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# Characterization of the Drilling Mud Adapted to the Geological Formations of the Agadem Oil Field, Termit basin (Southeastern Niger): Case of the Dibella Well

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**Abstract:** The objective of this study is to characterize the drilling mud adapted to the geological formations of the Agadem oil field (Niger). During the drilling process, the mud is monitored and adjusted regularly according to the instantaneous logging data. Thus, the typologies of drilling mud and their physicochemical and rheological properties at the level of each phase of drilling were determined in the laboratory of the site during the realization of the Dibella well. Two (2) types of mud (Pre-hydrated bentonite (PHB) and polymer) were used during the drilling of the Dibella well. The PHB mud, used from 0 to 800m depth, is characterized by a variable density depending on the lithology, a MARSH viscosity of 60 to 75 seconds and a pH between 8 and 9. The polymer mud, used between 800 and 2680 m, is characterized by an equally variable density, a MARSH viscosity of 55 to 60 seconds, a plastic viscosity of 10 to 20 mPa.S, a yield point between 2 and 10 Pa, an apparent viscosity of 3 to 5 mPa.S, a Gel strenght ($G_{10''}/G_{10'}$) of 1 to 4/2 to 10 Pa and a pH, always between 8 and 9. These parameters, which allowed the Dibella drilling to be carried out in an optimal way, can be used as a guide for the realization of new wells in the study area.

**Keywords:** Agadem oil field, Dibella well, Pre-Hydrated Bentonite mud, Polymer mud, Physicochemical and rheological properties.

## 1. INTRODUCTION

The Agadem oil field is an integral part of the Termit basin, located in the southeastern part of Niger. Important hydrocarbon deposits have been identified in the said basin where the sedimentary thickness would reach more than 4000m. The exploitation of these deposits necessarily involves drilling. Drilling is a complex activity whose success depends mainly on the quality of the drilling mud [1,2]. The choice of the mud is essentially linked to the nature of the ground to be crossed and the depth to be reached. The objective of this study is to determine the characteristics of the different muds used during the drilling of the Dibella well on the Agadem oil block. Thus, during the execution of the drilling, the mud is regularly monitored and adjusted according to the data of the instantaneous logging (parameters of the drilling machine) [3]. These parameters indicate the stability or not of the well walls, the water-bearing, porous, impermeable, clay or sandy zones. When crossing these zones, the drilling fluid is adjusted (addition of water, bentonite, soda ash or other products) to ensure the safe progress of the drilling [4]. Also, at each stage of modification of the mud, its characteristics are determined in order to elaborate a drilling mud model adapted to the Agadem oil field. The parameters characterizing the mud, determined in the site laboratory, concern the pH, viscosity, density and rheological properties [5]. Thus, the characteristics of the mud according to the type of formation crossed during the drilling of the Dibella well on the Agadem block, were established. These characteristics can be used as a guide for new drilling in the study area.

## 2. GEOLOGICAL CONTEXT

The Agadem Oil Block (Figure 1) occupies the hinge part of the Termit Basin, belonging to the large Eastern Niger Basin (Chad Basin). The Termit is characterized by a graben system controlled by a network of NS, NNW-SSE and NW-SE oriented faults [6]. The thickness of the sediments in these trenches can reach more than 4000 m, where significant accumulations of hydrocarbons have been demonstrated [7]. The age of the sediments identified in the grabens varies from early Cretaceous to Neogene. The existence of older series (Jurassic-Paleozoic) cannot be excluded [6].

Exploration drilling has discovered significant oil and gas reserves in the Termit Basin. These reserves are generally contained in the reservoirs of the Yogou formation in the Agadem block. The lithostratigraphic column below (Table 1) summarizes the succession of geological formations encountered on the Agadem block, their ages, their depths as well as their lithological descriptions. This column was established on the basis of the geological data acquired from the wells already drilled and the seismic profiles carried out.

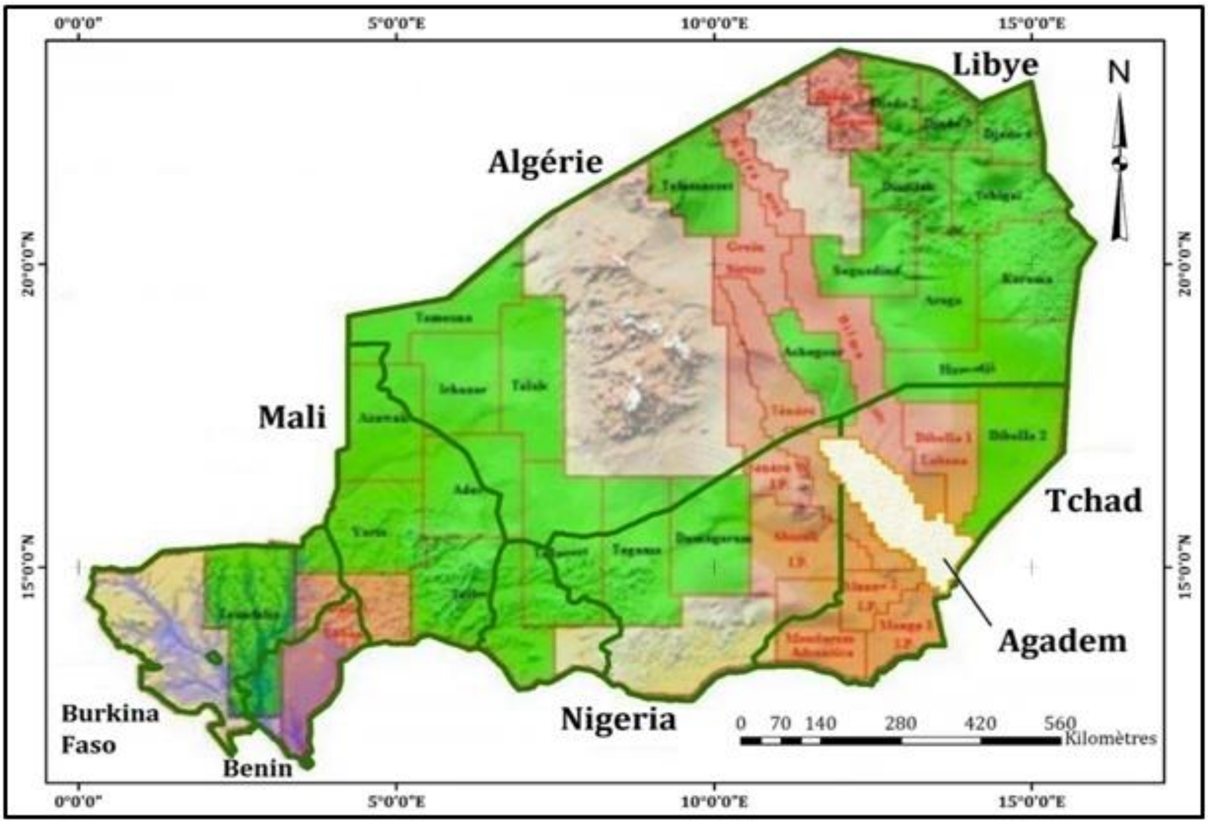


Figure 1. Location of the Agadem oil block [8]

The sedimentary filling of the Termit basin and its tectonic evolution are summarized as follows [9]:

- An initial rifting phase from the Aptian to the near Cenomanian constituted the first filling of the basin with fluvio-lacustrine shale.
- Another phase called thermal subsidence from the end of the Cenomanian to the Maastrichtian fills the basin with marine shales associated with striated sandstones and massive fluvial sandstones:
  • Deposition of a thick marine schistose series, slightly calcareous, called "Donga Clay" then newly defined "Fachi Clay" in relation with the general transgression towards the end of the Cretaceous (Cenomanian to Santonian),
  • During the decrease of the marine activity and as a result of the tectonic phase induced by the collision of the African and European plates there was first deposition of a thick layer of alternating shale and sandstone "Yogou Series" in the Campanian and then a thick layer of massive fluvial sandstones "Madama sandstone" in the Maastrichtian and after a complete transient uplift.
- Paleogene and Neogene tectonic phase :
  • Tertiary formation consisting of alternating fluvio-lacustrine shales and sand "Sokor Alternations" and then lacustrine shales "Sokor Shales" during the Paleo-Eocene,
  • Lake shales with small proportions of sandstone in the lower part of the "Oligocene Alternation" and "Oligocene Clay",
  • The aeolian sandstones are formed by fluvio-lacustrine and sandy shale series constituting the "recent formation" dated from the Pliocene half.

Table 1. Prognosis of the stratigraphy of the Dibella Well [9].

| Age | Geological division | Approximate depth | Lithological description |
|---|---|---|---|
| **Quaternary**<br>**Miocene** | Recent formation | 600 | Unconsolidated sand with occasional horizons of shallow lower section clay, fine to coarse grained sand and sandstone and gravel. Mainly quartz and some feldspar occasionally variegated by clay. |

| | | | |
|---|---|---|---|
| **Oligocene** | Sokor claystone | 1256 | Claystone |
| | Medium velocity claysttone | 1322 | Claystone |
| **Paleo-Eocene** | Sokor sandy alternance | 1990 | Intercalation of sandstone and claystone |
| **Cretaceous** | Madama | 2409 | Solid sandstone |
| | Yogou | 2680 | Claystone with sandstone intercalation |
| **Total depth** | | 2680 | |

## 3. DIBEILLA WELL MUD PROGRAM

The mud program for the Dibella well is closely related to the different formations to be drilled, the environmental and economic constraints and the possibilities of supplying the products of its preparation on site [8]. To develop this program (Table 2), data from previously drilled wells in the Agadem oil field and seismic data were used. Drilling mud is used in drilling to perform various roles.

### 3.1 Definition of drilling mud

A drilling fluid or drilling mud is a system composed of different combinations of liquids (water, oil), gases (air or natural gas) containing in suspension a solid phase (clay, cuttings, cements). It's a non-Newtonian fluid, viscous or viscoelastic, most often thixotropic.

### 3.2 Roles of the drilling mud

Mud plays a crucial role in drilling in general and particularly in oil drilling [1,10]. The drilling mud is in continuous circulation throughout the drilling process, both in the well and at the surface (Figure 2). It is injected from the inside of the drill pipe to the tool. Then, it goes up through the annular space loaded with cuttings formed at the face. At the exit of the shaft, it undergoes various treatments (sieving, dilution, addition of product, etc.) in order to eliminate the transported cuttings and to readjust its physicochemical and rheological characteristics in order to ensure its proper functions [11]. In a non-exhaustive way, the following roles are recognized for drilling mud [1,10]:

- Cleaning of the well,
- Keeping the cuttings in suspension,
- Sedimentation of cuttings on the surface,
- Cooling and lubrication of the tool and the shank train,
- Prevention of cavitation and tightening of the well walls,
- Consolidation and reduction of the permeability of the well walls,
- Prevention of water, gas and oil spills,
- Increased speed of travel,
- Tool drive,
- Reduction of the apparent weight of the drilling equipment,
- Provide information on the survey.

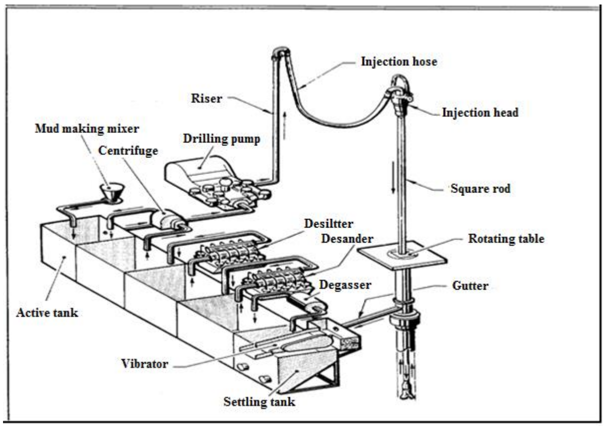


Figure 2: Drilling mud circuit [2]

### 3.3 Pre-Hydrated-Bentonite (PHB) mud

The PHB mud is planned for phases 1 and 2 of drilling for depths ranging from 0 to 800m. During these phases, the expected formations to be crossed are mainly sand and clay. This mud will consolidate the well's surroundings and ensure the continuity of the drilling in complete safety.

### 3.4 Polymer mud

Polymer mud is used during the 3rd drilling phase. This phase is crucial because it involves challenges that need to be addressed, such as the risk of gas ingress, high pressures on the hole walls and certain technical failures. At this stage, a polymer mud system will be prepared, whose characteristics must be regularly checked.

Table 2. Dibeilla well drilling mud program [8]

| Hole diameter | Depth | Mud system | Mud density |
|---|---|---|---|
| 17 1/2" | 0-800m | PHB mud | 1.03-1.05 g/cc |
| 12 1/4" | 800–2680m | Polymer mud | 1.05-1.15 g/cc |

# 4. MATERIALS AND METHODS

## 4.1 Drilling mud preparation

Several types of mud are needed to carry out drilling on the Agadem block. These drilling are prepared in tanks erected on the site (Figure 3).

Figure 3. Mud tank used on the Dibella well site

### *4.1.1 Preparation of the PHB (Pre-Hydrated Bentonite) mud*

Pre-hydrated bentonite mud is prepared using water, bentonite and sodium carbonate (Soda Ash). Other minor products, such as caustic soda and LCM (Lost Circulation Materials) are combined in the mixture.

Bentonite is a viscosifier and Ash soda is used to hydrate the clays and remove $Cu^{2+}$ ions. The mixing of these products must take at least 16 hours before the drilling operation begins. The dosages of these products are recorded in Table 3 below.

Table 3. The formulation of PHB (Pre-Hydrated Bentonite) drilling fluid

| Chemical | Function | Dosage (Kg/m$^3$) |
|---|---|---|
| **Bentonite** | Viscosifier | 60-90 |
| **Soda Ash** | Clay hydration and eliminate $Ca^{2+}$ | 2.0-3.0 |

### *4.1.2 Polymer mud preparation products*

The polymer mud is composed of bentonite and products controlling the viscosity, density, pH and gel of the drlling mud (PAC-L, NPAN, KPAM, XCD, PAC-R and NFC). The dosages of these products and their functions within the mud are shown in Table 4 below.

Table 4. Formulation of polymer drilling fluid system

| Chemical | Function | Dosage (kg/m$^3$) | Remarks |
|---|---|---|---|
| Bentonite | Viscosifier | 25-40 | |
| PAC-L | FL control agent | 3-8 | Can be replaced by NFC-1 or used together, total dosage is 3-8 kg/m$^3$ |
| NPAN | Thinner/FL controller | 3-6 | Also can inhibit formation clay dispersing |
| KPAM | Encapulater/Viscosifier | 2-6 | High molecule weight polymer |
| XCD | Gelling agent | 1-3 | For choice, increase viscosity |
| PAC-R | Viscosifier/FL | 1-3 | For choice, increase viscosity |
| NFC | FL control agent | 3-8 | Replaced PAC-LV |

## 4.2 Monitoring and determination of the physicochemical parameters of the mud

### *4.2.1 Monitoring of the mud physicochemical parameters*

The monitoring of the physicochemical parameters is done through tests carried out at the site laboratory. On site, it is essential to control the characteristics of the drilling mud at regular intervals for any mud system used.

- The first check to be made is the determination of the chemical nature of the water (concentration of magnesium or calcium ions), which will make it possible to know the quantity of Soda Ash to be added to eliminate them.
- During the drilling process, care must be taken to ensure that the characteristics of the mud allow the consolidation of the well walls (avoid friction due to GEL, yield point and plastic viscosity) and control the infiltration of the drilling fluid (when porosity and permeability are high). These two controls help to maintain the stability of the well.
- Then, the mud must be cleaned of all the drilled solids that could affect the physicochemical parameters (viscosity, density and pH), using specific instruments

in the mud circuit (decanter, desander, desilter, degasser, etc.).

### *4.2.2 Hydrogen Potential (pH) measurement*

The Hydrogen Potential of the drilling mud is measured on site with a pH-meter.

### *4.2.3 Fluid Viscosity (FV) or MARSH viscosity Measurement*

MARSH viscosity is measured by measuring the time in seconds that a certain amount of mud takes to flow through the nozzle of a standard funnel. The mud flows into a graduated cup. The procedure consists of:

- Take the MARSH funnel and close the nozzle with finger,
- Take mud from the gutter and pour it over the funnel screen until the mud level reaches the surface of the screen (corresponding to a volume of 1500 $cm^3$),
- Hold the funnel by the side handle, start a stopwatch and let the mud flow into the measuring cup,
- Stop the timer when the mud level reaches 946 $cm^3$ (1/4 gallon in the bucket),
- The number of seconds read on the stopwatch represents the MARSH viscosity of the mud.

Figure 4. Measurement of mud viscosity using a MARSH Funnel

### *4.2.4 Measurement of the density or Volumic Mass (MV) of the mud*

The measured density corresponds to the volumic mass. The measurement procedure consists of the following steps:

- Fill the cup with measuring mud,
- Put on the cover and drain off the excess mud that comes out through the central hole in the cover provided for this purpose,
- Clean with water and dry, taking care to keep the hole in the cover permanently blocked,
- Place the flail knives in the knife holder on the base,
- Move the cursor until the flail is horizontal. This horizontality must be checked with the spirit level located above the knives,
- Read the density directly on the arm of the flail, at the right of the cursor position.

Figure 5: Density measurement of the mudwith a densimeter

### *4.2.5 Rheological properties tests (PV, YP, AV and Gel Strenght)*

To test the rheological properties of the mud, a sample of smud is taken and tested in situ at the site laboratory. It is important to avoid the drop in temperature of the mud, which can lead to erroneous results. The device used is the "six-speed viscometer", which as its name indicates, has six speeds expressed in revolutions per minute (600-300 / 200-100/ 6-3). The test procedure is as follows:

- Pour the mud into the cylinder of the machine.
- Make the level of the mud in the cylinder coincide with that of the six-speed rotor by raising the plate on which the mud is placed until it reaches the level marker ring (of the six-speed).
- Hold the cylinder containing the mud with the plate fixing screw.
- Run the motor of the machine at high speeds (600-300 rpm) and record the readings on the "six-speed" chart or counter.
- Run the motor at intermediate speeds (200-100 rpm), also recording the readings.
- Run the motor at low speeds (6-3 rpm), always reporting the readings.

The velocity ranges and reported values will be used to calculate Plastic Viscosity (PV), Yield Point (YP), Apparent Viscosity (AV) and Gel Strenght ($G_{10''}/G_{10'}$) according to the following Bingham calculation model:

PV= (value of 600 rpm) - (value of 300 rpm) in milli-pascal second (mPa.s).

YP = 2(value of 300 rpm) - (value of 600 rpm)/2 in Pascal (Pa).

AV= (values of 600 rpm)/2 in mPa.s.

The Gel Strenght is determined in 10 seconds ($G_{10''}$) and 10 minutes ($G_{10'}$) as follows:

For 10 seconds, the procedure is as follows:

- Run the motor at 600 rpm for 10 seconds and stop.
- Observe a 10-second pause during which the gearshift lever is returned to the low gear level.
- Select the speed of 3 rpm and report the maximum value read.
- Divide the value obtained by two to get the Gel strenght in 10 seconds ($G_{10''}$).

For 10 minutes:

- The procedure is the same as before, except that the pause lasts 10 minutes instead of 10 seconds.
- The value read will also be divided by two to get the Gel strenght in 10 minutes ($G_{10'}$).

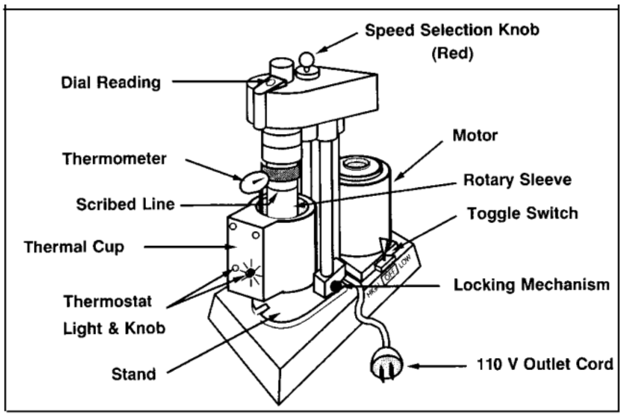


Figure 6. Six-speed viscometer [8]

## 5. RESULTS AND DISCUSSION

Two (2) types of mud were used in this study: the Pre-Hydrate Bentonite (PHB) and the polymer drilling fluid.

### 5.1 Characterization of the PHB drilling fluid

The PHB drilling fluid is used between 0 and 800m depth, in unconsolidated sand and clay formations. The results of the analyses carried out on this mud are recorded in Table 6.

Table 5. PHB drilling fluid properties

| MV g/cm³ | FV sec | PV mPa.S | YP Pa | AV mPa.S | $G_{10''}/G_{10'}$ Pa | pH |
|---|---|---|---|---|---|---|
| As designed | 60-75 | - | - | - | - | 8-9 |

Pre-Hydrated bentonite (PHB) mud is characterized by three (3) physicochemical properties: density (MV), viscosity (FV) and Hydrogen Potential (pH).

- The density is not specified (as designed) because it's variable at any time of drilling. It's very sensitive to changes in lithology or to the presence of fluids or pressures in the formations. This mud (PHB) has been used for recent, very poorly consolidated formations; this requires a density high enough to traverse safely [12]. In addition, a very dense mud is required to cross water tables.
- Fluid viscosity (FV) can be defined as all the phenomena of resistance to the movement of a fluid for a flow with or without turbulence. Viscosity reduces the freedom of flow of a fluid and dissipates its energy. Viscosity is one of the most important parameters of the mud because it's through viscosity that the mud performs the following functions [13]:
  • Sedimentation of fine cuttings on the surface,
  • Keeping the cuttings in suspension,
  • Cleaning the well,
  • Increasing the speed of travel,
  • Cooling and lubrication of the drilling tool and drill string.

  Very low viscosities are a favourable factor for the penetration of the drilling tool, but they do not favour the maintenance of cuttings in suspension and their evacuation on the surface [13]. In addition, when formations are poorly consolidated, high viscosity is necessary to better evacuate them. Hence the high viscosities (60 to 75 seconds) are measured for the recent formation which is made up of unconsolidated sand.
- The Hydrogen Potential (pH), characterizes the acidity or basicity of the mud. A mud can be acidic or basic depending on the nature of the formations or their content. Thus, as the geological formations of the Agadem oil field are more or less basic, the pH of the prepared mud must always be greater than or equal to 7 to avoid any acid-base reaction.

### 5.2 Characterization of the Polymer drilling fluid

The polymer drilling fluid is used between 800 and 2680m depth, in alternating sandstone and claystone, indurated. The results of the analyses carried out on this mud are recorded in Table 6.

Table 6. Polymer drilling fluid properties

| MV g/cm³ | FV sec | PV mPa.S | YP Pa | AV mPa.S | $G_{10''}/G_{10'}$ Pa | pH |
|---|---|---|---|---|---|---|
| As designed | 55-60 | 10-20 | 2-10 | 3-5 | 1-4/2-10 | 8-9 |

The polymer mud is characterized by physicochemical properties (density (MV), viscosity (FV) and Hydrogen Potential (pH)) and rheological properties (Plastic Viscosity (PV), Yield Point (YP), Apparent Viscosity and Gel Strenght ($G_{10''}/G_{10'}$)).

- The density (density) is not as specified (as designed) for polymer mud because it is variable at any time of drilling for its great sensitivity to changes in lithology, presence of fluids or pressures of formations [14]. At great depths, it also allows to control the pressure of the formations and gases, the invasion or the overflow of fluids in the well. This gives the well a great stability.

- The Fluid Viscosity (FV) is relatively low (55 to 60 seconds) compared to the PHB mud. This is due to the presence of consolidated formations in this portion of the borehole.
- The Plastic Viscosity (PV) of the mud is a state of viscoplasticity corresponding to a perfect solid behavior at low stresses and a viscous fluid behavior above a threshold stress [15]. This property is very useful for the transport and disposal of cuttings [16]. The PV has medium to high values (10 to 20 mPa.S) in the polymer mud. These values are relative to the greater or lesser depths of the Dibella well where this mud was used, since the greater the depth, the higher the value of plastic viscosity should be.
- The Yield Point (YP) or fluid pressure allows the mud to ensure the stability of the walls of the hole and to fight against the eruption of gas or hydrocarbons in the well [12,17]. This is the drilling mud pressure. This pressure must be high enough to fight against the pressures outside the well. At a depth of more than 2000 m, the pressure of the geological formations around the well is very high, as is the pressure of the fluids in the vicinity of the hole. The Yield Point of the polymer mud reaches 10 Pa at these depths, which is sufficient to stabilize the Dibella well.
- The Apparent Viscosity (AV) or dynamic viscosity of the mud is a physical quantity that characterizes the resistance to laminar flow of an incompressible fluid [18,19]. It is strongly dependent on temperature [20]. The AV must be low to avoid erosion of the cake by the mud at the hole walls [21]. It must also be low compared to the plastic viscosity. For the polymer mud used in the Dibella well, this viscosity is 3 to 5 mPa.S. These values characterize a low flow resistance of the mud.
- Gel Strenght $G_{10''}/G_{10'}$: This property allows the polymer mud to consolidate the walls of the well by forming a cake on the walls thanks to the phenomenon of freezing [22]. In addition, when the circulation stops, the sedimentation speed of the cuttings is of the order of a few m/min, but the freezing of the mud increases rapidly [22]. However, a not very high freezing point is appropriate to avoid early sedimentation. Nevertheless, a low gel is not effective for the lifting of cuttings. For the polymer mud used in the Dibella well, the gel measured at 10 minutes (2 to 10 Pa) is about 2 to 3 times that measured at 10 seconds (1 to 4 Pa). These average gels are adapted to the geological formations of the Agadem oil field.
- The Hydrogen Potential (pH) is always greater than or equal to 7, as for the PHB mud, given the basic nature of the geological formations of the Agadem oil field. Such a pH will avoid any acid-base reaction that could lead to the formation of a new product that could cause the mud to malfunction [20,23].

## 6. CONCLUSION

The characterization of the muds used during the drilling of the Dibella well on the Agadem oil field, was carried out through tests carried out in the site laboratory as the drilling progressed. These tests made it possible to determine the types of muds adapted to the Agadem oil field as well as their physicochemical and rheological properties at each stage of the drilling execution. Thus, two (2) types of mud (Pre-hydrated bentonite and polymer) were used during the drilling of the Dibella well. The PHB mud, used from 0 to 800m depth, is characterized by a variable density depending on the lithology, a MARSH viscosity of 60 to 75 seconds and a pH between 8 and 9. The polymer mud, used between 800 and 2680 m, is characterized by an equally variable density, a MARSH viscosity of 55 to 60 seconds, a plastic viscosity of 10 to 20 mPa.S, a fluid pressure between 2 and 10 Pa, an apparent viscosity of 3 to 5 mPa.S, a Gel strenght $G_{10''}/G_{10'}$ of 1 to 4/2 at 10 Pa and a pH, always between 8 and 9. These parameters, which allowed the Dibella drilling to be carried out safely, can be used as a model for other wells in the study area.

## 7. ACKNOWLEDGMENTS

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