الجمهورية الجزائرية الديمقراطية الشعبية
People's Democratic Republic of Algeria
وزارة التعليم العالي والبحث العلمي
Ministry of Higher Education and Scientific Research
-جامعة محمد خيضر -بسكرة
Mohamed Khaider University – Biskra-
Faculty of Science and Technology
Department of Mechanical Engineering

Specialization: Energy Engineering

Ref:…………….

Master's Degree

Rheological characterizations of water-based mud suspensions using local clays

Presented by:

Thoria Gherab

Jury:

Dr. Abdelhakim Begar	University of Biskra	President
Prof. Adel Benchabane	University of Biskra	Supervisor
Dr. Chawki Mahboub	University of Biskra	Examiner

Academic year: 2023 / 2024

Dedication

To my heart queen, dear mother

Lovely father Boubaker

To the souls of my grandfather & my grand mother

My adorable family: brothers Mohamad El Hadi&Abd El HafidhFouad.

Lovely sisters Hanane, Rayane & Salsabil

Special thanks to my sister Zoulikha & her husband Azzedine for their endless support

To all my friends, roommates & relatives

Acknowledgements

First of all, I would like to thank Almighty God who gave me the moral strength to complete this task.

After Allah, no doubt all love and appreciate to my dearest, mother then all my beloved family.

I would also like to thank my teacher and supervisor Pr. Adel Benchabane for his patience and encouragement throughout the realization of this work. I would also like to thank Prof. Abderrezak DEBILOU, head of the Technical Platform of Physicochemical Analyzes PTAPC - CRAPC - Biskra, as well as the engineers: Dr. Samir HAMEURLAINE, Dr. Karima LAMAMRA, Dr. Aissa MERAH and Mr. Boualem DJRIDI for their precious help to carrying out the experimental study, and all those who have helped me in any way to reach the end of this experiment, which I hope will motivate me to persevere in my research.

I would like to thank the community of SONATRACH, drilling division -the base of 24 February- (Hassi MSD) for the help given to me through its staff who have shown a lot of cooperation in the field during my internship.

Not forgetting also the Energy and Mines Directorate, which did not deprive me of any information they could have given me, which helped me to make great progress through their resources, in line with my second work placement.

All due respect to the administrative side and to all the engineers who made it easier for me to understand and assimilate the projects in professional life that concern the knowledge acquired during our academic studies.

Abstract

This work focuses on the rheological behaviour of water based drilling fluid. The objective of this work is to study the possibility of using local clays obtained from OuledDjellal (O), Doucen (D) and Leghrous (L) as drilling fluids without and in the presence of PAC HV as a viscosifier additive. An industrial bentonite (B) obtained from a drilling company was used as reference clay. TA Instruments Discovery hybrid rheometer HR20 is used for the rheological characterisation. The results showed that the direct use of local clays as aqueous clay suspensions is not desired. On the other hand, the water-clay-PAC HV system made it possible to obtain typical drilling fluid behaviour; where Herschel Bulkley model is used to model the flow behaviour in a satisfactory manner. A parametric study is carried out basing on Herschel Bulkley parameters (flow index, n, consistency, k and yield stress τ0) and thixotropic percentage. The parametric study showed a difference between industrial Bentonite and local clay suspensions, particularly for the flow index and thixotropic percentage. This shows the need to treat local clays before using them as water based drilling fluid.

Key words: drilling fluid, local clay, Rheological behaviour.

ملخص

يهتم هذا العمل بالسلوك الريولوجي لسائل الحفر ذو الأساس المائي. الهدف من هذا العمل هو دراسة إمكانية استخدام الطين المحلي المتحصل عليه من أولاد جلال (O)، دوسن (D) ولغروس (L) كسوائل حفر بدون أو بوجود PAC HV كمادة مضافة للزوجة. تم استخدام البنتونيت الصناعي (B) الذي تم الحصول عليه من شركة حفر كطين مرجعي. يستخدم مقياس الجريان الهجين TA Instruments Discovery HR20 للتحليل الريولوجي. أظهرت النتائج أن الاستخدام المباشر للطين المحلي كمعلقات طينية مائية غير ممكن. من ناحية أخرى، أتاح المركب ماء-طين محلي-PAC الحصول على سلوك نموذجي لمائع الحفر؛ حيث تم استخدام نموذج هيرشل بولكلي لنمذجة سلوك التدفق بطريقة مرضية. تم إجراء دراسة البارامترية على أساس معاملات هيرشل بولكلي (مؤشر الجريان، n، القوام، k وإجهاد الخضوع τ0) ونسبة المتغيرة الانسيابية. أظهرت الدراسة البارامترية وجود فرق بين البنتونيت الصناعي والمعلقات الطينية المحلية، خاصة بالنسبة لمؤشر الجريان ونسبة المتغيرة الانسيابية. وهذا يدل على ضرورة معالجة الطين المحلي قبل استخدامه كمائع حفر مائي.

الكلمات المفتاحية: مائع الحفر، الطين المحلي، السلوك الريولوجي

Summary

Introduction

Drilling fluid, commonly referred to as drilling mud, plays a vital role in the drilling operation particularly in oil and gas well drilling process. The drilling fluid serving various functions: (i) acting as a coolant, effectively reducing heat and serving as a lubricant to minimize wear on the drill bit; (ii) transporting cuttings removal from the drill bit to the surface, preventing blockages in the drill bit and wellbore; (iii) controlling pressure, ensuring well stability and preventing blowouts; (iv) preventing cave-ins or collapses by exerting pressure against the formation; (v) transporting of various additives, including weighting agents (for density enhancement), chemicals (for corrosion inhibition or formation damage control) and viscosifiers (for rheology control).

The composition of drilling fluid varies based on factors such as the geological formation, environmental regulations, and cost considerations. Typical components include water or oil as the base fluid, clays or polymers as viscosifiers, weighting agents like barite, and a range of chemicals tailored for specific purposes.

This master's thesis focuses on the rheological behaviour of water based drilling fluid known by water based mud. The objective of this work is to test the composition of drilling fluids based on local clays without and in the presence of PAC HV as a viscosifier additive.

This document is composed as follows: in the first chapter a bibliographical review on rheology and rotational rheometery are presented. In second chapter, we spot lights on drilling in general (petroleum drilling) which is most strong economic sector in Algeria, then drilling fluids specially the one known by water based mud, mentioning its role and the different components including some useful rheological models that serves to define various parameters needed to be controled.

The third chapter is about method and materials, where four different types of clay (one is industrial Bentonite, the rests are local clays and first time to be studied) are presented with one additive which is PAC HV. Finally a description of HR20 Rheometer, used in experimental study, is presented.

In chapter four is about experimental results and discussion. We used TRIOS software to treat results and excel solver for modelling the obtained flow behaviours. Finally, we end up by a general conclusion.

Chapter 1: Rheology and Rotational Rheometery

1 Historical Introduction

Rheology was first seen as a science in its own right not before the beginning of the 20th century. However, scientists and practical users have long before been interested in the behavior of liquids and solids, although some of their methods have not always been very scientific. A list of important facts of the historical development in rheology is given . Of special interest are here the various attempts to classify all kinds of different rheological behavior, such as the classification of Markus Reiner in 1931 and 1960, and of George W. Scott Blair in 1942. The aim of the rheologists' is to measure deformation and flow behavior of a great variety of matters, to present the obtained results clearly and to explain it.

2 Rheology Definition

Rheology is the science of deformation and flow. It is a branch of physics and physical chemistry since the most important variables come from the field of mechanics: forces, deflections and velocities. The term "rheology" originates from the Greek: "rhein" meaning "to flow". Thus, rheology is literally "flow science". However, rheological experiments do not merely reveal information about flow behavior of liquids but also about deformation behavior of solids. The connection here is that a large deformation produced by shear forces causes many materials to flow. All kinds of shear behavior, which can be described rheologically in a scientific way, can be viewed as being in between two extremes: flow of ideally viscous liquids on the one hand and deformation of ideally elastic solids on the other. Two illustrative examples for the extremes of ideal behavior are low-viscosity mineral oils and rigid steel balls. [1]

Rheology is the study of the flow of liquids or viscous materials. As such, it covers properties related to the flow behavior of liquids and the temporary and/or permanent deformation of

(semi-)solid materials. These are generally known as viscous, viscoelastic and elastic properties. These properties can be measured with a rheometer in both static and/or dynamic environments. Typical factors affecting these properties can be external forces, temperature, stress duration, creep and chemical changes in a material (e.g. hardening, chemical aging).

Rheological studies can be used to model processes, for example to mimic or optimize processing conditions, such as plastic injection molding (reaction), 3D printing or UV and thermal curing of adhesives. A rheometer measures material properties in a rotating or oscillating measurement mode in response to an applied force.

Different measurement configurations are possible, depending on the material or desired property to be measured. Common examples are cone-plate, plate-plate and cylinder-cup configurations.

Software is used to adapt to these different measurement configurations, and calculations are performed to derive the physical properties of interest. [3]

3 Rheological behaviour of fluids

We're only interested in fluids whose viscosity is independent of time. We distinguish between Newtonian and non-Newtonian fluids.

3.1 Newtonian fluids

Stress is proportional to shear rate. Their viscosity is therefore constant. Most common fluids, such as water and oil, are Newtonian.

3.2 Non-Newtonien fluids

Non-Newtonian fluids change their viscosity under stress. Applying a force to such fluids can cause them to get thinner or thicker. The stress is not proportional to shear rate. Their viscosity, or apparent viscosity, is therefore not constant, but depends on the shear rate. When viscosity decreases with increasing shear rate, we speak of a rheofluidizing fluid.

Remove the stress (let them sit still or only move them slowly) and they will return to their earlier state.[34]

Conversely, when it increases with increasing shear rate, we speak of a rheo-thickening fluid.

For some fluids, known as threshold fluids, the shear rate remains zero until the stress reaches a certain value. [4]

The table below summarises four types of non-Newtonian fluids.

Table 1.1: Non-Newtonienfluids behavior examples

Type of behavior	Description	Example
Thixotropic	Viscosity decreases with stress over time	Honey – keep stirring, and solid honey becomes liquid
Rheopectic	Viscosity increases with stress over time	Cream – the longer you whip it the thicker it gets
Shear thinning	Viscosity decreases with increased stress	Tomato sauce
Dilatant or shear thickening	Viscosity increases with increased stress	Oobleck

In some of these fluids, the molecules tend to orient in planes of maximum tension resulting in a decrease in viscosity with an increasing velocity gradient; these fluids are called pseudo-plastics or ‘shear-thinning’ fluids. With increasing shear rate, the fluid is ‘thinning’. In others, the viscosity will increase with an increasing velocity gradient. The fluid is called dilatant or ‘shear-thickening.’ Many biological fluids such as blood and polymer solutions are shear-thinning, while suspensions (paints) are shear-thickening.

For non-Newtonian fluids, the viscosity varies with the shear rate. The relation between shear stress and shear rate for structure viscous fluids can be written as a power law (with K as a constant factor):

$$\boldsymbol{\tau} = \boldsymbol{k} \times (\frac{\boldsymbol{du}}{\boldsymbol{dy}})^{\boldsymbol{n}}$$

with

$n < 1$ for pseudoplastic fluids (viscosity decreases with shear rate, shear-thinning);

$n = 1$ for Newtonian fluids and $K = \mu$ (constant viscosity)

$n > 1$ for dilatant fluids (viscosity increases with shear rate, shear-thickening).[35]

3.2.1 Viscoelastic Fluids

The viscoelastic non-Newtonian fluids typically include polymer solutions, thermoplastics, granular materials, resin, paints, asphalt, gel, biological fluids such as blood, cerebrospinal fluid, endobronchial secretions, etc. They are the subject of intensive research and development in medicine and many industries including polymer, metallurgy, chemical, plastics, oil, and food industries (Deville and Gatski, 2012; Miller and Ross, 1993; Oldham and Spanier, 1974; Podlubny, 1999; Samko et al., 1993).

In industries, an increasing number of metallic materials has been replaced by polymers and composites.[36]

4 Rheology applications

4.1 Food and beverage applications

The food and beverage industry is a vast field for which we offer a wide range of equipment, from rheological analysis of your products to texture analysis.

4.2 Building applications

The construction industry uses a wide range of products: glues, joints, coatings... Our instruments enable precise rheological analysis of these products.

4.3 Applications Chemistry

The possibilities for chemical analysis are many and varied. Their versatility means they can cover a wide range of rheological measurements.

4.4 Cosmetics applications

The products manufactured by the cosmetics industry are extremely varied. That's why it's essential to have a wide range of equipment at your disposal to cover all possible applications.

4.5 Paint applications

Accurate rheological analysis during paint formulation requires high-performance equipment to obtain the ideal texture for product application, storage and transport [6].

5 Rheometry and rheophysics

A rheometry experiment with a complex fluid is by no means an easy technique to implement. Obtaining reliable measurements that effectively represent the material's behavior is a delicate matter, as many phenomena can interfere with the measurements during the course of the experiment. The theoretical calculations used to interpret macroscopic measurements in terms of intrinsic material behavior are based on assumptions about homogeneity, sample shape and flow characteristics.

If these assumptions are no longer valid due to disruptive phenomena (sedimentation, shear bands, evaporation, deformation of the free surface of the sample, sliding on the walls, etc.), the calculations do not provide exact information about the material under consideration. Many experimental precautions are therefore necessary. Added to this is the fact that experimental procedures (i.e. the flow history imposed on the material) must be adapted to the type of behavior being studied.[8]

Current rheometry techniques involve flows that are sufficiently simple that, on the one hand, the law of behavior of the material under these conditions can be written as a relationship between a small number of variables, and, on the other hand, it is possible to measure these variables directly by “macroscopic” measurements, in other words, without local measurements inside the material.[8]

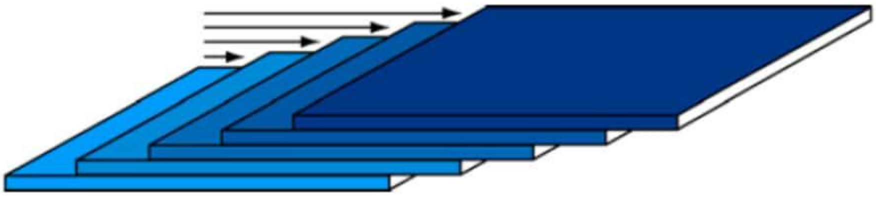


Figure1.1parallal shear deformation schematization [9]

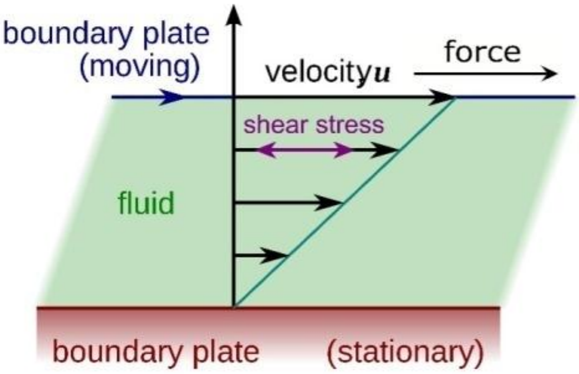


Figure 1.2forces applied during shear deformation [10]

-During simple shear deformation, it's as if the liquid layers were sliding parallel to each other.

$$shear\ rate = \dot{\gamma} = \frac{velocity\ differnce}{distance} = \frac{dv}{dy} \tag{1.1}$$

$$\text{shear stress} = \sigma = \frac{\text{F}}{\text{A}} = \frac{\text{FORCE}}{\text{AREA}} \tag{1.2}$$

$$\text{viscosity} = \eta = \frac{\sigma}{\dot{\gamma}} = \frac{\text{shear stress}}{\text{shear rate}} \tag{1.3}$$

6 Rotary rheometery

In rotary rheometry, the fluid is subjected to shear between two surfaces, one fixed and the other rotating about its axis. In practice, these two surfaces are usually a cone and a plane, two parallel planes or two coaxial cylinders (Couette geometry), geometries which we will describe in detail below. The shear gradient is determined by the surface geometry on the one hand, and by the rotational speed on the other. It can also be imposed by the rotational speed of a motor. In this case, we speak of rheometers with imposed speed or deformation. The shear stress is calculated by measuring the torque transmitted by the sample to be characterized. In imposed-strain rheometers, it is the stress that is controlled by the torque.

The shear gradient is calculated by measuring the speed of rotation of the moving surface.

6.1 Geometry measurements

6.1.1 Rotary rheometry in cone-plane geometry

In this geometry, the fluid is sheared between a cone and a plane as schematized in.

The cone is characterized by its radius R and by the angleα, which is of the order of a few degrees. It is attached to the rotating part of the rheometer, which allows it to rotate about its axis at a constant angular speedΩ.

This is one of the main advantages of using a cone-plane. Another advantage of this geometry is its ability to measure the first normal stress difference directly and easily.

The viscosity range accessible with this tooling is very wide. For low-viscosity fluids, the effects of inertia will limit measurements. In the case of high viscosities, measurements are limited by the hollowing out of the free surface [2].

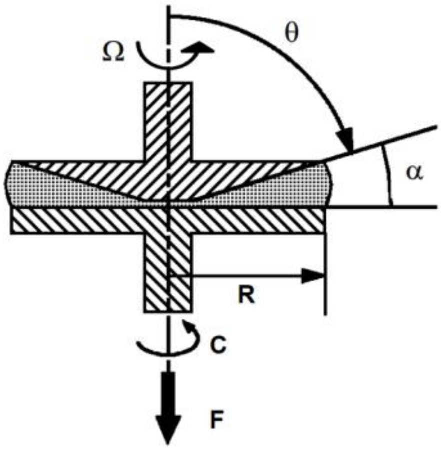


Figure1.3 Characteristics of cone-plane geometry.

6.1.1.1 Confining the liquid between a cone and a plate

The liquid is sheared between an upper rotating cone and a lower fixed plate as seen from the side. The shear stress comes directly from the torque.

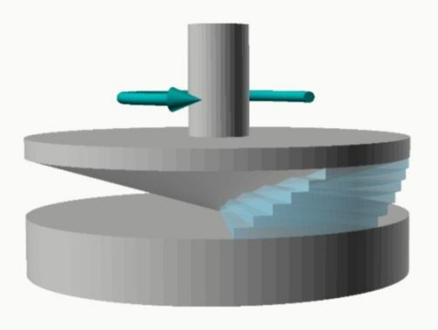


Figure 1.4 cone and plate rotation schematization

The cone and plate combination evenly shears the liquid, having completely horizontal fluid layers.

Pros: It requires an exceedingly small volume of the sample liquid and measures at a very well-defined shear-rate.

Cons: It is not optimal when measuring thin liquids or if the sample contains particles, as they can wedge between the narrow central gap. Evaporation can have a large effect.[10]

6.1.2 Confining the liquid between a plate and a plate

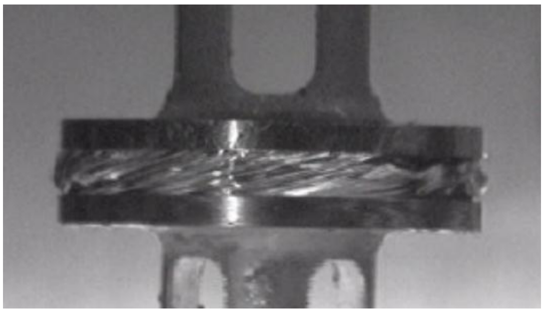


Figure 1.5 Hollowing out the free surface of a PDMS between two parallel planes under a high shear gradient [2]

The liquid is sheared between an upper rotating plate and a lower fixed plate, as seen from the side. The shear stress comes from the torque.[10]

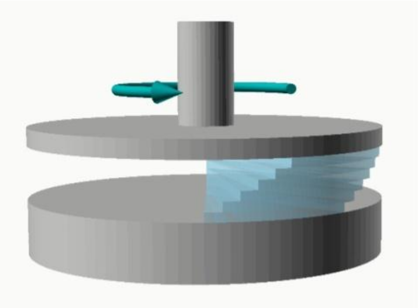


Figure1.6plate and plate rotational movement

The liquid is sheared between the two plates in a controlled manner, but not evenly as with the cone-plate geometry.

Pros: Compared to the cone-plate, this geometry can handle samples containing particles.

Cons: The instrument software typically compensates for varying shear rate measurement effects. Evaporation can have an enormous impact.

6.1.3 Confiningthe liquid between a cup and a bob (having a cylindrical gap)

The cross-section view below shows how the liquid shears between the central rotating bob and the fixed cup. Like the former, the shear stress comes from the torque.[10]

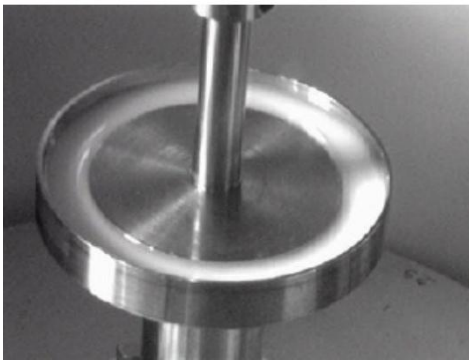


Figure1.7Using a cup in rotary rheometry to avoid fluid ejection problems at high rotation speeds[2]

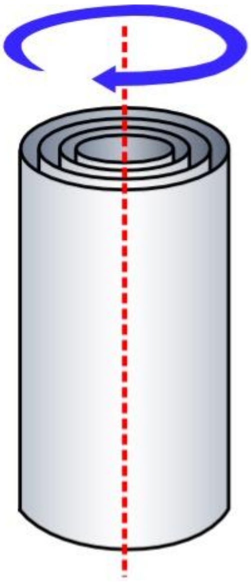


Figure 1.8 Rotary Rheometry of Couette

Here, the fluid layers become concentrical cylinders, such that the shear stress acts on a large surface area, compared to, e.g., the cone-plate geometry.

Pros:A cup-bob geometry is more sensitive when measuring on thin liquids compared to cone-plate or plate-plate. It is also less affected by possible evaporation effects.

Cons: The measurements require large sample volumes. Cleaning the geometry is more time-consuming than cone-plate or plate-plate.[10]

6.2 Evaporation problem

It intervenes especially in the suspensions during tests comprising a free surface. This phenomenon leads to a decrease in the volume studied. This could result in a decrease in the measured apparent viscosity. On the other hand, an increase in the mass concentration appears, which results in an increase in the apparent viscosity. The practical techniques, used to minimize the disturbances, consist in working under an atmosphere saturated by the interstitial fluid or in placing a liquid film on the free surfaces [34].

6.3 Wall Slip problem

This is the most common phenomenon encountered during the rheological study of fluids. It can occur in all flow geometries and results from the preferential shearing of a thin layer of the fluid under test near the walls. This phenomenon leads to measurement errors, in particular for threshold stress measurements with an imposed stress rheometer [Barnes (1995); Bonifas (1998)]. In the case of suspensions, sliding can be favored by the migration of particles from the parietal regions (decrease in the solid concentration near the smooth wall), an effect known as the sigma effect. This effect has been addressed by many authors, such as Quemada, for example, who reported the existence of this phenomenon in cylindrical pipes [Quemada (1977); (1978a) and (1978b)]. Work on the rheometry of clay suspensions has also shown the existence of this phenomenon at the walls [Yoshimura and Prud'homme (1988)]. These authors developed a mathematical model inspired by that of Mooney (1931).

The method of Yoshimura and Prud'homme (1988) consists in carrying out two series of measurements on geometries of the same type but with a single different characteristic. In another work and as part of his thesis, Bonifas (1998) took up the calculation method of Yoshimura and Prud'homme (1988) on bentonite suspensions using plane-plane and plane-cone geometries. He concluded that this model achieves a non-negligible and acceptable correction.

On the other hand, and alongside these calculation methods, we note the existence of another method where the sliding effect is controlled experimentally. This second solution consists in making the walls rougher to increase friction. In our tests, we adopted this second method by coating the surfaces of the cone and the plane with a thin layer of aerosol glue, then a thin layer of bentonite powder. Other authors proceed by covering the surface of the plane and the cone with a rough sandpaper [34].

Table 1.2:Advantages and disadvantages of the various rheometric tests [2]

	Avantages	Disadvantages
All geometries	- The placed sample can be used continuously (there's no tank to empty and andmayinterrupt tests)	in practice, perfect alignment is sometimes sometimes difficult, - inertia can become significant; It then creates a normal force which tends the rotating element closer to the element closer to the static element the formation of recirculations, which in turn the measured torque and normal force force, - at high rotational speeds, viscous dissipation viscous dissipation can lead to sample heating
Plane-cone	- the shear gradient is uniform and constant in the air gap between the cone and the plane. - allows direct, simple measurement of the first normal stress difference difference. - simple disassembly and visual inspection geometry.	- recirculation develops, particularly particularly for cones with a large angle, - presence of a free surface, - difficult to set up for very systems due to the development of development of normal stresses
Plane-plane	- the value of the air gap can be adapted to the type of sample handled. - allows indirect measurement of the second normal stress difference. - easy disassembly and visual inspection geometry.	- the shear gradient is not the same throughout the the same throughout the air gap, - presence of a free surface.
Couette	- limited edge effects thanks to the extent surfaces, - low risk of product ejection even at high shear rates, - particularly suitable for studying low-viscosity fluids	- inhomogeneous shear gradient in wide air gaps, - normal forces difficult to measure in due to the curvature of the streamlines lines, - visualization of the deformation field difficult, - filling the measuring cell difficult to fill, especially with fluids.

7 Rheological parameters

7.1 Flow curve for viscous products

A simple viscosity measurement (using a viscometer) can provide information on flow, but measuring viscosity at a single shear rate can only be used to compare easy, stable production processes... not much more. The flow curve, on the other hand, i.e. measuring viscosity over a wide range of shear rates, provides a much better understanding of the fluidity and behavior of your sample under different operating conditions.

7.2 Yield stress

This analysis determines the minimum shear stress to be applied before your material begins to flow. For some products or processes, knowing the flow threshold is mandatory. A product that is expected to behave like a solid must have a flow threshold, while a self-leveling material must have no flow stress at all.

7.3 Oscillation measurements

With oscillation measurements, it is possible to perform a frequency or amplitude sweep while avoiding sample flow, in order to determine the viscous and elastic moduli of your samples. Both properties will change as a function of the stress or strain to which they are subjected. A complete understanding of your sample's behavior under different conditions of use would require this type of analysis.

7.4 Amplitude and frequency sweep

Amplitude sweep and frequency sweep are used to study a material under the assumption that it does not flow. Viscoelastic materials exhibit both very brittle mechanical structures and solid or brittle mechanical structures that can be studied and characterized when at rest.

As a general rule, the structure of a cream or gel with a certain “consistency” should exhibit solid-elastic behavior at rest [7].

Chapter 2: Drilling fluid

1 Drilling

Drilling is the term used to describe all the operations involved in digging generally vertical holes. Drilling is mainly used to identify and exploit oil and gas deposits.

Other uses, of which there are many, include: geological or geophysical drilling to identify mineral deposits; drilling to find deep water tables, or to drain gas or water in mining operations; drilling to inject gas into porous, permeable formations for underground storage; and drilling into salt domes, enlarged by freshwater injection to store liquefied gases such as propane.

In the building and civil engineering sector, drilling is used to inject cement mortar for the consolidation of piers, bridge supports, dykes, etc., as well as to consolidate rock masses prior to excavation, and for subsoil reconnaissance by taking samples (coring) to determine the properties of the different layers of soil and thus the type of foundations to be adopted for building construction. The drilling technique, whatever its objective, uses means similar to those used for oil drilling[11].

Figure2.1 Drilling rig (Berkine basin _SONATRACH) [18].

2 Different types of drilling

2.1 Vertical drilling

allows the well to be drilled vertically in line with the reservoir zone where oil is likely to be present in the subsoil.

2.2 Deviated drilling

allows multiple targets to be drilled from a single drilling site. This limits the number of surface sites and enables the use of existing facilities.

2.3 Horizontal drilling

makes it possible to reach several targets in the subsurface from a single site, maximizing the exchange surface with the reservoir and reducing the number of drillings required[16].

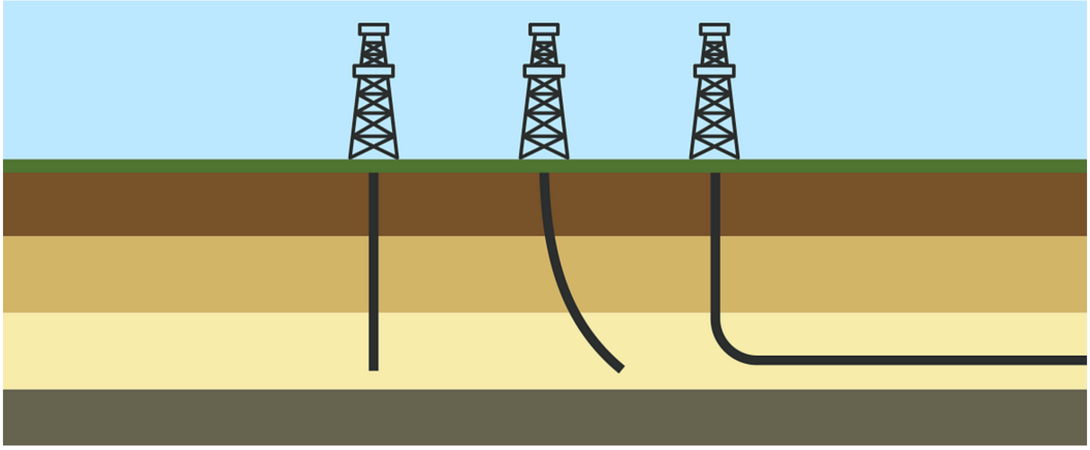


Figure2.2: showingdifferenttypes of drilling

For many decades, there was only one way to drill a well — vertically.

Now, with advanced drilling technology, operators can add steerable motors that enable “slant” or directional drilling. They can drill down vertically, build a curve, and drill at angles of 90 degrees or more in the horizontal direction. This is called horizontal drilling.

This means that hydrocarbon-bearing formations with oil and gas reserves that were previously nonviable drilling prospects are now economically feasible.

Drilling these types of horizontal wells is called unconventional or directional drilling. The Permian Basin, Bakken, Eagle ford, Haynesville, and other important shale plays rely on directional or horizontal wells.

Today, 95% of capital is going into directional drilling projects.[17]

3 Drilling fluid

One of the main roles of drilling fluid is to lift cuttings from the bottom of the well to the surface. The consistency of the mud must therefore be sufficient to prevent sedimentation of the cuttings in the updraft.

However, this consistency must not exceed certain limits, which would be incompatible with the power of the pumping installations and prevent the separation of the cuttings, after each cycle, in the surface separators.

Also, during traffic stoppages for maneuvering, spoil and dispersed solid particles must remain perfectly in suspension. This also implies certain rheological properties which, however, must not hinder recirculation, interfere with maneuvering or have any adverse influence during maneuvering (overpressures during descent of the rods or depressions during ascent)[12].

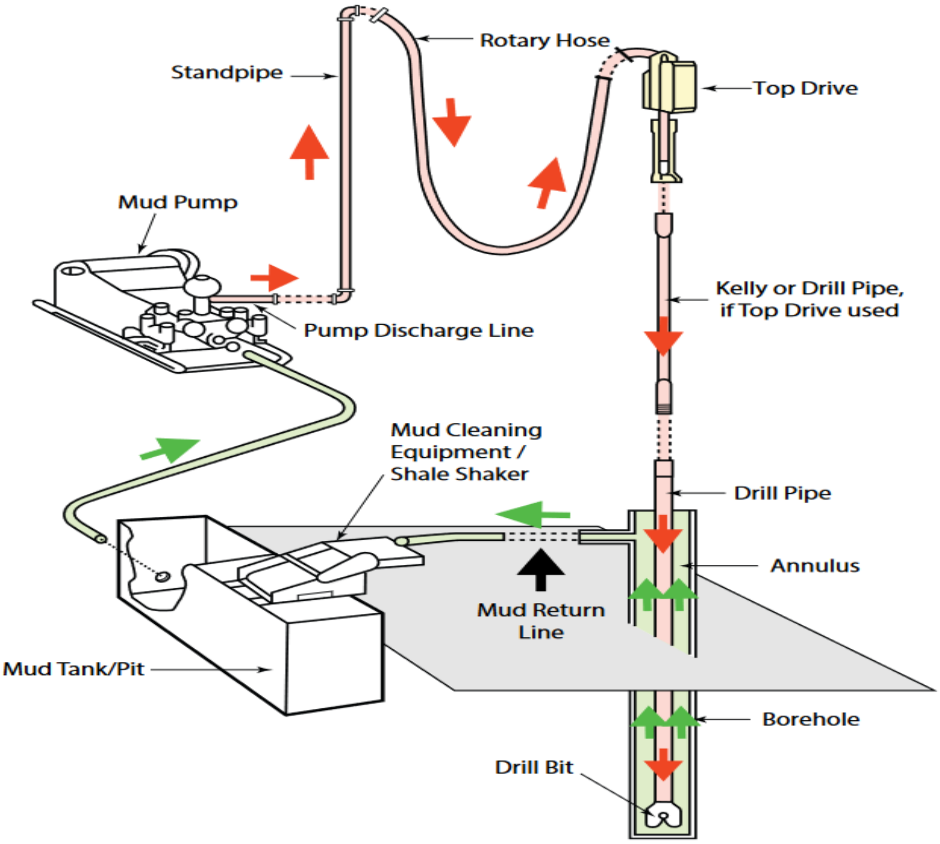


Figure2.3: Drilling equipment for mud circulation [19].

The adjustment and control of rheological characteristics will therefore play a vital role in Drilling fluid technology. Any significant change in rheological characteristics, which is a sign of fluid evolution, must be countered immediately. The desired properties will be obtained, at the start of use, thanks to an appropriate choice of composition, taking into account a certain number of imposed factors such as: origin of the base fluid (fresh or sea water), nature of the terrain traversed, temperature and pressure reached in the well.

During drilling, the initial composition is modified to a greater or lesser extent by the addition of products chosen according to the origin of the evolution. [12].

Drilling fluid is used for a variety of reasons. Combined with hydrostatic pressure, it helps to:

- Prevent formation fluids from entering wellbores by providing hydrostatic pressure;

- Help prevent formation damage, limit corrosion and stabilize rock;

- Suspend drill cuttings when the drilling rig is in or out, and when drilling is paused;

- Keep drilling clean, cool and lubricated;

- Transport drill cuttings;

- Bring rock excavated from the borehole to the surface;

- Maintain drilling stability;

- Transmit hydraulic energy to boreholes and tools [20].

3.1 Composition

In addition to beau and the diesel used as a continuous or emulsified phase, a very large number of products are used in the manufacture and treatment of drilling fluids, some of which have a specific role and others have multiple actions.

These products are classified into families:

3.1.1 Clay colloids

Bentonites, Attapulgites.

3.1.2 Organic colloids

Starches, CMC (Carboxy Methyl Cellulose).

3.1.3 Fluidizersor deflocculants

Polyphosphates, Tannins,LignosulfonateChoriogenins.

3.1.4 Mineral additives

Caustic soda (NaOH),Soda ash (Na_2CO_3), Gypsum ($CaSO_4$), Hydrated lime ($Ca(OH)_2$), Sodium bicarbonate ($NaHCO_3$)

3.1.5 Special organic products

-Anti-ferments.

- Anti-foaming agents.

-Anti-corrosion products.

- Anti-corrosion products.

- Anti-feedants.

3.1.6 Weighting agents

-Barite or barium sulfate ($BaSO_4$)

- Calcium carbonate ($CaCO_3$)

- Galena (PbS)

- Hematite ($Fe_2 O_3$)

3.1.7 Sealants

-Organic sealants

- Fibrous sealants

- Lamellar sealants

- Swelling sealants

- Setting sealants (hydraulic binders) [15]

3.2 Classification

Drilling fluids can be subdivided into three groups:

-Water-based drilling fluids.

- Oil-based drilling fluids.

-Gasified drilling fluids.

3.2.1 Water-based drilling fluids

These fluids are made up of three distinct phases:

3.2.1.1 Liquid phase

this represents water, this water can be fresh or salty, the salinity of drilling fluids depends on the salinity of the manufacturing water.

3.2.1.2 Colloidal phase

This phase is essentially made up of clays, which have two functions: one is primary, representing the viscosity offered by the clay, and the other is secondary, such as filtrate reduction.

3.2.1.3 Solid phase

Solids added to the drilling fluid, such as barite Ba So4, but also sands, limestones and dolomites, are insoluble in water and only act through the mass effect [13].

3.2.2 Oil-based drilling fluids

Oil-based muds are composed of oil as the continuous phase, water as the dispersed phase, emulsifiers, wetting agents and gelling agents. Other chemicals used for sludge treatment include filtrate reducers and weighting agents.

The oil for an oil-based slurry can be diesel, kerosene, fuel oil, selected crude oil, mineral oil, vegetable esters, linear kerosenes, olefins or mixtures of various oils.

There are several desired performance requirements for any oil:

-API gravity=36◦ - 37◦

-Flash point=180◦F or higher

-Fire point=200◦F or higher

-Aniline point=140° or more. [14]

4 Importance of rheology in solving drilling problems

A fairly extensive literature exists on the rheological behaviour of drilling fluids.

Drilling fluids are often colloidal suspensions which have a complex and variable behaviour depending on their composition and the conditions of use (Garcia and Parigot, 2004).

4.1 Rheological agent

A rheological agent is a substance added to a material to modify its rheological properties, its flow and deformation characteristics under stress. These agents can be used in a variety of materials, such as polymers, drilling fluids, paints, pharmaceuticals and foods, to control their viscosity, stability, adhesion and other properties related to their behaviour under stress.

Rheological agents can be classified into different categories according to their action on the material. For example, some agents can increase the viscosity of the material, while others can make it more fluid. Common rheological agents include thickeners, flow agents, dispersants, gelling agents, emulsifiers and suspending agents[21].

4.2 Composition of different types of mud

Historically, drilling fluids have evolved from a simple mixture of water and clay called ‘mud’ to increasingly complex systems made up of water or oil with a multitude of additives to meet the characteristics required and the problems encountered.

Drilling fluids are complex fluids classified according to the nature of their basic constituents.

Traditionally, drilling fluids have been classified into three categories according to the base fluid used in their preparation: air, water or oil (Ryan and Chillingar, 1996).

5 Water-based mud

These fluids are often referred to as ‘Water-Based Muds’ or WBM. In most cases, theymade up of suspensions of bentonites in water (30 to 60 g/L), the rheological and filtration characteristics of which are often adjusted by polymers.

rheological and filtration characteristics are often adjusted by polymers. The nature electrolytes and their concentration in water-based sludge formulations are chosen taking into account the characteristics of the formation (water activity of clay formations,dissolution of saline formations).

5.1 Additives included into drilling fluids

5.2 Viscosifiers

natural clays (often bentonites), synthetic polymers or biopolymers

5.3 Filtrate reducers used to consolidate the filtration cake

To limit invasion by the fluidstarches, carboxymethylcelluloses or CMC, polyanionic celluloses (PAC), or resins.

5.4 clay swelling and dispersion inhibitors

KCl, glycerol, silicates or various polymers such as partially hydrolysed polyacrylamide (PHPA), polyalkylene glycols (PAG).

5.5 weighting agents

such as barite (barium sulphate BaSO4) and calcite (calcium carbonate CaCO3), which are the most commonly used to give the sludge a suitable density.

Haematite (Fe2O3) and galena (PbS) are also used.

Calcite is often recommended for drilling the reservoir phase because it is soluble in acid and can be used in a variety of grain sizes to reduce problems of loss and damage;

5.6 sealants

rather exotic additives such as granular (walnut shells), fibrous (wood fibres, sugar cane) and flaky (oyster shells, cereals).(Herzhaft, 2001; Peysson, 2004).

6 Characteristics recommended by API for Drilling fluid

6.1 Density

Density is an important parameter for Drilling fluids. It must be high enough to counterbalance the pressure exerted by the influx of water, oil and gas and, consequently, blowouts.However, it must not exceed the resistance limit of the well walls (formations traversed) so as not to fracture themto avoid fracturing them and risking loss of mud during circulation.To make the mud heavier, barite (BaSO 4) has been used since 1922 (Stroud,1925).The pressure exerted by the mud on the well walls is given by the following expression.(Garcia and Parigot, 1968)

$$\boldsymbol{p = \frac{h_c.d}{10}} \qquad (2.4)$$

withP: Formation pressure (kgf/ cm2),

h_c : Depth of the layer traversed (m)

d: Mud density.

Because of this counter-balancing pressure under normal drilling conditions, diffusion of the fluid in the porous media is possible.

of the fluid in the porous media is possible. To reduce this invasion as much as possiblea thin filtration product, called cake, is formed on the walls of the drilled hole.

This cake must be of low permeability and must be easily removed before cementing (Peysson,2004)

6.2 Viscosity

Viscosity depends above all on the solids content of the slurry and the presence of polymers. An increase in viscosity can therefore only be combated by eliminating solids. From a practical point of view, we define two types of viscosity :

apparent viscosity (AV) and plastic viscosity (PV), which is often linked to particle size and shape.

$$V_A = L_{600}/2 \tag{2.1}$$

$$V_p = L_{600} - L_{300} \tag{2.2}$$

where L600 and L300 represent the readings at 600 and 300 rpm respectively on the fannrheometer.

On site, two types of tools are available to check the rheology of the sludge.

The Marsh viscometer, which is still widely used,Fann 35 rheometer, which measures stress at 2 or 6 shear rates, depending on the instrument.

Figure 2.4 viscosimeter Marsh

Figure 2.5RheometerFann 35 used in laboratoryconstruction site HASSI MSD

Description of Fann 35

The rheometer used is of the Couette type (concentric rotating cylinders). This is the class ofrheometers in which the substance under study is trapped between two coaxial cylinders of revolution coaxial cylinders of revolution with radii a few mm apart. Laminar shear is obtained by imparting to one of the cylinders a uniform rotational movement of angular velocity ω, the other cylinder remaining stationary.

The substance is broken down into coaxial cylindrical layers, with different angular velocitiesvarying continuously from 0 (for the layer in contact with the fixed cylinder) to ω (for the layer in contact with the moving cylinder).

layer in contact with the moving cylinder). As a result of the relative movement of the layersrelative to each other, a shear velocity and a shear stress appear at every point of the sample.The design includes a R1 Rotor Sleeve, B1 Bob, F1 TorsionSpring, and a stainless steel sample cup for testing according to American Petroleum Institute Recommended Practice for Field Testing Water Based Drilling Fluids, API RP 13B-1/ ISO 10414-1 Specification [13].

6.3 Yield stress

The solids present in the drilling fluid influence a parameter other than plastic viscosity.

viscosity, which is the threshold stress (expressed in Pa or lb/100 ft2), better known as the yield value or yield point.

$$Y_p = L_{300} - V_p = (V_A - V_p) \times 2 \qquad (2.3)$$

The threshold stress represents the initial resistance that must be overcome for the fluid to flow. This resistance is due to electrostatic attractive forces localised at the surface of the particles. It is a dynamic measure.

The threshold stress depends on the type of solids present and their respective surface chargesthe concentration of these solids, and the type and concentration of any other ions or salts present[24].

6.4 Gels and thixotropy

Thixotropy is a rheological property of certain materials which exhibit changes in viscosity or fluidity in response to an applied stress. It is characterized by a decrease in viscosity in the event of agitation or shearing and by a gradual increase in viscosity at rest. This is a desirable property in many products and applications, as it allows the material to be easily applied and spread when agitated or a force is applied, while providing greater stability and resistance to flow when at rest.[22]

A drilling fluid left at rest gradually builds up a structure which increases its rigidity which can be reduced by agitation. Thixotropy refers to the fact that this phenomenon is non-instantaneous and reversible. The thixotropic nature of a mud is assessed by measuring ‘gel 0’ and ‘gel 10’.

Gel 0 represents the resistance of the gel immediately after agitation of the sludge. They are measured using the Fann35 viscometer at a speed of 3 rpm and expressed in lb/100ft^2.

Gel 10 represents the gel strength after the slurry has rested for 10 minutes [24].

6.5 Measuring Gel Strength

The commonly used procedure for measuring gel strength is as follows:

1. Stir the sample thoroughly at 600 rpm.

2. Set the gear shift knob to the 3 rpm position, and then turn the motor to the OFF position.

3. After the desired wait time, turn the motor to the ON position at low speed.

4. Read the dial at the moment the gel breaks as noted by a peak dial reading. The

gel strength units are lb/100ft 2.

6.5.1 An alternative method for measuring gel strength

1. Stir the sample thoroughly at 600 rpm.

2. Turn the motor to the OFF position.

3. After the desired wait period, turn the gel knob (located below the gear shift

knob) slowly counterclockwise.

4. Read the dial at the moment the gel breaks as noted by a peak dial reading.

Thegel strength units are lb/100ft 2.[23]

7 Rheological models

7.1 Casson model

$$\tau^{1/2} = \tau_c^{1/2} + (\eta_\infty \times \dot{\gamma})^{1/2} \qquad (2.5)$$

7.2 GeneralizedCasson model

$$\tau = \tau_c + \eta_\infty \times \dot{\gamma} + k \times \dot{\gamma}^n \qquad (2.6)$$

7.3 Herschel-Bulkley model

$$\tau = \tau_c + k \times \dot{\gamma}^n \qquad (2.7)$$

With:

τ_c : represents the threshold constraint

η_∞:is the viscosity at infinite shear rate k : characterizes the consistency of the structure

n : dimensionless parameter between 0 and 1 that can be considered as a flow index.[25]

7.3.1 Flow Curves of a Herschel-Bulkley Fluid

This demonstration lets you generate and plot flow curves of Newtonian, Bingham, and shear-thinning (pseudoplastic) fluids using the Herschel-Bulkley model (figure 2.7). It provides visualization of the differences between Newtonian and non-Newtonian fluids and how they are affected by the yield stress, consistency, and flow index.

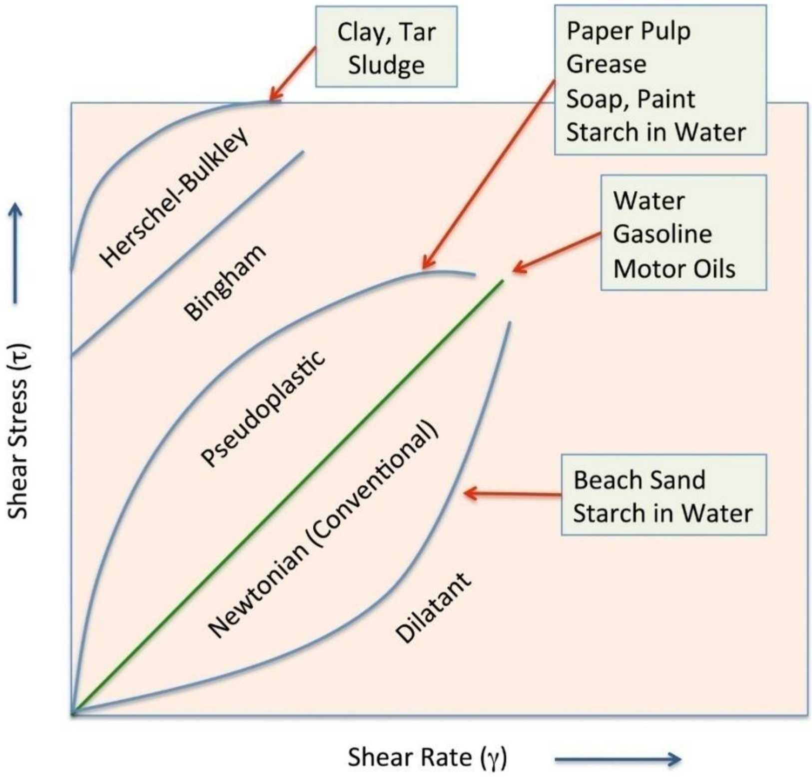


Figure (2.7): different types of flow curves relate shear stress with shear rate.

It also shows how the apparent viscosity of non-Newtonian fluids, unlike that of Newtonian fluids, changes with the shear rate.[37]

HB exhibits the same fluid behaviour characteristics as PLF, except it has a Yield Point.

HB fluids are time dependent meaning it will undergo hydration and set up over time once static. Examples: Cement Slurry.

Temperature has an affect on Viscosity and YP.

HB is considered a Non-Newtonian Fluids.

7.3.2 Generalized Herschel Bulkley

GHB is highly accurate and is the most commonly used fluid model.

GHB was developed by Halliburton to more accurately dictate the behaviour of cement slurry systems.

One of the advantages of this Fluid Model is that it can be used to describe the behaviours of all fluids by manipulating the values.

GHB exhibits the fluid behaviours of both Bingham Plastic and Power Law Fluids in regards to the fact they have a YP (Bingham Plastic) and a dynamic viscosity - apparent (Power Law Fluids).

Temperature has an effect on Viscosity and YP and GHB is considered a Non-Newtonian Fluids.

8 Recapitulation

8.1 Shear Rate(γ)

Denoted by the Greek letter gamma (γ) is the rate of shear in a fluid.

Is the velocity of the fluid divided by the distance from the fixed plate the fluid is moving against.Units of shear is reciprocal seconds.

8.2 Shear Stress (τ)

Denoted by the greek letter tau (τ) is a force applied to a substance acting in parallel to fixed place of reference.

8.3 Viscosity(η)

A fluids resistance to flow is quantified by its viscosity, Is the amount of force required to keep a fluid in motion.

Viscosity is measured in Pascal-Seconds or Centipoise.

Viscosity is defined as a mathematical ratio of shear stress at a specified shear rate.

8.4 Yield Point

Is the amount of force (stress) required (force per unit area) to get a fluid moving or initiate fluid movement. Yield Point is measured the same as shear stress lbf/100ft2

For fluids that has a yield point value, *NOTE* until the magnitude of shear stress is greater than the value of the yield point of a particular fluid, it will behave as a solid. (gel strength development)

Understanding fluid behaviour is a very critical cementing design parameter. It gives a cementing engineer critical intel in regards to calculating friction pressures for ECD purposes and determining a suitable rheological hierarchy.

It's very difficult to determine fluid behavior without testing a fluid's rheology using a Fann 35 viscometer. We would need to obtain the necessary rheological data first, then we can plot a data chart to identify our fluid's behaviour. [38]

Chapter3: Materials and methods

1 Materials

1.1 Bentonite clay

The first material is the industrial bentonite used in the operational zone at the HassiMessaoud drilling division.

Bentonite is a clay rock in which montmorillonite is the main mineral component. It often contains small amounts of illite, kaolin, zeolite, feldspar, calcite and other minerals. Bentonite is a valuable non-metallic mineral resource with over 1,000 uses and is known as the ‘universal material’. Bentonite can be divided into calcium-based, sodium-based, magnesium-based, sodium-calcium-based and magnesium-sodium-based depending on the different cations between the layers of montmorillonite.

Bentonite is generally white, grey, pink, yellow, brown and black in various colours, and its form is often an earthy cryptocrystalline mass, sometimes in the form of small scales and spherulites. Soft and slippery, water swelling, maximum water absorption can be 8 to 15 times its volume, with grease or waxy luster, fracture is conchoidal or jagged, hardness is 2 to 2.5; density is 2 to 2.7 g/cm3, melting point is 1330 ~ 1430℃. Bentonite has the properties of swelling, adsorption, suspension, dispersibility, cation exchange, stability, thixotropy, non-toxicity and cohesion[27].

Figure 3.1 some various colors of Bentonite

1.1.1 Types of Bentonite clay

There are three main types of Bentonite:

Highswelling (sodium)

Low swelling (calcium)

Moderate swelling (intermediate sodium-calcium) bentonite.

The sodium bentonites are the most useful because of their greater swelling capacity. They are used mainly as bonding clay in foundries, in Drilling fluid, in animal feed pellets, and for civil engineering applications [30]

1.1.2 Water-Bentonite system

When bentonite comes into contact with water, its volume can reach up to 8 times its initial size. Its swelling and adhesive properties make it an interesting material for a wide range of applications. [28]

It is produced by extraction and, even with a moisture content of 30%, it remains solid. Once extracted, it is usually ground and processed before use. One of the most common uses for bentonite is in well drilling. It is used as a mud component for drilling and is used to seal the borehole walls, remove drill cuttings and lubricate the cutting head[29].

1.1.3 Studied clays

Figure 1 showed the studied clays obtained (1) from a drilling company as reference clay, and from extension area of (2) OuledDjellal, (3) Doucen and (4) Leghrous.

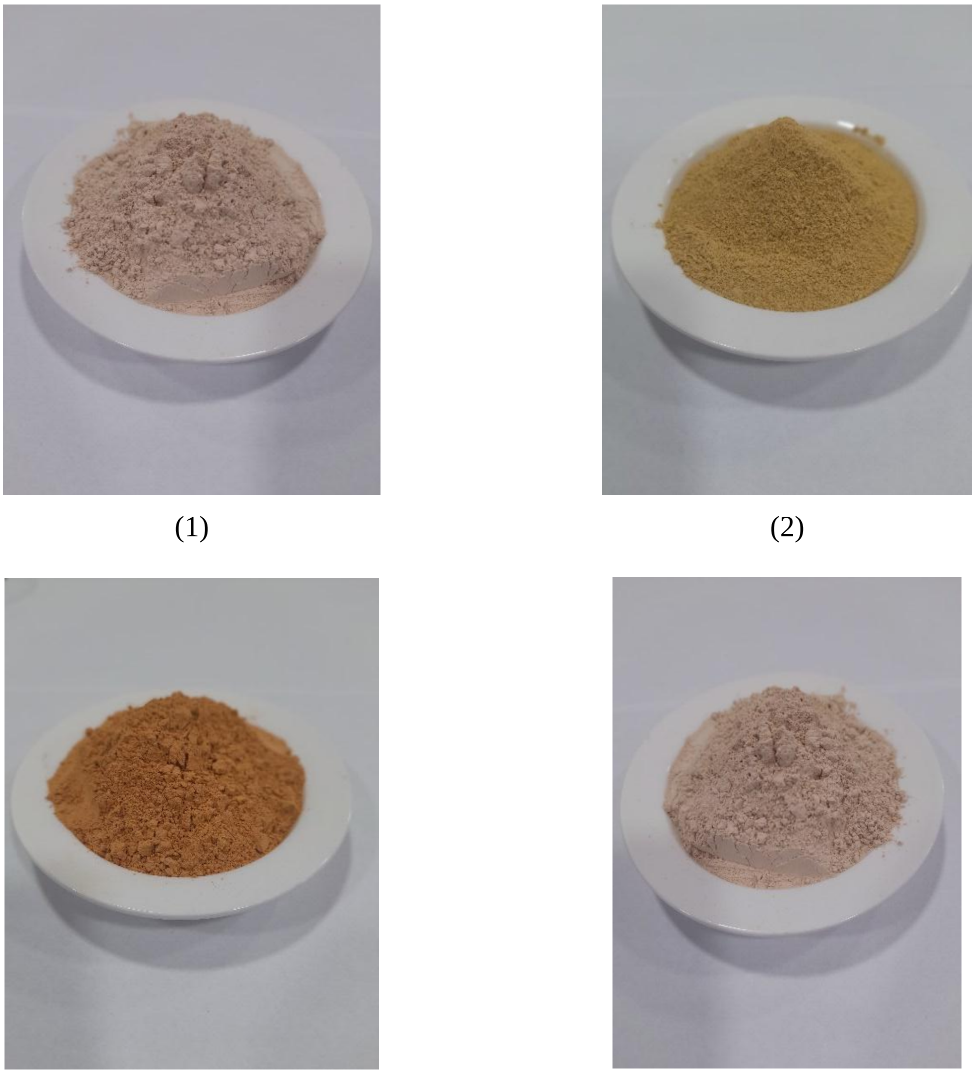
To simplify the use of samples, an abbreviation was used to refer to the clays:

B: industrial bentonite.

O:local clay of OuledDjellal.

D: local clay of Doucen.

L: local clay of Leghrous.



(1) (2)

(3) (4)

Figure 3.2: studied clays are obtained (1) from a drilling company as reference clay called (B clay), and from extension area of (2) OuledDjellal (O clay), (3) Doucen (D clay) and (4) Leghrous (L clay).

1.2 PAC HV

Landoil PAC-HV is a high molecular weight purified polyanionic cellulose polymer that is an extremely effective filtration control additive, viscosity and clay encapsulated in fresh, hard and saline water.

Landoil PAC HV is multifunction, an excellent viscosifier promoting better hole cleaning, forms a protective colloid which inhibits the hydration of water sensitive formations and promotes borehole stability through filtration control.

Landoil PAC HV will enhance the lubricating properties of the fluid and can be added to foam to improve cuttings transportation.

Landoil PAC HV can be added to enhance a Bentonite-based fluid system and is compatible with most polymers lubricants. Addition rates can be adjusted to suit specific applications.[31]

Figure 3.3 PAC HV in drilling site

2 Suspension preparations

2.1 Preliminary tests

2.1.1 Preparation of samples

For this purpose, transparent packaging are important, transparency facilitate the monitoring process, distilled water, scale to measure the mass of samples and water.

2.1.2 Water-clay suspensions

In this experimental protocol, I prepared four (4) different concentration from previous local clays and added them into 100 ml of distilled water, the concentration of clays according to the water was as following:(2,4,6and 8% from water weight).

After shaking the suspensions, letting them in rest was important to observe if samples will stay in suspension or start sedimentation.

The impact of various concentrations of clay on homogeneity of suspensions

In fact, adding the concentration progressively allow the determination of sedimentation rate ,in low concentration of local clays (D,L)we have fast sedimentation and in high concentration the sedimentation takes some time, while the local clay O stay in suspension for long time comparing into D and L ,the bentonite stays in suspension .

To see the next behavior of the suspensions by adding a polymer (Pac HV) with 1% concentration (1g of Pac HV),to see its impact on the samples, the results visualised presented below as following:

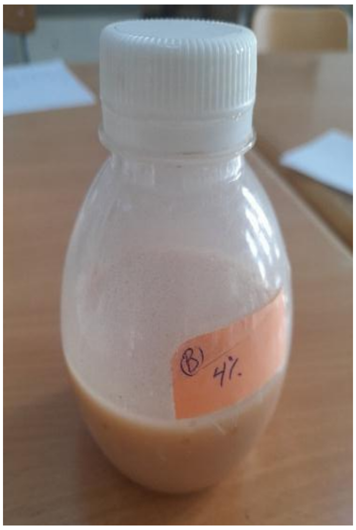


Figure 3.4 polymer added with 4%clay suspensionblend

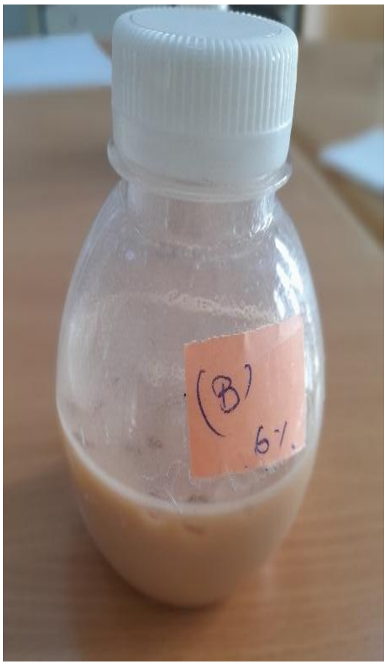


Figure 3.5 polymer with 6% clay suspension blend

2.1.3 Water-clay-PAC HV systems

First suspension: (1g PAC HV with concentration 4% of clay). Observation: Nearly homogenous blend

Second suspension: with concentration (6% of clay and 1g Pac HV). Non homogenous blend.

From this step, the concentration of clay defined to be used in next test was 3% and the concentration of additive should never depose 1%.

2.2 Sample preparation protocols

2.2.1 Water-clay suspension

3g of clay with 100g of water (distilled water)

2.2.2 Water –clay -Pac HV system

- 100 ml (100 g) of water
- 3% clay
- 0,5% Pac HV

And to assure homogenous blends obtaining, I used an agitator to mix well all the suspensions.

Figure 3.6 Agitator used to obtain homogenous blend for experiments.

2.3 Studied samples

This stage is based on Macroscopic observation only.

After fixing the protocol, the real experimental study begins by preparing 4 water-clay suspensions (100g distilled water+3g clay).

-And after immediate shaking of the samples, lettingthem in rest allow realisation of first factorwhich is sedimentation.

Figure 3.7 samples after shaking in (t=0 minute)

After 1 hourof rest:

Figure 3.8 Samples in rest(t=60min)

Letting the suspensions without any moves helps to define which one of samples stays on suspension and which one to sediments, and also how long it takes for full sedimentation.

After 15 days samples

Before the experiment realisation, we put the samples near to each other thus we observe the different between them all, according to sedimentation rate and swelling capacity for water-clay suspensions only.

In another side, from this experience swelling capacity can be observed for those different clays.

And it appears clear way after 15 days, in this test that the bentonite still in suspension phase hence fifteen days passed while for other suspensions full sedimentation but degradation in volume of sedimented clays is clearly different.

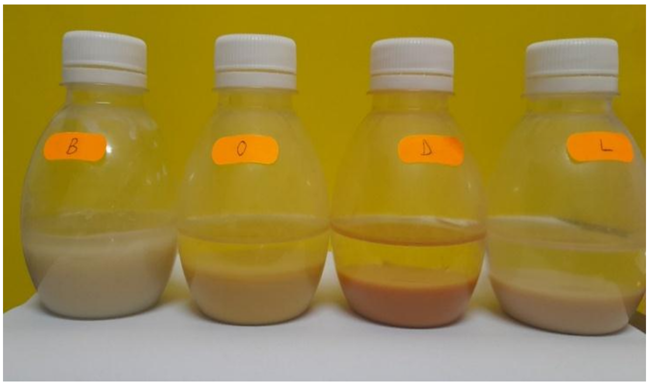


Figure 3.9 Different swelling capacities according to sedimentation volume for water -clay suspensions.

In order to moveto anotheridentification to suspensions behaviour, by comparing how the suspensions would look like with and without additives (here we are talking about PAC HV), after seeing that they don’t have similar results when it comes to sedimentation and swilling capacities in water-clay suspension only.

The results are clear in just observing, how impressive influence of polymer added to the suspensions.

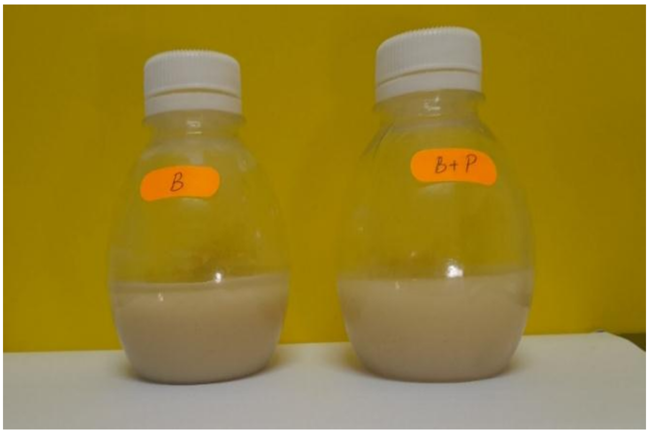


Figure 3.10 Bentonite suspensions.

Figure 3.11 OuledDjellal suspensions

Figure 3.12 DoucenClay-suspensions

Figure 3.13 Leghrouss Clay suspensions

3 Experimental study

This study is effected in College of Precision, Natural and Life Sciences, University of Mohamed Khaider in El Hadjeb ,Biskra.

Also known as: LaboratoryCRAPC-PTAPC Biskra- ELHADJEB-

Instruments used for experiment is Discovery hybrid rheometertype Discovery HR20

A rheometer is a laboratory device capable of measuring the rheology of a fluid. It applies shear to the sample. Generally, of small characteristic size (very low mechanical inertia of the rotor), it enables the fundamental study of the viscoelastic and flow properties of a liquid, suspension, emulsion, paste, plastic, resin, foam, powder, gel, etc., in response to an applied force.

3.1 TA Instruments Discovery Hybrid Rheometer, HR20

3.1.1 Description of HR20

Advances in basic measurement technology have made it possible to perform more sensitive measurements with very high accuracy. This means you can measure lower viscosities and more brittle viscoelastic structures, while using less material. Superior dynamic performance gives a higher level of accuracy when measuring G' and G", enabling to make decisions quickly and with confidence.

Figure 3.14 Rheometer HR20

3.1.2 Characteristics of HR20

-True position sensor (TPS)

-Controlled stress (stable, transient, oscillation)

-Controlled deformation (stable, transient, iterative oscillation)

-Normal force measurements with rebalanced normal force transducer (FRT)

-One-Touch-Away display

-Integrated sample illumination

-FastTrack

-Direct deformation (oscillation)

-Axial and adhesion testing

-DMA mode (optional)

-High-rigidity double radial bearing

-Fast data acquisition

-AutoPilot mode (optional) [7]

3.1.3 DHR Applications

- Flow Curve for Solutions and Dispersions
- Flow Curve for Polymers
- Creep and Recovery
- Flow Curve Predicts Suitability of an Adhesive Coating Formulation
- Viscoelastic Master curve
- Strain Sweeps Predict Dispersion Stability
- Viscoelastic Structure Development

- Extensional Viscosity Measurements
- Coefficient of Friction Measurement
- G’ and G” through cure improved by Optical Encoder Dual Reader
-

3.1.4 Advanced Analysis Capabilities

• More than 10 flow models including automatic model selection based on

best fit to experimental data.

• Time-Temperature Superposition (TTS) analysis with automatic curve shiftingand Master curve generation.

• Activation Energy calculation.

• Convert between temperature ramps and frequency sweeps.

• Cole-Cole, Van Gurp-Palmen, and Lissajous plots.

• Built-in models for: discrete and continuous relaxation or retardation spectra,Oldroyd and Spriggs models.

• Creep ringing analysis by Kelvin, Maxwell, or Jeffreys models.

• Viscoelastic transformations to interconvert between oscillation, stressrelaxation, stress growth, creep, relaxation spectra, retardation spectra, andmemory functions.

3.1.5 TRIOS software

TA Instruments' state-of-the-art software uses the latest technologies for instrument control, data collection and processing in thermal analysis and rheology. The intuitive user interface allows experiments to be programmed simply and efficiently, and to switch easily from the current experiment to data display and analysis.

- Control of multiple instruments using a single computer and software package

- Superimpose and compare results from different techniques, such as DSC, TGA, DMA, SDT, TMA and rheometers

- One-click repeat analysis for increased accuracy

- Automatic generation of customised reports, including: experiment details, graphs and data tables, analysis results

- Easy export of data to CSV, XML, Excel®, Word®, PowerPoint® and image formats

- Optional TRIOS Guardian software with electronic signatures for audit trail and data integrity, including FDA 21 CFR 11 complianceand Full results logging Auto Pilot data analysis.

TRIOS Express

Aide les utilisateurs à concevoir les mesures les plus courantes rapidement et facilement. Des procédures simples et des paramètres par défaut rationalisent le processus de conception et d'exécution des expériences.

TRIOS Unlimited

Gives a total control. A robust set of detailed experimental controls and data collection options ensures that you will be able to design the experiment you want and the data you need.[33]

3.2 Experimental Protocol

- Step (1)Conditioning-Sample
Temperature 25 °C Inherit Set Point: Off
Soak Time 10.0 s
Wait for axial relaxation: Off
Perform pre-shear: On
Shear rate 1.0 1/s
Duration 10.0 s
Perform equilibration: On
Duration 60.0 s

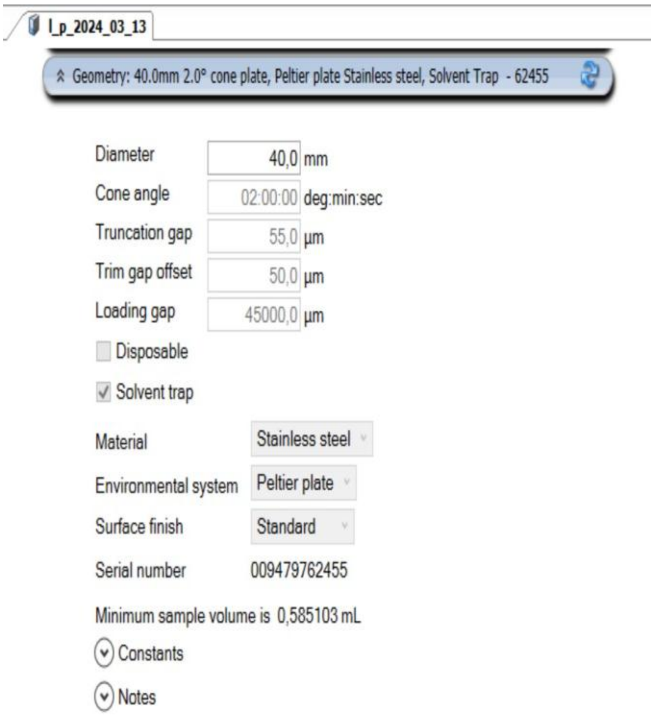
- Step (2) Flow-Ramp
Temperature Inherit Set Point: On
Soak Time 0.0 s
Duration 600.0 s
Mode Log is selected
Initial shear rate 1.0e-4 1/s to 600.0 1/s
Points per decade 10
Save image: Off

- Step (3)Flow-Peak Hold
Temperature Inherit Set Point: On
Soak Time 0.0 s

Duration 600.0 s
Shear Rate 600.0 1/s
Sampling interval 1.0 s/pt
Save image: Off

- Step (4) Flow-Ramp
Temperature Inherit Set Point: On
Soak Time 0.0 s
Duration 600.0 s
Mode Log is selected
Initial shear rate 600.0 1/s to 1.0e-4 1/s
Points per decade 10
Save image: Off

With TRIOS software, not only easy use but more details can be loaded including samples geometries, and the screenshot below from our current study, show some of these information obtained.



l_p_2024_03_13

Geometry: 40.0mm 2.0° cone plate, Peltier plate Stainless steel, Solvent Trap - 62455

Diameter 40,0 mm
Cone angle 02:00:00 deg:min:sec
Truncation gap 55,0 µm
Trim gap offset 50,0 µm
Loading gap 45000,0 µm
☐ Disposable
☑ Solvent trap
Material Stainless steel
Environmental system Peltier plate
Surface finish Standard
Serial number 009479762455
Minimum sample volume is 0,585103 mL

Figure 3.15 Trios window showing sample geometries

Chapter 4: Results and discussion

1 Flow behaviour analyses

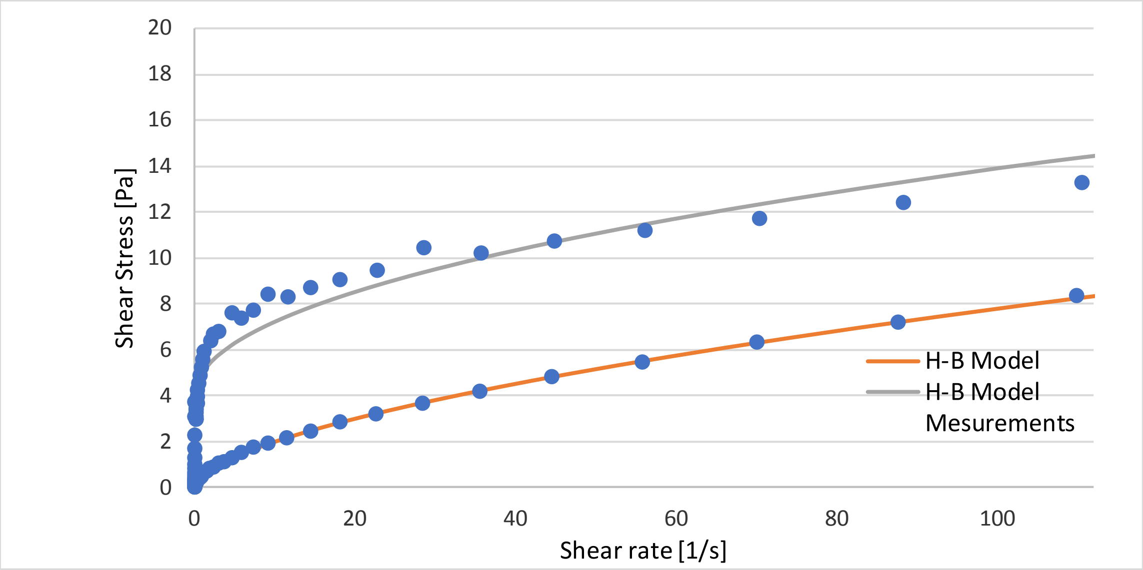


Fig 4.1 Rheogramm of Bentonite presents shear stress (τ)evolution according to shear Rate (while increasing and decreasing)

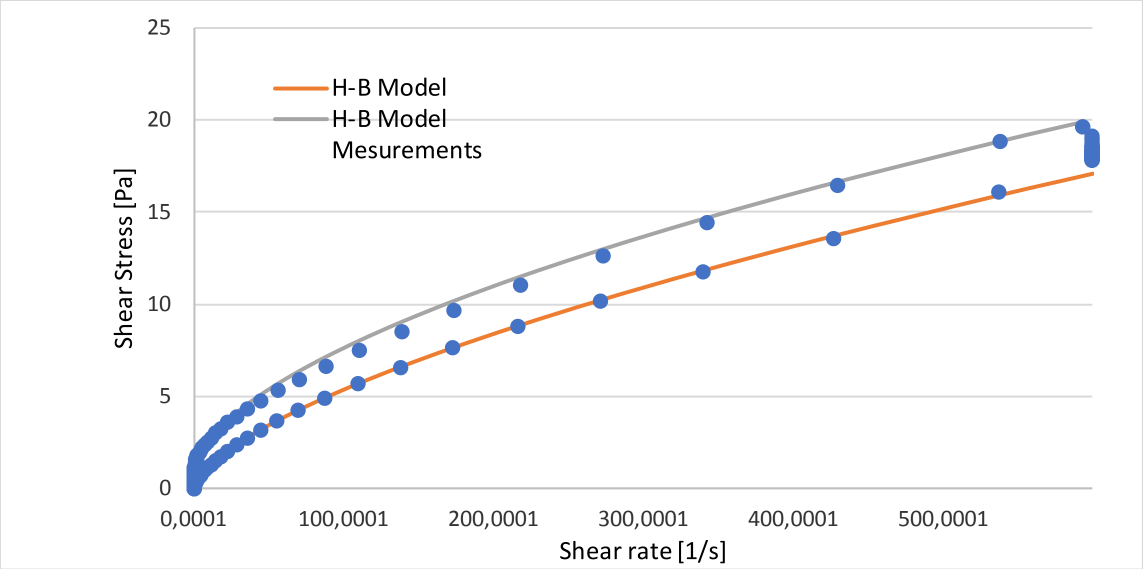


Fig 4.2Rheogramm shows shear stress (τ)evolution according to shear Rate (OuledDjellalclay)

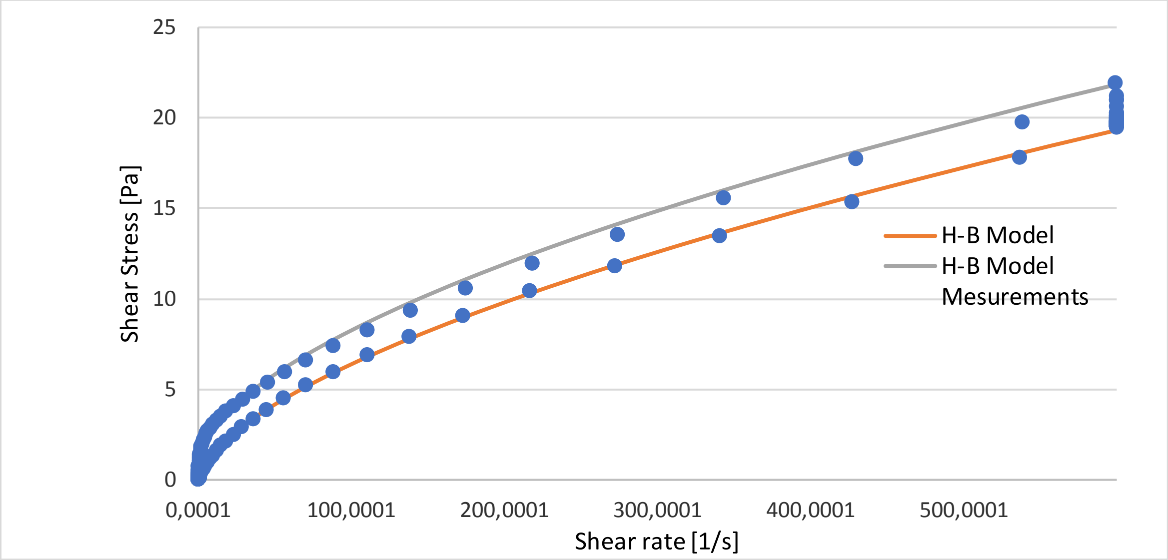


Fig 4.3 Rheogramm shows shear stress (τ)evolution according to shear Rate (Doucenclay)

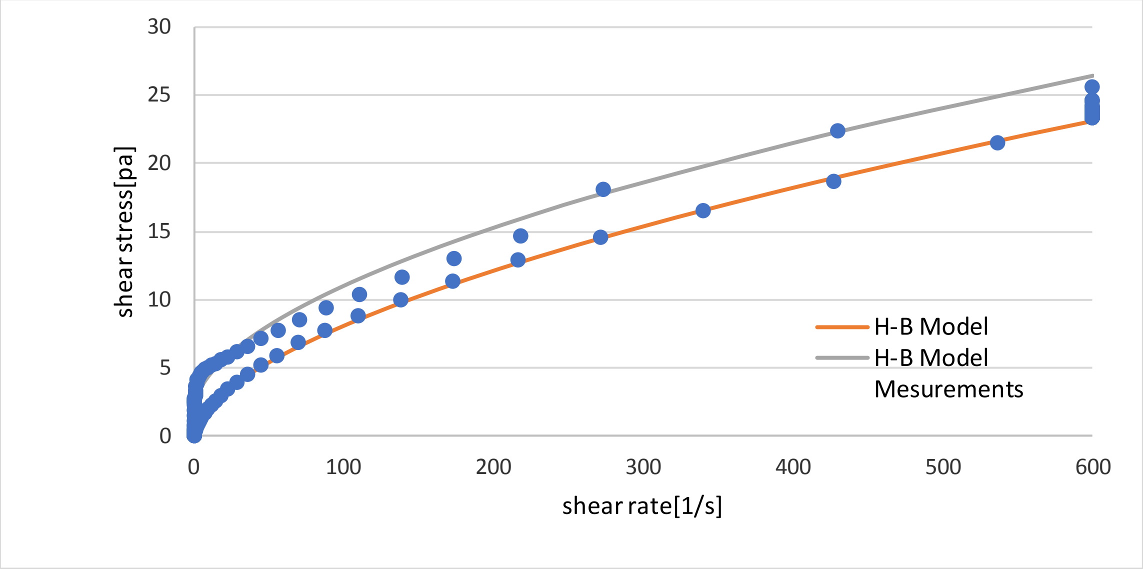


Fig 4.4 Rheogramm shows shear stress (τ)evolution according to shear Rate (Leghrouss clay)

2 Rheological model

The values of measured parameters like yield shear, consistency and flow index are used to identify which rheological model to be used, like in our case it is Herschel Bulkley.

2.1 H-B: Herschel Bulkley model

$$\tau = \tau_0 + K.\dot{\gamma}^n \qquad (4.1)$$

τ_0: yield stress

K: consistency characteriser

n: flow index

2.2 Coefficient of determination

When evaluating the goodness-of-fit of simulated ($\tau_{pred.}$)vs. measured ($\tau_{meas.}$) values, it is not appropriate to base this on the R^2 of the linear regression.

The R^2 quantifies the degree of any linear correlation between (τ_{pred}) and ($\tau_{meas.}$), while for the goodness-of-fit evaluation only one specific linear correlation should be taken into consideration:

$\bar{\tau}$ the mean value of measured shear stress:

$$\bar{\tau} = \frac{1}{n}\sum_{i=1}^{n} \tau_i \qquad (4.2)$$

Then the variability of the data set can be measured with two sums of squares formulas: The sum of squares of residuals, also called the residual sum of squares:

$$\mathrm{SS_{res}} = \sum_{\mathrm{i}} (\mathrm{\tau_i} - \mathrm{f_i})^2 = \sum_{\mathrm{i}} \mathrm{e_i^2} \qquad (4.3)$$

The total sum of squares (proportional to the variance of the data):

$SS_{tot} = \sum_i (\tau_i - \bar{\tau})^2$ 4.4S S tot = ∑ i (y i − y ¯) 2

The most general definition of the coefficient of determination is:

R 2 = 1 − S S r e s SS t o t$R^2 = 1 - \frac{SS_{res}}{SS_{tot}}$ 4.5

In the best case, the modelled values exactly match the observed values, which results in $SS_{res} = 0$, SS res = 0 and $R^2 = 1$.

A baseline model, which always predicts $\bar{\tau}$, will have $R^2 = 0$.

3 Parametric analysis

Different identification parameters are obtained within this study, where each parameter refer to specific indication, and drift into certain values, and according to it, we modelling the results with fitting Rheological model, like what we got in current work, as shown in the tables below, each clay has its own values so we can compare between them easily.

	τ_0	K	n	R^2	sum	Area	%thixotropy
SM	4	1,066196	0,484018	0,6	362,5308	1201,223	52,55794
SD	0,07	0,457779	0,616835	0,9991	0,197298	569,8848	

Table 4.1measurement results of differentparameters of Bentonite

	τ_0	K	n	R^2	sum	Area	%thixotropy
SM	1	0,330004	0,634833	0,58	64,79492	7494,805	16,74167
SD	0,02	0,457779	0,616835	0,65	30 ,0735	6240,049	

Table 4.2 measurement results of different parameters of local clay (O)

	τ_0	K	n	R^2	Sum	Surface	% Thixotropy
SM	1,8	0,72903	0,55	0,9404	106,2209	10211,17	14,44938
SD	0,01	0,53	0,59	0,9996	0,752199	8735,716	

Table4.3 measurement results of different parameters of clay (L)

	τ_0	K	n	R^2	Sum	Surface	% thixotropy
SM	1	0,48	0,59	0,9797	32,8264	8179,228	12,58783
SD	0,03	0,369567	0,618491	0,9997	0,4427	7149,641	

Table 4.4 measurement results of different parameters of clay(D)

3.1 Shear stress

One of multiplerheologicalbehavior that has influence on flow.

The shear stress of studied suspensions with components (Water +clay+polymer) is shown in both cases structured and non-structured in table below.

Table4.5 shear stress values in structured and non-structured cases

τ_0	L	O	D	B
structured	1,8	0,8	1	4
Non stuctured	0,01	0,03	0,03	0,04

Measurement show that in structured case, a clear difference in shear stress values ,Bentonite takes highest value(τ=4) ,Leghrouss (1,8),Doucen (1)and lowest value Ouled -Djellal with 0,08 .

In non-structured case important remarkable decreasing in bentonite shear stress from 4 to 0,04 where OuledDjellal and Doucen clay takes same value, and almost annulled for Leghrouss clay.

3.2 Consistency

Table (4.7): consistency values

K	L	O	D	B
structured	0,72903041	0,47	0,48	1,06619582
Non-structured	0,53	0,26662476	0,36956734	0,45777888

In structured case, Bentonite register highest value (k=1,066), Leghrouss takes high value (n=0,73) where lower values are for Doucen and OuledDjellal respectively. In unstructured case ,an important decreasing in values specially Bentonite(k=0,45)where it became less than Leghrouss(k=0,53)

Flow index:

According to obtained results, in structured case clear convergence in flow index values for local clays confined between (0,55<n<0,6) comparing to Bentonite, its value less than others(n=0,48<0,5) while in non-structured case, important increasing appears for all samples (B, O, D~0,65) near results but lowest value recorded for Leghrouss(n=0,59)

3.3 Flow index

Table (4.8): flow

n	L	O	D	B
Structured	0,55	0,58	0,59	0,48401812
Non -structured	0,59	0,65	0,61849105	0,61683518

According to obtained results, in structured case clear convergence in flow index values for local clays confined between (0,55<n<0,6) comparing to Bentonite, its value less than others(n=0,48<0,5) while in non-structured case, important increasing appears for all samples (B, O, D~0,65) near results but lowest value recorded for Leghrouss(n=0,59)

Conclusion

This document focuses on the flow behaviour of water based drilling fluid. The objective of this work is to study the possibility of using local clays obtained from OuledDjellal, Doucen and Leghrous as drilling fluids without and in the presence of PAC HV as a viscosifier additive.

The results showed that the direct use of local clays as aqueous clay suspensions is not desired. On the other hand, the water-clay-PAC HV system made it possible to obtain typical drilling fluid behaviour; where Herschel Bulkley model is used to model the flow behaviour in a satisfactory manner. A parametric study is carried out basing on Herschel Bulkley parameters (flow index, n, consistency, k and yield stress τ_0) and thixotropic percentage. The parametric study showed a difference between industrial Bentonite and local clays, particularly for the flow index and thixotropic percentage. This shows the need to treat local clays before using them as water based drilling fluid.

References

[1] NTRODUCTION. RHEOLOGY: SUBJECT AND GOALSRheology Concepts, Methods, and Applications 2012, Pages 1-8

[2] El Kissi et al., Rhéologie, Vol. 10, 13-39 (2006)

[3] https://www.eurofins.fr/materials-and-engineering-sciences/nos-techniques/rh%C3%A9ologie/

[4]http ://culturesciencesphysique.ens-lyon.fr

[5] Rheol Acta (2008) 47:621–642-DOI 10.1007/s00397-008-0268-1

[6] https://www.lamyrheology.com/applications/

[7] https://www.alfatestlab.com/fr/prodotti/mesures-de-viscosite-et-proprietes-rheologiques/

[8] https://www.futura-sciences.com/sciences/dossiers/physique-rheophysique-matiere-tous-etats-1664/page/5/

[9]©Philippe Coussot

[10] https://fluidan.com/different-types-of-rheometers.

[11]https://www.universalis.fr/encyclopedie/forages/

[12] CARACTÉRISTIQUES RHÉOLOGIQUES ET COMPOSITION DES BOUES DE FORAGE

Communication présentée au Comité Technique de la Société Hydrotechnique de France

le 20 mars 1970 PAR MIl(' M. MARTINArticlepublished by SHF and available at:

https://www.shf-lhb.org/articles/lhb/pdf/1970/05/lhb1970034.pdf

[13] https://fr.scribd.com/document/367687451/fluide-de-forage

[14]https://fr.medrillingfluids.com/news/oil-based-mud-systems-and-non-aqueous-fluids-44154901.html

[15] (les boues de forage) formation de ENSP 2008.

[16]https://www.vermilionenergy.com/fr/nos-activites/la-recherche-du-petrole-les-activites/les-differents-types-de-forage-en-france/

[17]published at https://www.energyfunders.com on May 8, 2019.

[18] https://elwatan-dz.com/bassin-de-berkine-sonatrach-et-eni-annoncent-une-importante-decouverte-de-petrole

[19] IADC Drilling Manual Copyright © 2014INTERNATIONAL ASSOCIATION OF DRILLING CONTRACTORS

[20] http://www.plastechplus.ca/nouvelles/a-quoi-servent-les-boues-de-forage.aspx

[21] https://www.futura-sciences.com/sciences/definitions/physique-rheologie-2093/

[22] https://rheoplus.com/fr/quest-ce-que-la-rheologie

[23] Model 35 Viscometer Instruction Manual 208878 Revision N, February 2013 17

[24]https://oatao.univ-toulouse.fr/7728/1/khodja.pdf

[25]18ème Congrès Français de Mécanique Grenoble, 27 -31 août 2007

[26]documents d'origine :Ministère d'énergie et des mines(OuledDjellal)

[27] 14/12/2021|In Industry News |By ALPA Powder

[28]https://www.ecoflora.be/fr-be/d/product-detail/16300-bentonite

[29]http://www.plastechplus.ca/nouvelles/quest-ce-que-bentonite.aspx

[30]https://resources.vic.gov.au/geology-exploration/minerals/industrial-minerals/bentonite

[31]https://www.landoilchem.com/pac-hv-pac-lv-product/

[32]https://f.nordiskemedier.dk/237hz07bw52196qa.pdf

[33] https://www.dksh.com/global-en/products/ins/ta-instruments-rheometers

[34] https://www.sciencelearn.org.nz/resources/1502-non-newtonian-fluids

[35]K. Van Canneyt, P. Verdonck, in Comprehensive Biomedical Physics, 2014

[36]L. Zheng, X. Zhang, in Modeling and Analysis of Modern Fluid Problems, 2017

[37]Mark D. Normand and Micha Peleg (March 2011) "Flow Curves of a Herschel-Bulkley Fluid"

[38]Brian Lockett-‘most beautiful fluid-published ‘:28August 2017