general constituents of drilling mud for laboratory analysis are illustrated below.

Bentonite   +   350ml +   Additives
Clay   water

In preparation of mud, there exist about three different standards used, which are based on the content of the clay in the mud; these include.

- 17.5g of clay for lower level

- 21. 5g of clay for medium level

- 24.0g of clay for higher level

The above classification also encompasses the properties of mud which include Viscosity and other rheological properties. The bentonite clay is the solid discontinuous phase of the drilling mud.

The additives which are usually added in lower concentrations and when needed include caustic soda for pH correction, barite for weight, polymers for increase viscosity and filtrations properties, lignite for high temperature-high pressure drilling operations and so on (API, 1990).

CHAPTER THREE

MATERIALS AND METHOD

This section gives the materials and equipment as well as the experimental procedures carried out in this work.

3.1 Materials and Equipment.

The materials and equipment used in the course of the study are presented in Tables 3.1 and 3.2, respectively.

Table 3.1 List of Materials used in the Experiment.

Materials	Source	Remarks
Bentonite clay (Aquagel)	NL Bariod	Laboratory Reagent
MTB Clay	Bosso Local Government	Local Clay
BSM Clay	Chanchaga Local Government	Local Clay
Sodium Carboxymethyl Cellulose (SCMC)	NL Baroid	Laboratory Reagent
Polyanionic cellulose (DRISPAC)	Drilling Specialties Co. NL Baroid	Laboratory Reagent
Hydroxyethyl Cellulose (HEC)	NL Baroid	Laboratory Reagent
Lignosulphonate (Q-Broxin)	Georgia Pacific Corp	Laboratory Reagent
Sodium Hydroxide (NaoH)	Park Scientific Ltd U.K	Laboratory Reagent

Table 3.2 List of Equipment used for the Experiment.

Materials	Source	Remarks
Multimixer and cup	NL Bariod	Mixing of the base fluid and the additives
Mud Balance	NL Baroid	Measuring mud density
Marsh Funnel and measuring cup	NL Baroid	Measuring marsh funnel viscosity
Viscometer (12 speed)	Ofite equipments Co.	Measuring: temperature, viscosities, & Gel strength
Sand Content Kit	NL Baroid.	Measuring sand content
Stop watch	NL Baroid	For timing
Liquids and solids content Retort Kit	NL Baroid	Measuring liquids and solids contents.
Beam balance	Denver Equipment Co. UK	Weighing of the mud
Measuring Cylinder	Moramber, U.K	Measuring water contents

3.2 Preparation of the Clay Samples.

Local clays specifically from Bosso Local Government and Chanchaga Local Government areas of Niger state, Nigeria were used for the experiment.

The bentonite clay were usually collected after excavation of the soil between 10-20 ft, because it is expected that the upper most part of the deposit will be mixed with sand and also erosion will have washed away some of the constituents which give it an edge over other clay.

For collection of the two samples in the two Local Governments, the same procedure was followed, that is, digging up to 10-12 ft before the clay samples were collected. The wet and large lumps of clay samples were collected and they were reduced to smaller sizes. The

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ground clay samples were sun dried for two days and were checked so as to ensure complete drying. With the aid of pestles and mortal, the clay samples were ground to 250-300 mesh size and sieved into seventy five (75) microns (200 mesh size) using a sieve shaker.

3.3 Preparation and Characterization of Local Clay.

In classification of the local clays used in this study, two physical processes were employed to classify the clay, either to be hydrated or non-hydrated clay.

The first process involves the mixing of 20g of each of the two clays with 100ml of water in a measuring cylinder. The clay and water level were noted and at interval of four (4) hours the levels of water and clay were checked. After sixteen (16) hours, the level of water and clay samples for the two local clays remain unchanged, this shows that the clay do not hydrate (absorb water).

Secondly during the above process, the settling capacity of the clay samples were determined in comparison with the bentonite clay. At the end of the sixteen (16) hours the whole local clay particles have settled leaving clear water on top. But for bentonite clay, the particles are suspended on the top of the clay solution. These simple experiments confirm the superiority of bentonite to the two local clays, in terms of their rheological properties, for example gel strength.

In preparation of drilling mud in the laboratory, a barrel of the mud was prepared and its characteristics based on its properties were analysed. One standard laboratory barrel of drilling mud according to American Petroleum Institute (API) is three hundred and fifty (350) ml of continuous phase was used. Because the project focused on the water-based drilling fluid, the continuous phase was water (freshwater).

3.4 Preparation of Drilling Mud Using Local Clay Samples.

The final clay obtained using the 75-micron size sieves for the two samples were weighed using the beam balance in the laboratory. The following steps were employed to produce different compositions of mud:

The first part involved the use of the two samples; BSM and MTB with ten different compositions of clay, sodium carboxymethyl cellulose (SCMC), with and without Q-Broxin (Lignosulphonate).

This section of the study involves preparation or formulations of drilling mud using all the three levels of clay composition as follows, 17.5 g, 21.0 g and 24.5 g, Caustic soda and sodium Polyanionic Cellulose (DRISPAC).

Lastly this section involves preparation of drilling mud using all the three level of clay composition as follows: 17.5 g, 21.0 g and 24.5 g, Caustic soda and Hydroxyethyl Cellulose (HEC).

In each case stated above, after the formulation of the drilling mud, the characterization of the mud, i.e. its properties are analyzed. The sequence of development and characterization are as follows:

3.4.1 Weighing of the Mud.

The equipment used in weighing the mud is a beam balance. It was calibrated by turning the knob at the left end of the balance until a balance was achieved. Petri dish was used in weighing the mud and it was placed on the beam balance and was weighed for the various weights of sizes of ranges 0.1 to 100 g. As a balanced beam was achieved, the clay was then measured as required. The weight was calculated as the weight of the Petri dish and the clay sample.
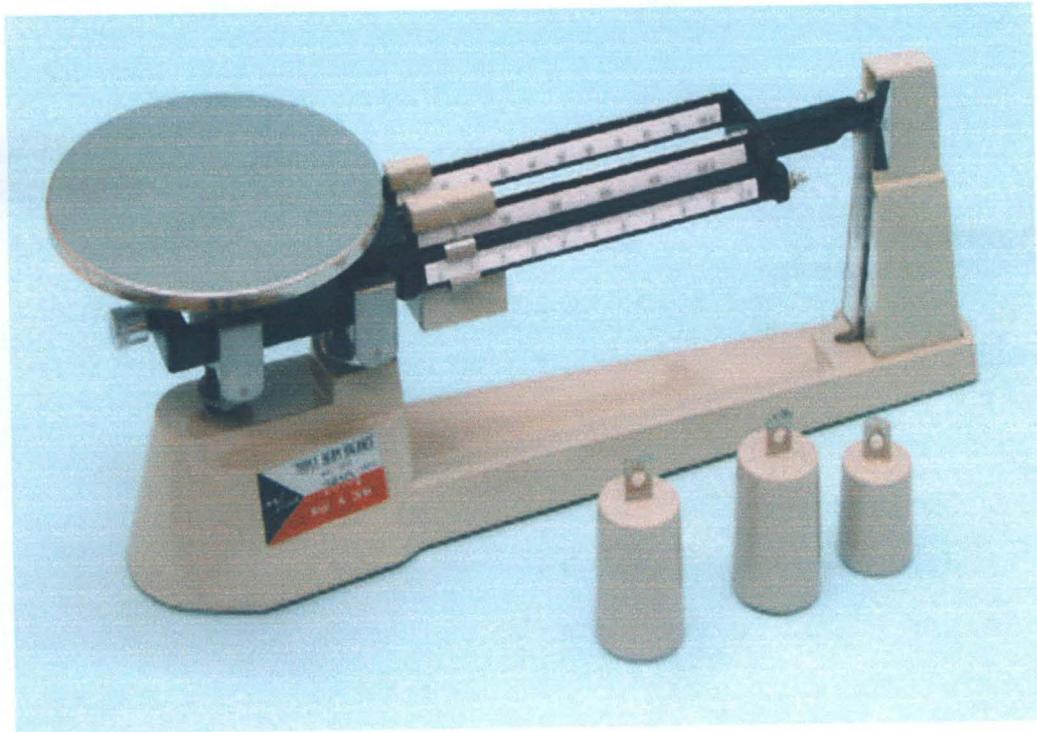
Figure 3.1 Beam Balance.

3.5 Laboratory Preparation of Mud.

Three hundred and fifty (350) ml of fresh water was measured and charged into a stirring cup. The stirring of the fresh water began with the Hamilton beach mixer and subsequently caustic soda was added and was stirred continuously for at least ten minutes until the pH rose to 9 and above. The clay was weighed as required.

In field measurement, preparations of a barrel of drilling mud involved one hundred and fifty nine (159) litres of water in 9.4 kg of bentonite clay was added to the stirring tank. The stirring of the water continued for another twenty (20) minutes and was interrupted for about three times as a means of ensuring that no clay adhered to the wall of the stirring cup. The addition of the clay was gradual and usually in small portions. The mud was allowed to age for at least sixteen (16) hours before being analysed. In some other cases of the experiment, there was need to add the additives which was either polymers and/or lignite before finally allowing the mud to stand for complete swelling of the clay for 16 hours.

3.6 Characterization of Drilling Mud.

After expiration of 16 hours, the properties of the mud were analysed and compared with the American Petroleum Institute (**API**) standards. In addition, a control or a standard was prepared using the imported AQUAGEL- (Bentonite clay) by Baroid Nig. Ltd. The following properties were analysed.

3.6.1 Determination of Density.

The NL Baroid mud balance was used to measure the density of the mud. In measuring the density of the prepared mud, the lid of the mud balance was removed and after stirring the prepared mud for at least one minute, it was poured into the cup to the brim, for trapped air bubble in the mud, the cup was tab briskly until they break out. The lid was then replaced and rotated until it was firmly sealed, with the vent hole on top of the cup. The

exterior of the mud balance was wiped with towel and the balance was placed on its base with knife-edges on the fulcrum rest. The rider was moved until the instrument was balanced in position as indicated by the level vail on the beam. The mud density was recorded in units of lb/gal.

Figure 3.2: Mud Balance.

3.6.2 pH Determination.

The pH of the mud was measured by using a pH Hydrion dispenser paper. It was performed by taking about one-inch of strip of the indicator paper and placing it on the surface or dipping into the prepared mud. Sufficient time was allowed to elapse for the paper strip to soak up filtrate and changed colour (thirty seconds to one minute). The colour of the soaked strip was compared with the standard chart, and the pH was recorded based on the colour match with the chart.

3.6.3 Determination of Rheological Properties.

The equipment used to determine the rheological properties was a Rheometer, a 12-speed rheometer, powered by electricity. It consisted of a mud cup, which could contain up to 70-80 ml of the prepared mud. The prepared mud was stirred for at least one minute and subsequently poured into the cup. The cup was adjusted upward so that the rotor immersed completely into the mud content in the cup. Read/Enter button was pressed and a display, "Please wait" appeared with a countdown in seconds and the temperature of the mud appeared in degrees Fahrenheit (^{O}F) as well.

The "OFITE" rheometer was also used to test the rheological properties of cement, the button for mud was pressed and the 600 rpm was pressed also, the 600 rpm value was display with a countdown of 10seconds and then that of 300 rpm value was disclosed.

The rheometer automatically determined the other rheological properties. After exactly 10 minutes which was timed by the machine, the following properties of the mud were displayed with their appropriate units as follows: Plastic Viscosity, Yield Point and Gel Strength.

Figure 3.3: OFITE Model 900 Viscometer

3.6.4 Determination of Marsh funnel viscosity.

The equipment used to determine the marsh funnel viscosity were marsh funnel, stop watch and a mud cup. Five (5) barrel of prepared mud was used for the experiment. The marsh funnel was filled with the prepared mud to the marked point while holding the exit point beneath with one of the fingers. The timer was set to zero and the finger at exit point of the funnel was released and the timing started concurrently. The mud released was collected in the mud cup. The time it took to reach the mark of one (1) quartz (946 ml) was taken in seconds.
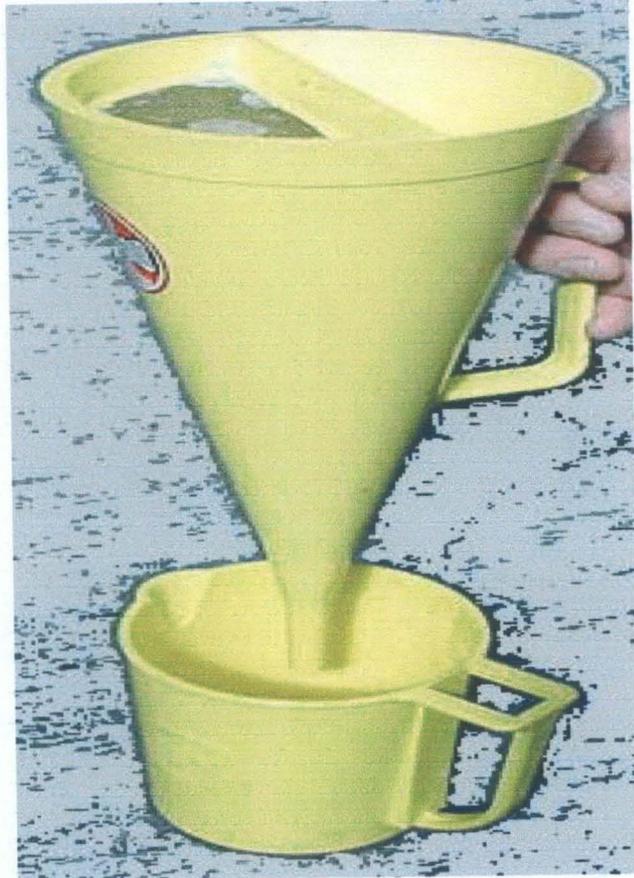
Figure 3.4: Marsh Funnel

3.6.5 Determination of Sand Content.

Sand content apparatus was employed to determine the sand content which consisted of a funnel-like plastic with an attached sieve and a glass test-tube. After stirring for about a minute, mud was filled into the glass to the marked "MUD" and water was then added to reach the upper level marked "water". The content in the glass tube was shaken for about 2 minutes and was poured through the funnel-like plastic into a mud cup. The mud passes through the sieve and sand particles larger than the sieve size were left on the sieve surface. These particles were then washed into the glass tube and water was added to it. The glass tube was clipped to a retort stand and was allowed to stand for at least 30 minutes undisturbed. The settled sand level was read in percentage from the glass tube (the glass-tube is calibrated in percentage).
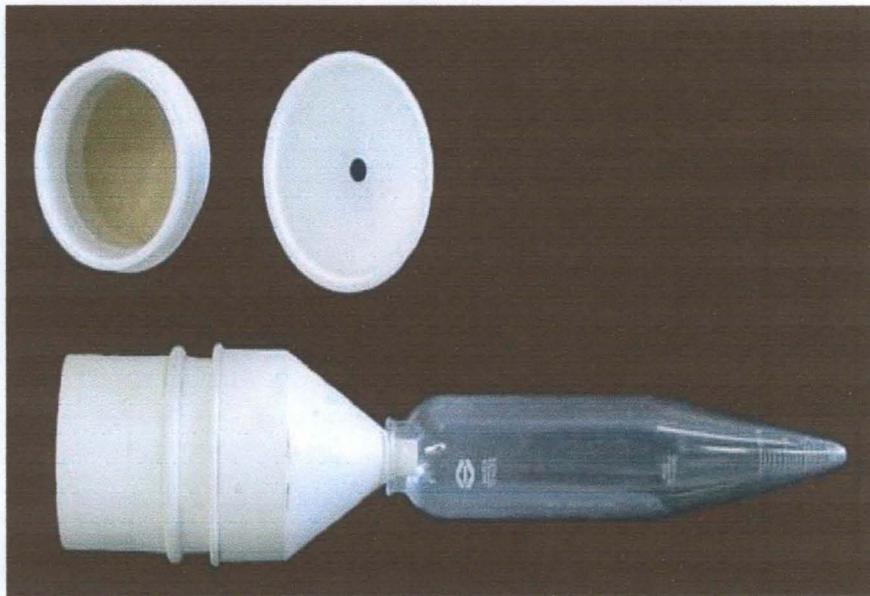
Figure 3.5: Sand Content Kit.

3.6.5 Determination of Liquids and Solids Content.

A retort kit was used to determine the liquid and solids content of a drilling mud. It involved application of pressure of about 100 psi to 10 ml of mud until the liquids content was vapourised and was passed through an opening which was finally collected in a graduated cylinder.

The sample chamber of the retort kit was filled with 10 ml of the prepared mud and the lid was replaced, thereby allowing excess of the mud to escape, making sure that air was not trapped in the screw into the upper chamber, the retort was subsequently placed back into the insulator. A 10 ml measuring cylinder was placed under the condenser to collect the liquid. The heating was carried out at temperature and pressure of 100 ^{o}C and 100 psi respectively which lasted for about 20-25 minute. The volume of liquid collected was measured and the differences with the 10 ml of the prepared mud was recorded which gave the solids content of the mud. The values were multiplied by 10 to give the result in percentage.

Figure 3.6: Retort kit

CHAPTER FOUR

RESULT

The results obtained from the experiments are presented in this chapter. It contains the different compositions of the local clays, the additives added and various properties analysed.

Table 4.1: Formulations of BSM and MTB Local Clay in 350 ml of water with and without Q-Broxin

COMPONENTS/COMPOSITIONS	01	02	03	04	05	06	07	08	09	10	Control AQUAGEL
Local Clay (g)	24.5	22.05	19.6	17.15	14.7	12.25	14.7	17.15	19.6	22.05	24.5
Sodium Carboxymethyl Cellulose (SCMC) (g)	0	2.45	4.9	4.9	7.35	7.35	2.45	2.45	0	0	0
Q-Broxin (Lignosulphonate) (g)	0	0	0	2.45	2.45	4.90	7.35	4.90	4.90	2.45	0
Total (g)	24.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5

Table 4.2: Properties of BSM Local Clay– with/without Q-BROXIN

PROPERTIES		01	02	03	04	05	06	07	08	09	10	Control AQUAGEL	API Standard
Mud Density lb/gal		8.70	8.7	8.65	8.7	8.65	8.6	8.6	8.6	8.6	8.7	8.7	8.65
Mud P^H		6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	7.0	9.5-12.5
Rheological Properties													
$\varnothing$ 600 (cP)		2.4	4.7	9.1	10.3	15.1	16.9	7.1	5.9	2.3	3.2	35	32
$\varnothing$ 300 (cP)		1.3	3.2	4.6	5.1	8.1	9.2	3.7	1.8	1.9	2.3	25	
Apparent Viscosity (cP)		1.2	2.35	4.55	5.15	7.55	8.45	3.55	2.95	1.15	1.6	17.5	
Plastic Viscosity (cP)		1.0	1.5	4.5	5.2	7.0	7.7	3.4	4.1	0.4	0.9	10	8-10
Yield Point(lb/100ft$^{2)}$)		0.2	1.7	0.2	0.6	1.1	1.5	0.3	0.3	1.1	1.6	15	3PV(min)
Gel Strength	10Secs	0.05	0.0	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.0	13	
(lb/100ft^2)	10mins	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.0	21	
Solid Content (%)		2	2	2	2	2	2	2	2	2	2	4	-
Liquid Content (%)		98	98	98	98	98	98	98	98	98	98	96	-
Sand Content (%)		0.5	0.4	0.4	0.4	0.5	0.3	0.4	0.5	0.4	0.4	1.1	1-2%
Temperature(^{0}F)		75.4	98.1	77.4	75.8	75.7	75.5	81.1	80.9	79.5	77.2	76.4	
Marsh Funnel Viscosity (sec/quart)		26.5	25.9	25.9	25.9	26.3	27.1	26.0	25.9	25.9	25.9	48.0	52-56

Table 4.3: Properties of MTB Local Clay– with/without Q-BROXIN

PROPERTIES		01	02	03	04	05	06	07	08	09	10	Control AQUAGEL	API Standard
Mud Density lb/gal		8.7	8.7	8.65	8.65	8.6	8.6	8.6	8.6	8.6	8.6	8.7	8.65 (min)
Mud pH		7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	9.5- 12.5
Rheological Properties													
$\varnothing$ 600 (cP)		2.3	4.4	8.9	9.6	14.2	16.1	6.4	5.6	2.7	3.2	35	32
$\varnothing$ 300 (cP)		1.1	3.1	4.5	4.7	7.8	7.8	3.4	2.7	2.3	2.1	25	
Apparent Viscosity (cP)		1.15	2.2	4.45	4.8	7.1	8.05	3.2	2.8	1.35	1.6	17.5	
Plastic Viscosity (cP)		1.2	1.3	4.4	4.9	6.4	8.3	3.0	2.9	0.4	1.1	10	8 – 10
Yield Point (lbs/100ft^2)		-0.1	1.8	0.1	-0.2	1.4	-0.5	0.4	-0.2	1.9	1.0	15	3PV (min)
Gel Strength	10Secs	0. 0	0. 0	0. 0	0. 0	0. 0	0.2	0. 0	0. 0	0. 0	0. 0	13	
(lb/100ft^2)	10mins	0. 0	0. 0	0. 0	0. 0	0. 0	0.3	0. 0	0. 0	0. 0	0. 0	21	
Solid Content (%)		2	2	2	2	2	2	2	2	2	2	4	
Liquid Content (%)		98	98	98	98	98	98	98	98	98	98	96	
Sand Content (%)		0.6	0.5	0.5	0.5	0.55	0.4	0.5	0.6	0.5	0.5	1.1	1 – 2%
Temperature(^{0}F)		77.2	76.9	77.0	70.4	77.2	78.4	78.1	76.8	77.3	78.4	76.4	
Marsh Funnel Viscosity (sec/quart)		26.0	26.0	26.0	26.0	27.5	28.0	26.0	26.0	26.0	26.0	48.0	52 - 56

Table 4.4: Rheological Test Properties of BSM Clay Sample in 350ml of Fresh Water

BSM CLAY CONCENTRATION IN 350ML OF FRESH WATER (g)	RHEOLOMETER READING (cP) 600	RHEOLOMETER READING (cP) 300	MUD DENSITY (Ib/gal)	SAND CONTENT (%)	PLASTIC VISCOSITY (cP)	APPARENT VISCOSITY (cP)	YIELD POINT (Ib/100ft^2)	TEMPERATURE OF THE MUD (^{O}F)	P^H
17.5	2.0	1.0	8.60	0.33	1.0	1.0	0.0	75.8	5.0
21.0	2.2	1.1	8.65	0.43	1.1	1.1	0.0	75.3	5.0
24.5	2.4	1.3	8.70	0.50	1.0	1.2	0.2	75.5	6.0

Table 4.5: Marsh Funnel Viscosity of BSM Clay Sample

SAMPLE CONCENTRATION IN 350ML OF FRESH WATER WITHOUT TREATMENT (g)	MARSH FUNNEL VISCOSITY READINGS (SECONDS/QUARTS)
17.5	26.1
21.0	26.3
24.5	26.5

Table 4.6: Rheological Test Result DRISPAC (Polyanionic Cellulose) Treated Sample

BSM CLAY CONCENTRATION IN 350ML OF FRESH WATER (g)	Weights of DRISPAC Used(g)	RHEOMETER READING (cP)		PLASTIC VISCOSITY (cP)	APPARENT VISCOSITY (cP)	YIELD POINT (Ib/100ft^2)	MUD DENSITY (lb/gal)	GEL STRENGTH (Ib/100ft^2)		pH TEST using 1.0ml of 1M, NaOH
		600	300					10secs	10mins	
17.5	0.5	13.4	7.1	6.3	6.7	0.8	8.64	0.0	0.0	11.0
21.0	0.5	16.7	9.8	6.9	8.35	2.9	8.63	0.1	0.1	11.0
24.5	0.5	18.9	10.8	8.1	9.45	2.7	8.75	0.1	0.2	11.0
17.5	1.0	19.3	11.7	7.6	9.65	4.1	8.72	0.1	0.1	11.0
21.0	1.0	19.5	11.8	7.7	9.75	4.1	8.70	0.1	0.3	11.0
24.5	1.0	20.1	12.0	8.1	10.05	3.9	8.77	0.0	0.2	11.0
17.5	1.5	20.3	16.4	3.9	10.15	12.5	8.80	0.1	0.1	11.0
21.0	1.5	22.5	17.6	4.9	11.25	12.7	8.00	0.1	0.1	11.0
24.5	1.5	23.7	19.1	4.6	11.85	14.5	8.00	0.1	0.2	11.0
17.5	1.5	26.3	18.8	7.5	13.15	11.3	8.60	0.3	0.9	11.0
21.0	2.0	28.1	19.4	8.7	14.05	10.7	8.80	1.1	2.3	11.0
24.5	2.0	32.6	19.9	12.7	16.30	7.2	8.60	2.0	3.3	11.0
17.5	2.0	33.3	22.0	11.3	16.65	10.7	8.4	4.3	5.6	11.0
21.0	2.5	35.1	25.7	9.4	17.55	16.3	8.70	5.2	7.3	11.0
24.5	2.5	39.4	27.2	12.2	19.7	15.0	8.70	7.2	9.2	11.0
17.5	3.0	39.7	29.9	9.8	19.85	20.1	8.75	9.1	11.1	11.0
21.0	3.0	43.6	33.7	9.9	21.8	23.8	8.60	10.3	13.1	11.0
24.5	3.0	49.4	38.2	11.2	24.7	27.0	8.70	12.1	14.7	11.0

Table 4.7: Rheological Test Properties using Hydroxyethyl Cellulose (HEC) Treated Sample

BSM CLAY CONCENTRATION IN 350ML OF FRESH WATER (g)	Weights of HEC Used(g)	RHEOMETER READING (cP)		PLASTIC VISCOSITY (cP)	APPARENT VISCOSITY (cP)	YIELD POINT $(Ib/100ft^2)$	MUD DENSITY (lb/gal)	GEL STRENGTH $(Ib/100ft^2)$ x 10^{-1}		pH TEST using 1.0ml of 1M, NaOH
		600	300					10secs	10mins	
17.5	0.5	7.2	3.1	4.1	3.6	1.0	8.52	0.0	0.4	10.0
21.0	0.5	8.1	4.6	3.5	4.05	1.1`	8.70	0.1	0.2	10.0
24.5	0.5	12.2	6.8	5.4	6.1	1.4	8.73	0.2	0.4	10.0
17.5	1.0	9.5	5.4	4.1	4.75	1.3	8.70	0.1	0.3	10.0
21.0	1.0	10.7	6.2	4.5	5.35	1.7	8.71	0.1	0.2	10.0
24.5	1.0	14.2	8.7	5.5	7.1	3.2	8.66	0.2	0.5	10.0
17.5	1.5	13.6	9.1	4.5	6.8	4.6	8.65	0.2	0.6	10.0
21.0	1.5	14.7	11.4	3.3	7.35	8.1	8.60	0.3	0.7	10.0
24.5	1.5	23.4	16.2	7.2	11.7	9.0	8.75	0.2	0.8	10.0
17.5	1.5	31.6	25.4	6.2	15.8	19.2	8.61	2.3	3.7	10.0
21.0	2.0	37.8	29.1	8.7	18.9	20.4	8.66	4.3	6.1	10.0
24.5	2.0	42.4	33.5	8.9	21.2	24.6	8.74	5.7	7.8	10.0
17.5	2.0	38.7	30.6	8.1	19.35	22.5	8.70	7.3	9.7	10.0
21.0	2.5	47.4	37.3	10.1	23.7	27.2	8.70	8.9	11.2	10.0
24.5	2.5	54.6	38.7	15.9	27.3	22.8	8.70	9.3	13.8	10.0
17.5	3.0	46.5	36.3	10.2	23.25	26.1	8.70	10.1	15.	10.0
21.0	3.0	57.2	42.6	14.6	28.6	28.0	8.65	11.9	17.5	10.0
24.5	3.0	66.4	51.4	15.0	33.2	36.4	8.65	13.9	19.3	10.0

POWER INDEX AND CHARACTERIZATION FACTORS (n & k)

The results for the power index (n) and characteristic factor (k) are shown in Tables 4.8 to 4.12

Table 4.8: BSM Local Clay

Samples	n	k
17.5	0.9994	1.10×10^{-2}
21.0	0.9994	1.10×10^{-2}
24.5	0.8840	2.67×10^{-2}
Control	0.4851	6.1938

Table 4.9: BSM Local Clay – with/without Q-BROXIN

Samples	n	k
01	0.8840	2.68×10^{-2}
02	0.5543	5.15×10^{-1}
03	0.9837	5.09×10^{-2}
04	0.0135	4.69×10^{-1}
05	0.8980	1.53×10^{-2}
06	0.8768	1.98×10^{-2}
07	0.9397	5.39×10^{-1}
08	1.7117	2.13×10^{-2}
09	0.2755	1.7390
10	0.4762	6.023
Control	0.4851	6.1938

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17.5	0.9994	1.10×10^{-2}
21.0	0.9994	1.10×10^{-2}
24.5	0.8840	2.67×10^{-2}
Control	0.4851	6.1938

Table 4.9: BSM Local Clay – with/without Q-BROXIN

Samples	n	k
01	0.8840	2.68×10^{-2}
02	0.5543	5.15×10^{-1}
03	0.9837	5.09×10^{-2}
04	0.0135	4.69×10^{-1}
05	0.8980	1.53×10^{-2}
06	0.8768	1.98×10^{-2}
07	0.9397	5.39×10^{-1}
08	1.7117	2.13×10^{-2}
09	0.2755	1.7390
10	0.4762	6.023
Control	0.4851	6.1938

Table 4.10: MTB Local Clay – with/without Q-BROXIN

Samples	n	k
01	1.0635	7.40×10^{-3}
02	0.5049	6.79×10^{-1}
03	0.9833	4.99×10^{-2}
04	1.0298	3.90×10^{-2}
05	0.8638	1.82×10^{-1}
06	1.0449	5.89×10^{-2}
07	0.9120	5.88×10^{-2}
08	1.0519	1.95×10^{-2}
09	0.2312	2.7749
10	0.6073	2.43×10^{-1}
Control	0.4851	6.1938

Table 4.11: Polyanionic Cellulose (DRISPAC)

DRISPAC (g)	Samples	n	k
	17.5	0.9158	1.20×10^{-1}
0.5	21.0	0.7685	4.15×10^{-1}
	24.5	0.8069	3.60×10^{-1}
	17.5	0.7217	0.6630
	21.0	0.7243	6.58×10^{-1}
1.0	24.5	0.7437	5.93×10^{-1}
	17.5	0.3076	12.2882
	21.0	0.3541	9.8686
1.5	24.5	0.3111	14.0027
	17.5	0.4840	4.6898
	21.0	0.5342	3.5388
2.0	24.5	0.7117	1.2002
	17.5	0.5977	2.7210
	21.0	0.4494	7.9547
2.5	24.5	0.5343	4.9584
	17.5	0.4088	11.9199
	21.0	0.3714	16.9631
3.0	24.5	0.3707	19.3130

Table 4.12: Hydroxyl ethyl Cellulose (HEC)

HEC	Samples	n	k
	17.5	1.2150	8.11×10^{-3}
0.5	21.0	0.8158	1.45×10^{-1}
	24.5	0.8428	1.81×10^{-1}
	17.5	0.8145	1.72×10^{-1}
1.0	21.0	0.7868	2.34×10^{-1}
	24.5	0.3167	8.0705
	17.5	0.5793	1.2531
1.5	21.0	0.3666	5.9126
	24.5	0.5302	3.0297
	17.5	0.3149	18.1851
2.0	21.0	0.3771	14.1370
	24.5	0.3397	20.548
	17.5	0.3386	18.8984
2.5	21.0	0.3455	22.0663
	24.5	0.4963	8.9409
	17.5	0.3571	19.9756
3.0	21.0	0.4249	15.3614
	24.5	0.3692	26.2305

CHAPTER FIVE

DISCUSION, CONCLUSIONS AND RECOMMENDATIONS

This chapter consists of discussion of results, conclusions derived from the results obtained, and recommendations sourced from the course of study.

5.1 Discussion of Results

Table 4.1 depicts the different formulations used for experiments involving the local clay samples, sodium carboxyl methyl cellulose and without/with Lignosulphonate respectively. The formulation was a random one and do not take any established pattern to arrive at the figures. Ten (10) different formulations were used for the experiment.

Table 4.2 is the results obtained using the formulations in Table 4.1 with/without Lignosulphonate. That is only the BSM local clay and SCMC were used for composition 01 to 03. The rheological properties of the mud as shown in Table 4.2 were all below the API standard. The 600 rpm range between 2.4 – 16.9 centi Poise (cP) for the tests, while the Aquagel (Bentonite) yielded 35 cP with the API standard set at 32 cP. It is important to state that due to the high content of SCMC and Q- Broxin in composition 05 and 06 this gave them the highest value for the 600 rpm and 300 rpm. The apparent viscosity ranges between 1.2 -8.45 cP while the Aquagel test recorded 17.5 cP. Plastic viscosity ranges between 0.4 – 7.7 cP, while aquagel test yield 10 cP and the API standard have limits of 8 – 10 cP. The yield point results was between 0.2 -1.7 cP, the control result was 15 cP while the API standard is 3PV minimum , that is thrice the value of the plastic viscosity which can be translated to be between 24 – 30 lb/100ft^2.

The gel strength results were very low with the highest at 0.1 lb/100ft^2 for both 10 seconds and 10 minutes gel strength, but the control gave 9.0 and 21.0 for 10 seconds and 10 minutes respectively.

The solids and liquid contents are 2% and 98% respectively and 4% and 96% for the control test.

The sand content was between the range of 0.3- 0.5% while the control recorded 1.1% and the API standard to be between 1 - 2%. This shows that the sand content of the local clay falls below the API standard.

The temperatures recorded were between the ranges of 75.4 - 80.9°F.

The Marsh funnel viscosity for the ten (10) samples recorded values below the API standard of 52 – 56 sec/quartz. The values recorded are in the range of 25.9 – 27.1 sec/quartz and the control test is 48 sec/quartz.

Table 4.3 is a test result using the composition in Table 4.1 with and without lignosulphonate using MTB local clay sample, since same formulations and characterization are employed, the MTB clay do not show significant difference in properties compared to BSM clay.

Following the trend of the formulations, the values obtained are below the standard, but as the quantity of the additives are increased their follows a corresponding increased in the properties of the mud.

Comparing the two clay samples using Table 4.2 and 4.3, the BSM clay shows better response to additives than the MTB clay and further research or formulations using the BSM clay was considered.

Table 4.4 and 4.5 shows rheological properties for BSM local clay sample at different clay formulations with addition of DRISPAC and HEC polymers. It was observed that as mass of clay is increased the rheological properties responded with a corresponding increase.

Table 4.6 and 4.7 depict the result obtained in formulations of the local clay with polyanionic cellulose (DRISPAC) and Hyroxylelhyl cellulose (HEC) using different quantity of clay samples in concentrations of 17.5 g, 21.0 g and 24.5 g and varying the polymer addition within the range of 0.5 – 3.0 g.

From Table 4.6, using 0.5 g of DRISPAC at different concentrations of 17.5, 21.0 and 24.5 g of BSM clay in 350 ml of fresh water, the mud density was recorded to be 8.64 lb/gal with readings recorded for 600 rpm and 300 rpm to be 13.4 cP and 7.1 cP for 17.5 g of BSM clay respectively, as the clay sample concentration was increased to 21.0 g, an increase in both the 600 rpm, 300 rpm and also the plastic viscosity increase as well as apparent viscosity and yield point. The gel strength did not increase significantly for both 10 seconds and 10 minutes gel strength. For clay concentration of 24.5g, the 10 minutes gel strength yielded $0.2lb/100ft^2$, the pH was raised to 11 by addition of 1ml of 1M NaOH.

The addition of 1.0g of DRISPAC for the different concentrations of the BSM clay shows significant increase in the rheological properties. This shows that an increase in the quantity of polymer used will result in an increase in the rheological properties. 600 rpm and 300 rpm for

24.5 g clay sample concentration were 20.1 cP and 12.0 cP, the mud density also increase to 8.77 lb/gal with 8.1 cP plastic viscosity. The plastic viscosity recorded was within the limits of API standard of 8 – 10 cP.

The gel strength did not significantly increase. Using 1.5 g of DRISPAC recorded another increase in the properties of the mud produce, but with decrease in plastic viscosity to 4.9 cP. The apparent viscosity increase due to increase in values recorded for both 600 rpm and 300 rpm for each of the concentrations of local clay used. As 2.0g of DRISPAC was used, this resulted in significant increase in the gel strength of the mud at both 10 seconds and 10 minutes gel strength, for 24.5g of clay, 2.0 and 3.3 lb/100ft^2 was recorded for 10seconds and 10minutes respectively. The plastic viscosity increases to 12.7 cP, which falls above the API limits.

Addition of 2.5 g of DRISPAC resulted in increase in the properties of the mud. For 24.5 g of local clay 39.4 and 27.2 cP were recorded for 600 rpm and 300 rpm respectively. The plastic viscosity at this concentration was 12.2 cP, above API standard, but at clay concentration of 21.0 g with same mass of DRISPAC, both the values recorded at 600 rpm (35.1) and plastic viscosity (9.4) attains the API standard with gel strength recorded to be 5.2 and 7.3 lb/100ft^2 for 10 seconds and minutes gel strength respectively.

The use of 3.0 g DRISPAC gave as high as 49.4 cP for 600 rpm with the 17.5 g and 21.0 g concentrations recording values both at 600 rpm and plastic viscosity within the API standard. The yield point despite not up to the value of API standard, that is thrice the values of plastic viscosity, was more than twice the plastic viscosity for the concentrations.

Table 4.7, with the addition of HEC follows the same trend with that of DRISPAC, the significant difference is the gel strength. The same addition of 3.0g of HEC in 24.5g of BSM clay yield 1.39 and 1.93lb/100ft^2 for both 10 seconds and10 minutes gel strength respectively, compared to 12.1 and 14.7 when DRISPAC was used.

Considering Tables 4.8 through to Table 4.12, it shows the corresponding values of n and k values for all the experiments conducted. The n values are flow behavior index (Power law index) which relate the power consumption of liquids with respect to the rate of shear or the number of times the peller rotates. The consistency index (k) and power law index (n) are an estimation of the effectiveness of the hole cleaning capacity of the drilling mud. The k values of less than one (1) shows it ineffectiveness of hole cleaning capacity, while values above one (1) shows its ability of hole cleaning and the greater the value ,the more efficient the mud in hole cleaning. The k values is a measure of mud viscosity and the thioxotropic nature of the fluid as associated with hole cleaning.

In the classification of fluids, the drilling mud falls under the category of non-Newtonian fluids, which are shear rate dependant. The n values depicts whether a fluid is Dilatant or Pseudo plastic.

Table 4.8 gives the properties of n and k for BSM mud, with the n and k values less than one .this shows poor hole cleaning capacity of the local clay.

Table 4.9 depicts n and k values below the value of one (1), with composition 09, 10 and the control with k values greater than one. This result is similar with insignificant variations with results presented in Table 4.8. Table 4.10

From Table 4.11, when 2 g of DRISPAC was used, the n values obtained are within values recorded for the Aquagel (control). At clay concentration of 17.5 g on addition of 1.5 g of the polymer the k values are all above one and recorded the highest value of 19.3130 at clay concentration of 24.5 as 3.0 g of DRISPAC was used.

Table 4.12 depicts n and k values. Only sample with clay concentration of 17.5 g using 0.5 g HEC was above one for the n values while the rest with values below one. The k values obtained from addition of 1.0 g of HEC at clay concentration of 24.5 g record values greater than one. The highest at 24.5 g of clay and 3.0 g of HEC with k value of 26.2305. The n values are satisfactory compared with values recorded for the Aquagel (control).

5.2 Conclusions

The chief important application of this project is in the drilling industry, precisely the offshore oil drilling operations, because it focused on local clay and the advantage of formulating with environmental friendly polymers to obtain the most suitable characteristics so that it can be use in drilling operations.

In this project work, BSM and MTB local clays, sodium carboxyl methylcellulose (SCMC) and with/without lignosulfonate were used. The results in the characterization show slight response when SCMC and lignosulfonate were added, with highest rheological properties at 600 rpm to be 16.9 cP and gel strength of 0.4 lb/100ft^2. These values are below the API standard of 32 cP for 600 rpm.

High viscous Polyanionic Cellulose (DRISPAC) yielded a result that satisfies the API standard. At clay concentration of 17.5 g and 2.5 g of DRISPAC, a satisfactory results were

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obtained, therefore the use of 2.5 to 3.0 g of DRISPAC depending on the requirements of the well is recommended to achieve API standard.

In the case of Hydroxyl Ethyl Cellulose (HEC) the results obtained when 2.0 g of the polymer was used gave a satisfactory results, but with lower gel strength. However, the API standards were satisfied.

Despite the fact 2.0 g of HEC gave a satisfactory results compared with 2.5 g of DRISPAC, the use of DRISPAC is concluded to be the preferred polymer because of its high gel strength when compared with results when HEC was used.

5.3 Recommendations.

I hereby make the following recommendations for more investigative research work by drilling companies and additives producers.

1. Colloidal stability of additives containing drilling fluids and the effectiveness of its application should be improved by increasing the thermal stability of the additives over a broad range of temperatures.

2. The drilling companies should further investigate the use of local clay and/or blending of the local clay to attain API standards.

3. The drilling mud and mud additives producers should have one general representation of each product with attached respective trade name, rather than given different names to a single and same product, thereby causing problems in identifying additives.

4. The government should encourage the drilling companies to use the local clay by enacting laws that mandate them to use or blend the local clay for drilling operations.

ue to non-health hazard of polymer drilling mud, it should also be use in the borehole drilling perations to minimize the energy requirement when an air compressor is used.

5. Research work on the production of drilling mud additives locally should be investigated.

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APPENDIX

Plastic viscosity $= \theta 600rpm - \theta 300rpm$
(cP)

Yield point $= \theta 300rpm$ - plastic viscosity
$(lb/100ft^2)$

Apparent viscosity $= \theta 600rpm\,reading/2$
(cP)

Yield point/plastic ratio $= YP/P.V$

Power Law index, n

$3.32 \log \dfrac{\theta 600}{\theta 300}$

Where: $\theta 600rpm$ reading

$\theta 300rpm$ reading

Consistency or characteristic index, k

$5.1 \times \theta 600 / (Y_2)^n$

where

$\theta 600rpm$ reading

$Y_2 = 1021$ (Constant)

n = Power law index