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Optimization of mechanicals drilling bit parameters

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Dedication

We are very thankful to ALLAH that He enable us to finish this work after years of education.

We want to dedicate our work in the first place, to our dear parents, for their sacrifices, patients and encouragement, during the whole period of studies.

We also dedicate this work to our brothers and sisters, for their support and contribution to our formation.

Also, To our best friends and relatives.

To all our family, the olders and youngers:

BAHAFID

BOURAS

HADJ-AHMED

Abstract

ملخص :

يعتبر حقل حاسي مسعود من أكبر مخازن البترول في الجزائر ، ولاستخراج هذا البترول يجب القيام بعملية الحفر التطوري، الا أن هذه الأخيرة تظل جد مكلفة ولتقليص هذه التكلفة يجب تقليص الوقت المخصص لها وذلك من خلال ايجاد سرعة الحفر المثالية المرهونة بعدة عوامل او تعديلات سواء ميكانيكية أو هيدرولوكية. فمنذ سنة 1958 والعلماء والباحثين يطورون في النظريات وتطبيقها في مختلف حقول النفط للوصول الى السرعة المثالية وبأقل تكلفة ممكنة. في عملنا هذا أجرينا دراسة حول نظرية الطاقة الميكانيكية الخاصة التي تتمثل في كيفية التحسين وايجاد التعديلات الميكانيكية المثالية فقط التي تضم سرعة دوران أداة الحفر والثقل المطبق عليها. تشمل هذه الدراسة أيضا تطبيق نظرية الطاقة الميكانيكية الخاصة في دراسة حالة على بئرمن ابار حاسي مسعود باستخدام برنامج الماتلاب.

كلمات مفتاحية : أداة ، حفر، عوامل ، ميكانكية ، مثالي ، ثقل ، دوران، طاقة، احتكاك، سرعة، اختراق **.**

Abstract:

Hassi Massaoud field is considered as one of the greatest oil reservoirs in Algeria, in order to excavate it we have to do a developing drilling operation but this latest is still very expensive, in order to reduce its cost, it's require a time profiting from the process and that require the amelioration of rat of penetration. From 1958, the researchers are developing the theories and the ROP models to fin ROP optimal with lowest cost. Our work is included the education of mechanical specific energy theory which include the optimization of mechanical drilling parameters which are rotation rate(RPM)and weight on bit. By using MATLAB program, we have applicated this theory on OMM-302 Well.

Key words: drilling, mechanical, torque, energy, optimization, parameters, rotation, weight, bit.

Résumé :

Le champ de Hassi Messaoud est considéré comme l'un des plus grands réservoirs pétroliers en Algérie. Pour le puisé on doit procéder le processus de forage de développement, cependant ce dernier reste très couteux et pour le réduire, il faut diminuer le temps de l'opération de forage c'est-à-dire trouver la vitesse d'avancement optimal de l'outil, et pour ce faire il est nécessaire d'optimiser les paramètres mécaniques et hydraulique de forage. Depuis 1958 les scientistes sont développe les théories et les model d'optimisation de la vitesse d'avancement. Dans ce travail on réalisé une étude du model d'énergie mécanique spécifique (MSE) basé sur l'optimisation des paramètres mécaniques qui sont la vitesse de rotation et le poids appliqué sur l'outil à l'aide l'utilisation le programme de Matlab. Nous avons appliqué ce model sur le puit OMM-302.

Mots-clés *:* optimisation, mécanique, outil, Energie, forage, poids, paramètres, rotation, torque.

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Nomenclature

A_b: Area (section) in^2

D_b: bit diameter

ROP: Rate of penetration

PDC: Polycrystalline diamond compact

TSP: thermally stable polycrystalline

UCS: Uniaxial Compressive Strength

CCS: Confined compressive strength

WOB: Weight on bit

RPM: Rate per minute

N: Rotary speed

T, T_{bit}: Bit torque

α: constant

μ: sliding friction

MSE: Mechanical specific energy

Es: specific energy (psi).

EFF_M: Maximum efficiency factor

IADC: International Association of Drilling Contractors

ρ: Mud Density

ρ_c: fluid Density

G_P: pore pressure gradient

μ: Mud viscosity

d: Nozzle diameter

C_f: Drilling cost per foot;

C_b: Bit cost;

C_r: Hourly rig rate;

t_t: Trip time;

t_c: Connection time;

t_b: Drilling time;

Δh: Footage drilled.

Optimization of drilling activities for oil and gas wells is an area for which numerous detailed research studies have been performed.

The rate of penetration is considered one of the prime factors in drilling hydrocarbons wells and it is therefore given a prime consideration when drilling an oil well. However, a lot of extensive analysis on ways of increasing the rate of penetration from both theoretical and experimental standpoint has been carried out till date.

The drilling parameters are the major leaders for guiding the rate penetration performance and the estimated drilling time for each section, therefore it should be controlled during the drilling operation. Furthermore, some problems are detected during the drilling operation in such as drill string and bit vibrations which are considered as obstacles to increase and optimize the rate of penetration, this thesis includes the analyze some of those problems and the suggestion of their solutions.

The objective of this thesis is to make a mathematical model of the penetration rate (ROP), considering the mechanical parameters that make the bit to drill through the rocks in the formation. After modelling of the drilling process, optimization of the controllable parameters will be done. Data for well OMM-302 from Hassi Messaoud field is used for this case study. The well was drilled in 2018 to a depth of 3438 m. MatLab program is used in analyzing data and modeling the rate of penetration in the optimization part.

This thesis is divided on four chapters :

The first chapter presents the Rotary drilling process with several description, and the effects of drill bit on rotary drilling process, also gave the drilling parameters either mechanicals or hydraulics.

The Second chapter contains Drilling bits types with more details and description, we focus in the PDC bits and present its working mode and its wear detection.

The third chapter includes the modelling part of optimization, the explanation of the Mechanical specific energy theory and definition of the drill string and bit vibration types.

The Last chapter comprise the case study which contains the application of mechanical specific energy (MSE)application and modeling result and analysis.

CHAPTER I

ROTARY DRILLING PROCESS

1. Introduction:

Oil drilling is an operation to reach a permeable porous reservoir, which contains liquid or gaseous hydrocarbons, so to reach the latter there are two techniques, threshing-shear drilling or using a rotary action that make Turns to drill string and bit and binds with a force of weight to exert on the bit this technique called rotary drilling or conventional drilling and currently it is the most use.

In this chapter we present and give a general description of rotary drilling system and its principals basic, as well as the bits to use and the related drilling parameters.

2. The principal basic of rotary drilling process:

The conventional drilling technique consists of the use of tooth bits either roller cone bit as tricone or cutting fixed bit as natural diamond or PDC (polycrystalline diamond compact), on which we apply a force exerted by a weight all led to rotation. this technique has advantages and the injection of fluid is more important which happens in the orifices of the bit to make the cooling and carrying out the cuttings from bottom to the surface through the annular space. The mechanical treatments are done on the surface to make the separation of the cuttings and the recovery of the drilling mud. [1]

Fig 1.1: drilling rig (ENAFOR rig #34)

3. Drilling Rig Classification:

The classification of a drilling rig is based on two main characteristics:

• the Maximum drilling depth capability.

• the puissance of Draw-works.

The rule of the thumb gives a pragmatic way: "For 100 feet of drilling, it takes 10hp of puissance to the Draw-works " From where:

-	Small rig	4921’’ - 6561’’ (1500m –2000m)	650 HP
-	Moyen rig	11482’’ (3500m)	1300 HP
-	Heavy rig	19685’’ (6000m)	2000 HP
-	super Heavy rig	26246’’- 32805’’ (8000m –1000m)	3000 HP

4. General description:

The rotary drilling basically consists of two main parts: drilling rig (surface material) and drill string (bottom material). [1]

4.1. the drilling rig installation:

The drilling rig installation is the part located on the ground surface; it contains several equipements to install the hydraulic system (mud pump), power system (motors and generators), BOP rams, rotation system and the hoisting system that encloses the derrick. [2]

The surface installation must provide three main drilling functions:

• The weight on the bit

• The rotation of the bit

• The injection of mud

4.2. The drill string:

The drill string is considered as a rig train that is descending into the well, it makes the transmission of rotating from rotatory table or tope drive to the bit, also does the guide and control the well trajectory and fluid flow, as well as the exerting force and weight on the bit

(WOB), it consists of drill collar, heavy weight, drill collars and drill pipe and other accessories such as stabilizers, shock absorbers(jar), safety valve etc.

5. Main Elements and Functions of a Drilling Rig:

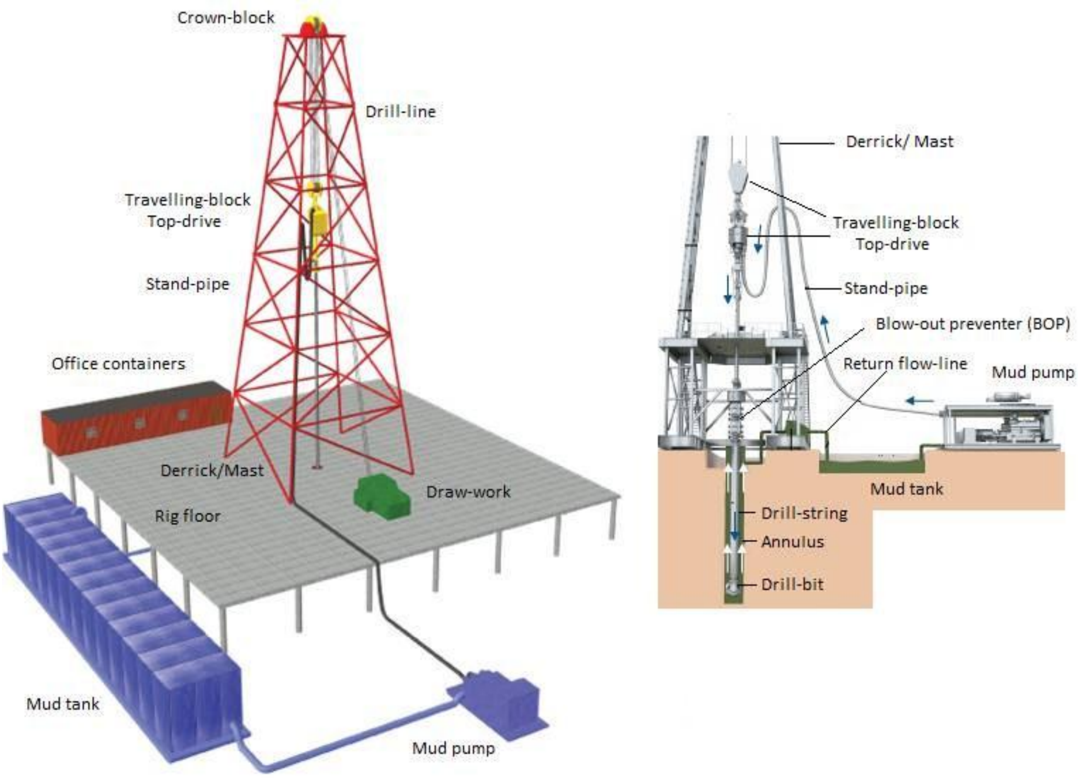

Fig 1.2: the principal elements of drilling rig. [4]

5.1. Hoisting system:

The importance of this function is to lift the drill string (drill pipes - heavy weights - drill collars), it is necessary to use a large capacity crane because of the drill string can reach a weight of 150 tons or more. This crane consists of: Mast or derrick, the fixed and mobile muffle (crown and traveling block), The hoisting hook (Hook), The drilling winch (Draw-work) The drilling cable (Drilling-line) and anchor. [3,5]

They make it possible to control the weight on the bit (WOB); Bit changes (drill string maneuvers), The descent of casing columns; Mast lifts and descents (DTM)

5.1.1. The Derrick [mast]:

Derrick is the "tripod" that supports the hoist. it replaced the tower for the rapidity of its assembly and disassembly. At its summit is placed the fixed mitten. A catwalk is placed in the middle; it serves as a work place for the eye-catching, who hangs on or off the "lengths" of drill pipes during the ascent or descent of the bit in the well. Another adjustable height gangway, placed lower, serves to guide the casing to screw it down into the well. [5]

A working floor is built at the foot of the mast. It serves as a work area for the team. A dog house is set up on this floor to allow the workers to rest. The floor is elevated a few meters above the ground, to allow the introduction of elements of the wellhead and shutters.

allowed to: - The raising and lowering maneuver of the drill string.

. - The storage of the drill string after its ascent

Fig 1.3: Derrick (mast).

5.1.2. the Draw-work:

It is the body that can support the total load of the drill string(BHA) is in addition to the weight of the modern unit tope drive. It is like a drum shape around which the drill cable is wrapped. At the ends of this drum are fixed rims which serve for braking, in contact with steel bands containing ferodo pads, actuated by a lever. [3,5]

The Draw-works gathers a set of mechanical elements and ensures several functions:

• Lift and descent maneuvers (hoisting) of the drill string at fast and safe rates

• The drive of the rotation table when it is not driven by an independent motor.

Fig 1.4: Draw-works (Baohao petroleum Machinery)

The gearbox is integrated in the Draw-works or positioned on the first section of the transmission (rear Draw-works), it allows to drive the various shafts of the Draw-works at speeds using the engine speeds of rotation,

- ***The braking system The Draw-works:***

The pad brake is used to brake and completely stop the drill string.

The retarder can be hydraulic (Parkersburg) or electromagnetic (MAGO). The hydraulic retarder is composed of a propeller, driven by the Draw-works shaft which rotates in a crankcase filled with water, which slows down its movement.

The electromagnetic retarder comprises a rotor, driven by the Draw-works shaft, which rotates in a stator. An electromagnetic field produced in the stator slows the movement of the rotor.

In addition, the Draw-works is equipped with a backup braking system, which automatically stops the Draw-works to avoid the collision between the crown and mobile blocks (block-to-block).

5.1.3. Traveling block:

It is formed by a certain number of pulleys for which the cable passes, it moves on a certain height between the working floor and the crown block. It has at its lower part a hook which is used to suspend the packing during drilling. Legs are hung on either side of this hook to support the elevator, used for the maneuvering of the drill string.

5.1.4. Crown blocks:

For which makes the passage of cable. It is supported by the upper platform of the tower. It should be noted that the load on the crown block and at the same time on the drill rig is greater than the hook load: indeed, the hauling is such that there are two additional strands: the dead and the active strand. which is connected to the Draw-works.

. The hook has a damper to limit shocks to the recovery of the load and facilitate the screw connections. To both side ears hang the arms of the elevator.

5.1.5. The hook:

It is suspended directly from the mobile muffle or integrated with it. It includes the "hook" itself, on which comes to rest during the drilling the handle of the injection head and two side for the suspension of the elevator legs used in maneuvers (Links).

5.1 .6 Drilling line:

The drilling line consists of several strands arranged helically around a core.

Each strand is composed of several wires arranged in a helix of several layers.

lines are forms of high tensile strength cords. They commonly used on drilling sites are: 1 ", 1"1/8, 1"1/4,1"3/8 in diameter.

5.1.7. Dead line anchor:

This is the anchor point of the drill string (dead end). It measures the line tension. (Reading on MARTIN DECKER). It allows the introduction into the system of a certain length of new line to move the points of wear on the pulleys of the block. This spinning operation followed by a subsequent cut allows the longevity of the drilling line.

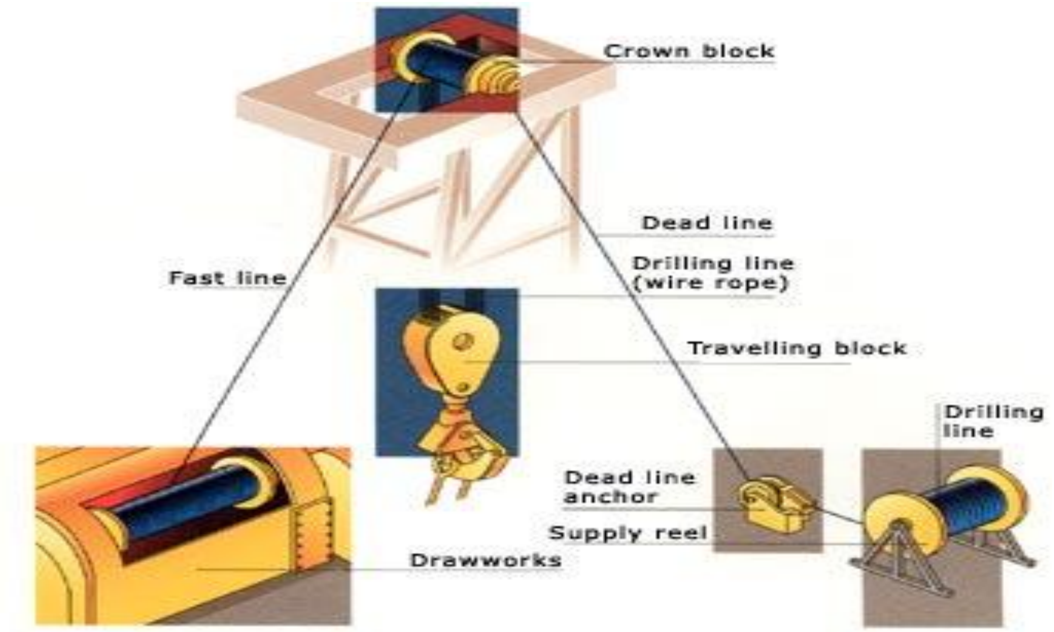

Fig 1.5: Hoisting system

5.2. Circulation system:

The mud is manufactured in large capacity ponds. It is then sucked by mud pumps and pushed back into the hollow pipes from stand pipe. It is circulated in the interior of the drill string, then it leaves through the holes of the bit, goes up in the annular space between the drill string and the well bore to the surface. There, it is collected in a vertical tube (fountain tube), can go out through another tube horizontal (chute) to shale shakers, to be rid of cuttings, before being reinjected into the well. [20]

5.2.1 The mud tanks:

Mud tanks are high capacity reserves in which manufacturing, storage and deferential mechanical treatments of drilling mud are made, there are:

- Traffic(active) tanks
- Reserve tanks
- The settling tanks
- Treating and fabrication tanks

5.2.2 Mud pumps:

Mud pumps are the main elements of the circuit, the pump is an alternating pump volumetric in 2 pistons (duplex pump) or 3 pistons (triplex pump). It is driven by a diesel engine or electric motors their role is to aspire the mud and pushes back into the well.

Fig 1.6: Mud pumps Triplex(SENOPEC)

It is divided into two principals parts:

a) The mechanical part serves to transform the rotational movement received by the transmission (motor) into a reciprocating motion communicated to the pistons.

b) The hydraulic part It is the housing of the wearing parts. It comprises two or three "bodies" (depending on the type of pump) in which shirts and pistons are mounted.

5.2.3. Equipment for mechanical treatment of drilling mud:

a) Shale shakers:

whose role is to separate the cuttings from the mud comprise one or two frames bearing special metal cloths.

b) The mud cleaner:

Their role is to remove solid particles from mud that may have infiltrated through Shale shakers and are of the order of 80µ.

c) The dessilter:

They do not differ from desanders by their increased separation power (and by their diameter)

d) The degassers:

It is essential to rid the mud of the gas it contains because a gaseous mud decreases in density and therefore cannot offer resistance to pressures from the well. The degassing operation is provided by the degassers.

e) Centrifuges:

These are devices designed to recover barium and remove impurities while decreasing the density of the mud.

f) clay-jectors:

They remove light solids from circulating mud as well as chemical contaminants while retaining barite. They can be used to treat the mud in storage, to recover the barite and to reuse it in addition to the heavy mud in circulation.

g) Mixers (hydraulic mixers):

The addition of the powdered mud products is done in a funnel above a collector in which a mud jet flows.

h) Agitators (helix -mixer): These are pallet mixers which, each actuated by an electric motor, stir the mud in the tanks to keep it always homogeneous.

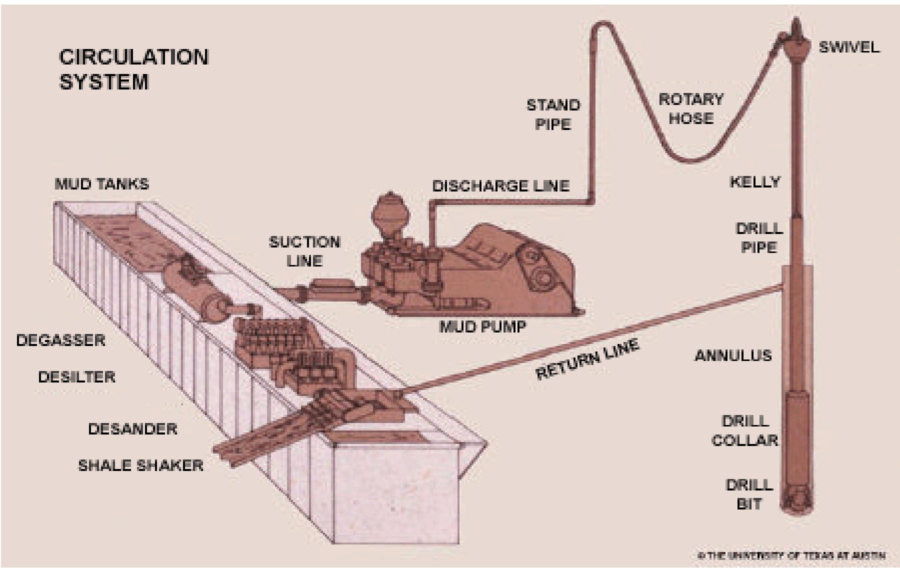

Fig 1.7: circulation system

5.3 Rotation system:

The rotation of the drill string is ensured by the rotation system. Currently, there are two types of this systems: The "Conventional" System and the Modern unit Top-Drive System.

5.3.1 Conventional System (The rotary table):

For the conventional system the power of the rotation of the drill string is communicated by the Rotary Table and the kelly square.

• During drilling, the rotary table transmits the rotational movement to the drill string through a square-passageed , driveway the kelly, by the Intermediate furs [bushings] of the kelly, and being maneuvered [trip], supports the weight of the drill string via retaining wedges by slips.

Fig 1.8: Rotary table(SENOPEC)

Recently, a new rotation system has been used. This is the Top-Drive.

5.3.2 Top-Drive System or Motorized Injection Head:

It is a modern unit suspended in the mast using elevator links and has a mechanism to incline them to the monkey-board. The tope drive is driven by electric motor attached to the injection head is used to rotate the drill string, This unit combines:

• The keys
• The hoisting
• The rotation
• Injection head

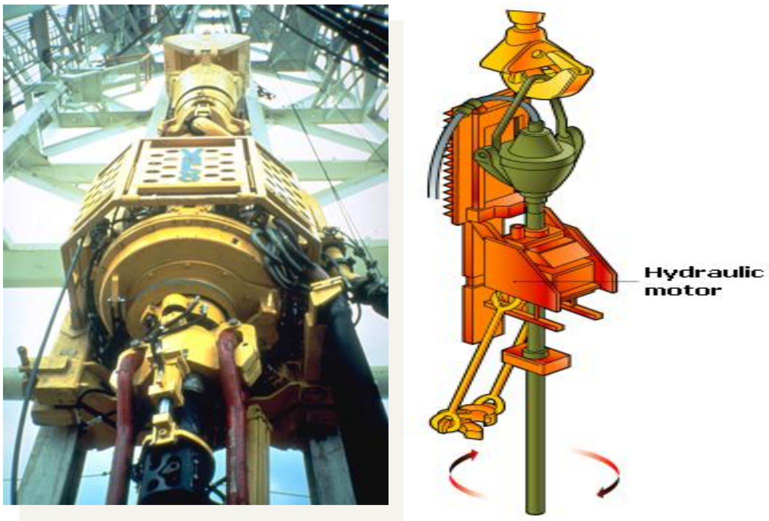

Fig 1.9: Top drive(NATIONAL OIL WELL)

It rotates drilling string without rotary table and square shaft, mud injection and pipes screwing

Note: By using Top Drive, drilling is done in lengths (three pipes) not by one.

5.4. Power Generation System:

On all drilling rigs, there is a force which is called the driving force that ensures the energy of all drilling functions, whether primary or auxiliary. The diesel engine is the element of the original source of the electrical energy .It drives all the generators that can produce this energy of a form of continuous and / or alternating current .Then this current is used to power the DC or AC motors on the one hand, on the other hand the current arrives in the electric converters to operate the accessory and the lighting. [21]

5.5 Security system:

bloThe safety equipment ensures the safety of the well in case of arrival and consists of Well shutters and closers, pressure accumulator, choke manifold and safety valves. [21]

5.5.1. Blowout Preventer BOP:

This is a group of large valves installed at the top of the well which can close and secure the well quickly from the annular and tubular, it allows control to follow the mud of drilling in case of loss mud or blowout. It is operate using the accumulator.

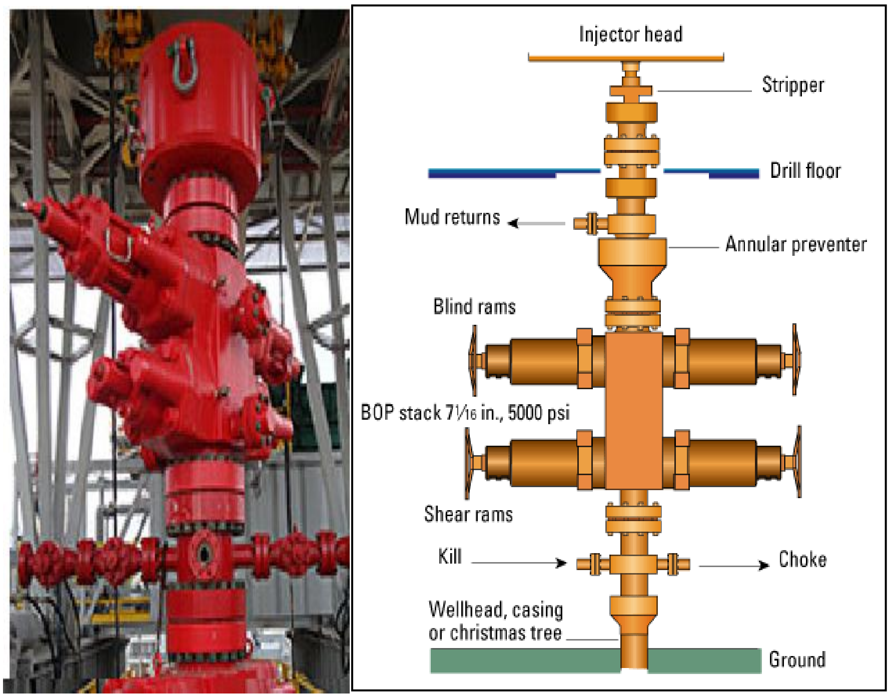

Fig 1.10: Blow Out Preventer (NATIONAL OIL WELL)

5.5.2. Accumulators or hydraulic control unit of BOP (Koomy):

This is the command part of shutter control; their role is of an accumulator that remotely controls the valves of the BOP from the high pressure spigots. It is capable of pumping a high-pressure fluid to close or open the BOP valves.

5.5.3 The Choke Manifolds:

This is a set of chokes and valves that control the well in a case of blowout.

Fig 1.11: Choke Manifolds(NATIONAL OIL WELL)

6. The importance of the bit in the Rotary drilling system:

The drill bit is the first element that touches and attacks the ground, so it is the most important to achieve a well. In the drilling domain, the bit is located and screwed from a connection to the ends of the drill string that drill the terrain with a rotary action.

it is played a major role in the rig, currently the bit is the only part of the equipment that makes the hole, this fact suggests that we should estimate all other drilling equipment as auxiliaries of the bit. This means that the other equipment has also played an important role in making the hole.

The contractor defines the drilling rig in relation to the parameters (the terrain that we are going to drill, the depth and types of the rocks of terrain ...).

In the field of drilling, to make a hole, it is necessary to put the bit at the bottom and turn it to the right. The choice of bits is intended in relation to the information that must be drilled (the nature of the rocks).

As a conclusion, the bit is the key point for Rotary drilling, and the contractor's question about a wellbeing a contract is: "How many bits will be used? "The answer gives him that is not only the idea of a cost price or the cost of the bits but also the estimate of the period that we will take (days of drilling) and its total cost.

The choice of type of the tool depends on the type of formation that will be drilled:

As example

• bit for soft formations, which require little weight, thinner cones, have smaller bearings, and

legs of smaller section than bit for hard formations. This leaves more longer, thin cutting elements.

• bits for hard formations, which work with larger weights, have shorter and more solid cutters, stronger bodies and larger bearings.

Manufacturers have developed several types of bits, each type of tool used to drill a special type of training as tricones, PDCs, TSPs, Diamonds and impregnate bits…etc.

7. Drilling parameters:

The drilling parameters are factors that are very important variables influencing the drilling operation either for the time or the cost comes back from this technique. These factors are mechanical and hydraulic parameters. They are also carried out on the ROP, which corresponds to the depth of drilling and the time, it is generally expressed in (m / h). The improvement of this latest is very important aspect in Estimate of drilling process analysis. [18]

7.1. Mechanical parameters:

7.1.1. For roller cones bits:

a): weight on bit (WOB) parameter:

ROP is linked to the weight on the bit (Weight On Bit) as it can reach its maximum if the weight on the bit reaches the limit load. This load is necessary to fully penetrate a tooth in the ground. Beyond this force, all the additional weight can be supported by the body of the cone which is applied against the formation and there results a decrease in the life of the bearing without corresponding increase in the ROP. This limit weight is more considerable in hard formation. [18]

By the weight provided by drill collars used: in which it is necessary the apparent weight of drill collar greater than about 20% of the maximum weight. The drilling bit may be applied to certain steep formations with a tendency to deflect the bit. We try to limit this tendency to deviation by the use of stabilizers, we can take considerably the acceptable weight on the bit.

b) rotary Speed (RPM):

The weight on the bit is closely related to the RPM. There is no indefinite and simultaneous increase, these two parameters without causing extremely hard work for the drill string. An increase in one often results in a reduction of the other.

The penetration Rate of rock does not increase in direct proportion to the RPM. There is an optimal ra beyond which the speed of advancement no longer increases. This maximum rotational speed decreases as the hardness of the formation increases and the optimal rotational rate decreases as the weight on the bit is increased.

The rotary speed can be limited also by:

- the great depths.
- the vibrations of the drill string (resonance phenomenon which can be the cause of fatigue and breakage). [19]

7.1.2. For diamond bits and PDCs:

For diamond bits, it is important to respect the parameters indicated by the manufacturer because the efforts applying to the bit have been taken into account to achieve it.

For natural diamond bits, weight is an important parameter. On the other hand, for PDC bits, the rotary speed is the most important parameter.

certain types of bits (pastille) that work by grinding, the weight factor is more important; excessive rotational speed would reduce the speed of travel as well as the deterioration of tungsten carbide.

7.2. Hydraulic parameters:

7.2.1. For roller cone bits:

a) Drilling flow rate:

The phenomenon of carrying out the cuttings is more directly proportional to the link between penetration and weight is called balling up or stuffing point of the bit. Beyond this point the flow is no longer sufficient to evacuate all the cuttings as they are produced by the teeth of the bit and a portion of the weight placed on the bit is supported by the cuttings.

We can delay the appearance of balling up by increasing the speed to the chokes, which allows a better cleaning of the face of size. The flow therefore has an influence on the progress but up to a certain limit value beyond which it no longer improves the progress and on the contrary risks being harmful by the formation of cellars (turbulence through the joints bits and drill collar), the erosion to the right of the drill collars where the rate of the mud is all the higher as one uses oversized drill collar.

The flow is calculated according to the rate of rise of the cuttings. This rate is greater in soft terrain than in hard terrain. Some prefer to use lower flow rates but focus on the jet bit rate.

The fact of wanting to delay the appearance of the balling up should not however lead to use a flow such that:

- in soft terrain there is risk of formation of cellars,
- in poorly consolidated terrain, erosion of the walls,
- increased losses circulation in the annulus producing at the bit the same effect as an increase in density, resulting in reduced progress, and causing traffic losses.

b) Minimum rate through jet of the bit:

The mud jet has the effect of cleaning the bottom of the well and inducing sufficient turbulence to wash the teeth of the bit. Before the nozzle, the pressure must be high and the speed is low. In contrast, after the nozzle, the pressure is low and the speed must be high

c) Influence of jet (nozzle) of the bit:

• *Slightly open:* little flow and little cleaning ability

• *Properly open:* firm and directed flow and best cleaning

• *Too open:* flow without force and no cleaning

7.2.2. For diamonds and PDCs:

To properly cool the diamonds and PDC bits and avoid "burning" them, it is important to have a high flow rate.

The respect of a high flow rate is preponderant for this type of bit firstly to cool the cutters and then to clean the face of size.

8. Conclusion:

The description of the rotary drilling process, the different systems and their component parts, as well as the influence of drill bit and its Importance on this process, and the mechanical and hydraulic parameters, have been presented in this chapter. This thesis resides on the study of ROP of the drilling bits in order to optimize it. In the next chapter, we gave more descriptions of the drilling bits and their working mode.

CHAPTER II

DRILL BITS OF ROTARY DRILLING PROCESS

1. Introduction :

The drill bit ranked among the smallest tools but it considered as the most important element to achieve the drilling well. furthermore, it's the unique part which being in contact with the ground while drilling. Selecting the drill bit is depend mainly on the nature of the geological formation crossed .While drilling the bit face many factors which effect on the rate of penetration ROPin this we find :

- The rock nature, it drillability, trend of deviation, hardness, abrasiveness of the minerals.
- Characteristics of the surrounding environment (stresses in place, sediments diagenesis, formation pressure, Strike and dip refer to the orientation or geological "attitude" …etc.),
- The well trajectory which acts on the distribution of the stresses in the rock,
- The means used to achieve the well (type of drill bit, bit nozzles, type of mud used… etc.),
- Parameters in use to brake the rock (WOB, RPM, Flow, etc.),
- Modern Technic: using turbines.

2. The different types of the drill bits

2.1. Roller cone drill bits:

There are two different types of the roller cone drill bits specially as:

2.1.1 . Bicones:

Nowadays, the usage of the bicone is rare, refer to use it in deviation cases. [24]

Fig 2.1: Bicone (baker huge)

2.1.2. Tricones :

The tricone bit consists of three rotating cones working inside each other and each with its own row of cutting teeth. Roller cone bits (or rock bits) are still the most common type of bit used worldwide. The cutting action is provided by cones which have either steel teeth, or Tungsten Carbide (WC) inserts. These cones rotate on the bottom of the hole, and drill hole predominantly with a grinding and chipping action. Rock bits are classified as milled tooth bits, or insert bits, depending on the cutting surface on the cones (Figures 2). [1]

.

Fig 2.2: Roller cone bit (DBS)

2.1.2.1. Roller cone with Steel tooth:

Steel tooth cones are machined from forgings of an alloy steel. The cones are milled to form the shape of the steel tooth. The shape of the actual teeth will depend on the purpose of the bit. To protect the steel tooth, hard facing is welded on the cutting structure. The hard facing contains of tungsten carbide particles designed to maximize the cutting life of a tooth. The shape and density of the teeth depends on the formation application. Larger teeth with bigger space between are much suitable for soft to medium formations. Large teeth can grab and crush bigger volume of rock, thus drilling faster. Smaller teeth with small space between are designed for medium to harder formation. Harder formation drills slowly with low ROP and RPM. In order to drill this formation, the bit has to be able to carry a high weight on bit and resist to damage. That's is the main reason small teeth are applied. They are able to grind the formation slowly with high weight on bit. [1,24]

2.1.2 .2. Tungsten Carbide Insert:

. The insert teeth are milled and machined and then mount on the cones. The amazing thing here about this type of bit technology is that the only force that holds the tungsten carbide inserts pressed in the bit cone, is the friction between the insert and the body. The size and type of the components in the bit depends on the formation hardness. Bits for soft formation require smaller weight, smaller bearings, smaller cone shell thickness and thinner legs. That gives more room for long, thin cutters. Drilling in hard formations requires weight, bigger bearings, steadier body and stubbier cutters. [1]

- The tooth has milled on the cone.
- The picots on Tungsten Carbide which are inserted on surface of the cone

- **The Compact shapes :**

There are four main compact shapes that are used according to the application requirements.

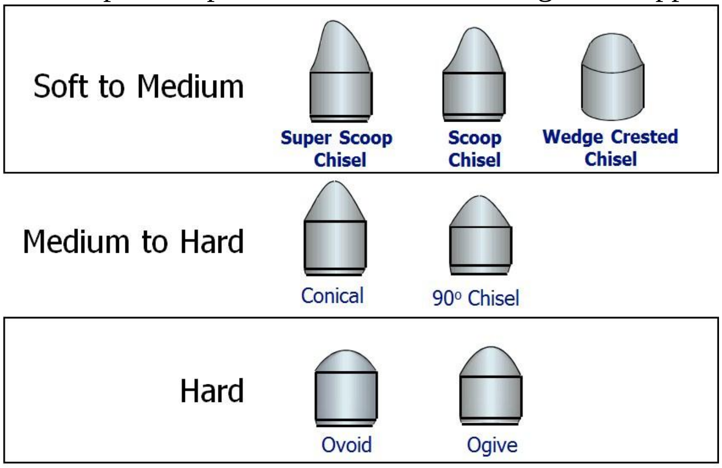

Figure 2.3: Compact shapes types (baker huge)

2.1.2.3. Conventional bit:

The conventional bit is replaced by chucks of tungsten carbide, but the flow is important enough at the bottom of the well for which turbulence occurs which pushes back and up instantly the cutting at the surface through the annular space. As a result, there was better bottom cleaning and avoided regrinding of the cuttings. [24]

2.1.2.4. Jet bit:

the nozzle bit has interchangeable tungsten carbide chucks that are placed between the knurls to improve cleaning and to allow rock destruction in soft ground. The choke joint has a shape of "O" ring to ensure tightness, so When mounting do not forget to put this seal and never use twice the same "O" ring during successive reassembles.

The nozzles are attached to the bit by circlips or threaded rings, depending on the bit manufacturers. [24]

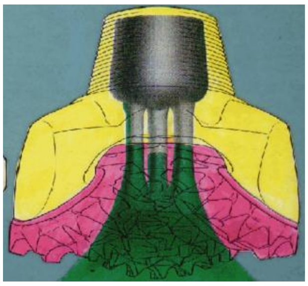

Fig 2.4: conventional bit (IADC)

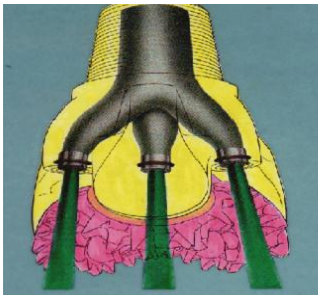

Fig 2.5: Jet bit (IADC)

2.1.2.5. Working mode of a Tricone bit:

The operating mode of tricone is based on:

Percussion with a tooth penetration in the formation, and to have a better progress so it is logical the more the ground is soft that the hard ground, the more the tooth will have to be big.

The sliding (shifting) of the cones on themselves produces a tearing of the chips of terrain; therefore, on each cone, It is necessary to make a shift of the rows of teeth. This pulling is done by the effect of sliding or shifting, the axis of each cone and the axis of rotation of the bit are not in the same direction, they are offset. This shifting is called "offset". It is even larger than the bit used on soft terrain, on the other hand it becomes zero for the bits to use on hard terrain in which the chip removal is no longer possible and the sliding effect would be harmful to teeth of the bit. [1]

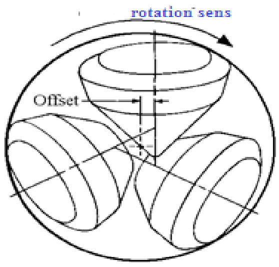

Fig 2.6: Offset in soft formation (ENSPM)

2.2. Bits with fixed cutting elements:

Cutting bits do not have rotating elements, they are monobloc tools such as natural and synthetic diamonds that are used for their manufacture. The work of natural diamond tools work as a file while that of synthetic diamond bits work as a planer.

2.2.1. Natural diamond:

Diamond: Diamond (crystallized carbon) is considered to be the hardest mineral that has a high crush strength in the order of 80,000 bar. it is resistant to background conditions in the case of high temperature and high pressure.

• The crush strength of tungsten carbide is 50,000 bar while it is about 15,000 bar for steel (C.45). it has a very high melting point (3650 ° C), but it is slightly transformed into graphite at the point of 1450 ° C. The diamond weight is measured with the carat unit (1 carat = 0.2 grams).

• Concerning the drilling bits, the size of the stones is measured in number of stones per carat and generally varies between 2 and 12 stones per carat. these stones have a very good quality and are more angular forms.

Fig 2.7: Diamond (baker huge)

The diamond is the hardest material that we currently know of. Hardness is described as resistance to scratching and it has a range of 1 (softest) and 10 (hardest). Diamond has the hardness of 10 on the Mohs scale of mineral hardness. There are two mechanical properties that describe the diamond – hardness and toughness. Toughness is the material ability to resist breakage from forced impact.

Synthetic diamonds are diamonds that are produced in the laboratory. The majority of the available diamonds are produced by so called High Pressure High Temperature process. Diamonds appeared around 1870 in the search for coal. They are more used in the oil industry recently. Their use practically joined oil drilling at 1930 (coring) but they appeared in Europe in 1953. [24]

There are some good qualities of diamonds in the industry:

- ✓ Carbonado (South America);
- ✓ Congo (South Africa);
- ✓ West Africa (South and West Africa)

In general, diamond bits are divided into three types: natural diamonds, PDC (pollycristallin diamond compact) cutters and TSP (thermally stable pollycristallin) cutters.

The natural diamond is a crystallized carbide with a density of 3.52. Diamond and graphite are chemically similar but they are completely opposite on the physical point of view. Graphite is fragile, black, weak, often used as a lubricant against the diamond is enormously hard and the best thermal conductor, excellent insulation; most of the time transparent, it also has a better resistance to abrasion and wear, used in abrasive and harder formations, but it did not use in fractured and broken ground because of its resistance at most low. [7]

2.2.2. Synthetic diamonds:

We classify it into two synthetic products:

- The low temperature synthetic diamond "PDC",

- The high temperature synthetic diamond "TSP".

2.2.2.1. PDC Low Temperature Synthetic Diamond:

In general, the PDC (Polycrystalline Diamond Compact) is exist in two forms either with steel body or with matrix. The steel body is machined and then covered with tungsten carbide to protect against erosion. The body is made from the same source of tungsten carbide material as natural diamond bits. In reality, the PDC bit is in the absence of the moving parts which is considered a fundamental advantage and which named the monobloc bit. in the other hand, the weak point of PDC is not to resist the temperature which exceeds 8000°C. [7]

Fig 2.8: PDC bit (baker huge, VAREL)

The PDC generally is in the form of a slat being thin of synthetic diamond with thickness is equal to 0.5 mm and impurities of cobalt nickel placed on tungsten carbide substrate. These blends begin to wane around 750°C.

2.2.2.1.a. Designation of a PDC bit: [7]

The designation of PDC is contains several elements: The body of the bit, the profile, density of the cutters, partial characteristic angles, useful length (L_{edge}).

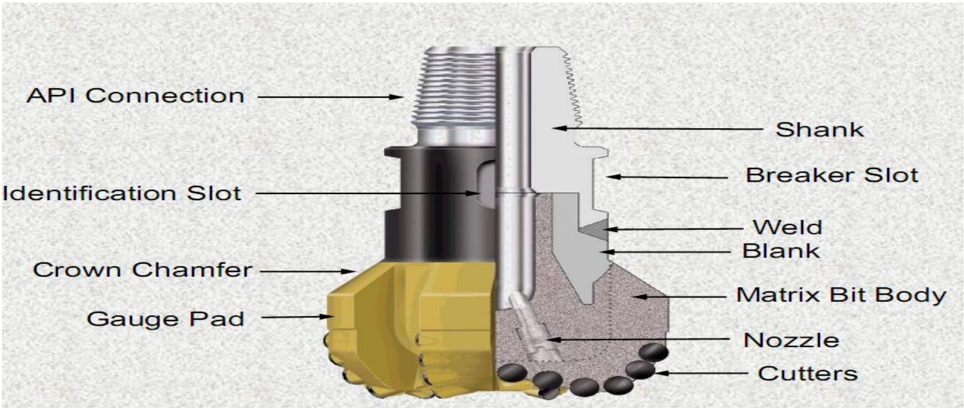

Fig 2.9 : PDC description (IADC)

A) PDC cutter:

. This synthetic material is 90-95% pure diamond and is manufactured into *compacts* which are set into the body of the bit. Hence the name of these bits.

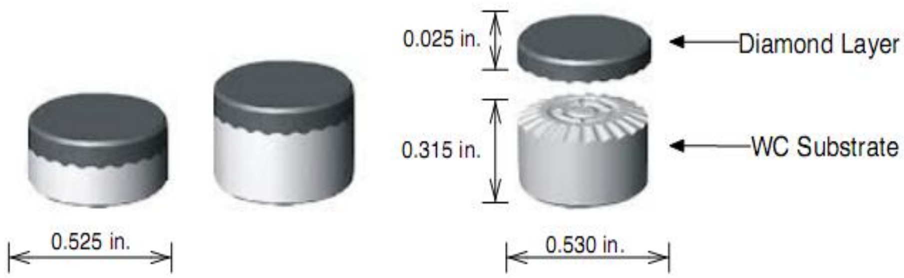

Figure 2.10: PDC cutters (baker huge)

B) bit body:

Currently, there are two types of bit bodies: Steel body and Tungsten carbide (Matrix body).

B.1. Steel body:

The bits use periscope type PDC cutters that are taken directly into the steel body without any mixing**.** The protection of the tool diameter is done by exiting tungsten carbide studs over the entire height of the external pledge.

- **The advantages of steel body:**

- possibility to replace the periscope cutters after using the bit if any time there has been erosion of the body.

- possibility to use the entire surface of the cutter since this type of cutter is fully exposed.

- **The disadvantages of the steel body:**

- Very fast "wash out" wear of the steel body, which considerably limits its service life. This life is directly proportional to the amount of solids contained in the sludge, however this wear by "Wash out" can be reduced by providing a hard metallization on the attack surface of bit.,

B.2. Matrix body:

The tools are equipped with cylindrical cutters that are directly based in a recess that has been fitted into the tool body.

❖ **The advantages of Matrix body:**

- The very high abrasion resistance of the body, which is made of tungsten carbide, which gives a longer service life than the cutter life itself.

-The recess arranged in the body of the bit to receive the given cutter**.**

❖ **The disadvantages of Matrix body:**

- its price is significantly higher than the steel body. - once used, this tool can not be repaired.

- The entire cutter surface cannot be used because of its position in the die.

C) The profile: There are mainly three deferential PDC bit profiles:

C.1. Flat profile or with a weak inner cone: The angle of the cone is weak and less than 15°. In this type of profile, the weight is distributed evenly over the cutters, but the number of these is limited and their wear is integral due to the stability of the tool. Tools with this profile are used for soft ground and are not very favorable for fast advancement. They are more economical in consolidated land.

C.2. Double cone profile: The inner cone is very pronounced. The cutters are increasingly distributed to the periphery, improving stability and directional accuracy. Tools with this profile are used for hard terrain.

C.3. Parabolic: profile Short or long, this type of profile has a large surface on which a large number of cutting is fixed. The short or medium profile has the advantage of reducing the resistance torque during drilling, which makes it possible to apply more weight to the tool and, consequently, to increase the forward speed. In addition, the parabolic profile is easier to steer with a bottom motor in a deviated well.

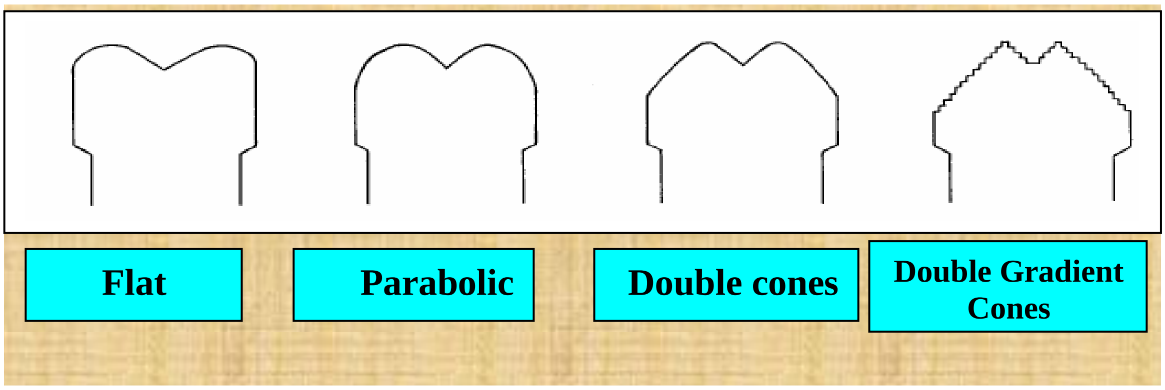

Fig 2.11: Different types of PDC profiles.

D) Density of cutters: The cutter density is the number of cutters per unit area on the face of the bit. The cutter density can be increased or decreased to control the amount of load per cutter. This must however be balanced against the size of the cutters. If a high density is used the cutters must be small enough to allow efficient cleaning of the face of the bit.

$$Density\,of\;\;cutter = \frac{WOB_{total} / cutter\;\;numbers}{Section\;cut}$$

E) Angle characteristics of PDC pastille:

Three characteristic angles are defined on the PDC pastille:

1- The cutting angle Wc (back rake angle).

2- The draft angle Wd (clearance angle).

3- Side angle Ws (Side rake angle).

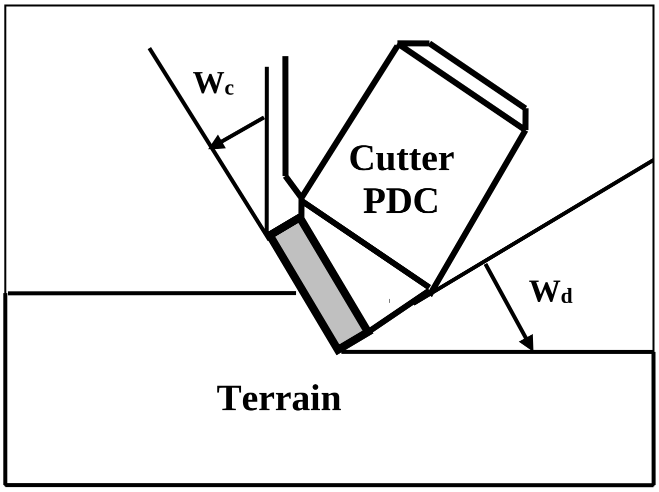

Fig 2.12: Characteristic angles of a PDC

F) Utile length L_d:

The distance between the bit matrix and the bottom of the borehole dug by the PDC is called the "utile length" (exposure). If $\mathbf{L_d}$ is the distance measured vertically between the bit matrix and the center of the D-diameter pastille, Then the $\mathbf{L_d/D}$ ratio is called $\mathbf{L_{edge}}$. These two parameters are of paramount importance in the chip evacuation system and the cleaning of the wells and lateral efforts.. High exposure of the cutter provides more space between the bit body and the formation face, whilst low exposure provides good backup, and therefore support to the cutters.

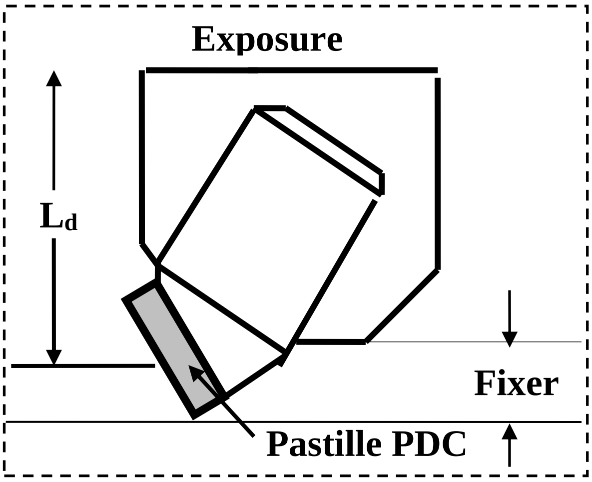

Fig 2.13: Utile length L_d

2.2.2.1.b. working mode of PDC bit:

- The efforts applied on the cutter:

  -The cutting force Fc (horizontal force),

  -The normal force Fn (weight on the bit),

  -The lateral force FL.

At the beginning of operation, the PDC cutter attacks the ground and cuts the rock to a depth of h, it subjected to a resulting effort R, whose normal component to the face of the pastille called cutting force Fc which is the first responsible for breaking the rock by shearing. This resulting effort also has a lateral component FL.

The lateral forces of each pastille are balanced between them so that the lateral force is zero.

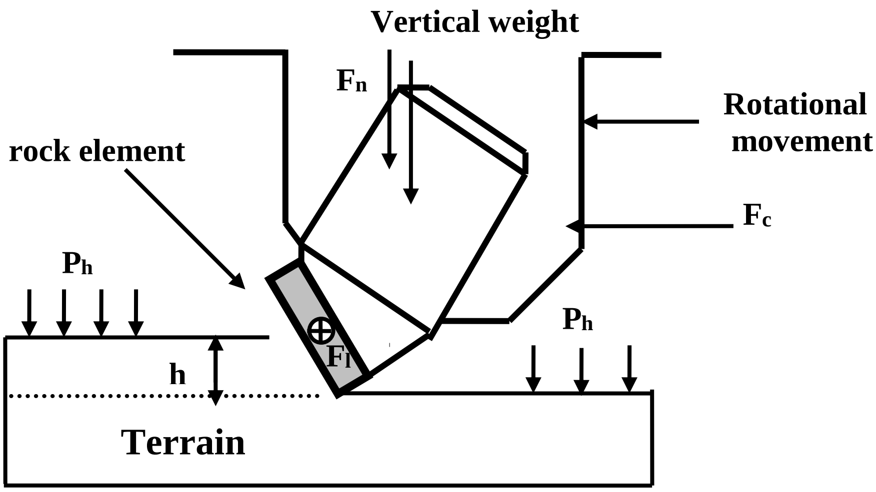

Fig 2.14: The efforts applied on the cutter

The rotary movement of the drill string rotates the axis of the PDC bit for it must create a so-called bottom-hole sweeping phenomena. It is also doing to describe concentric circles of all the points of the bit**.**

With the effect the vertical load on the bit(weight) and with the help of each these elements make it possible to maintain driving in the rock. this depression is defined as a thickness whose bit has sunk. Therefore, at every moment the bit overwrites new elements of virgin rock.

2.2.2.1.c. Attack of the rock by bit:

A) Shear:

Sweeping the bottom of the hole is obtained by the rotational movement of the bit around the drill axis. If the bit is Monoblock, all the points of the bit describe in this movement concentric circles; in particular each of the elements of the bit, which is held down in the rock under the effect of the vertical load, pushes in this rotational movement a rock element, the thickness of which is equal to the depth of which it is is pressed, and every moment it crushes a new element of virgin rock. If the rotational speed of the bit and the resistance of the rock is uniform, each bit element, in contact with the bottom of the hole, will have a helical trajectory whose step will be equal to the advancement of the tool by tower. This produces a continuous cut.

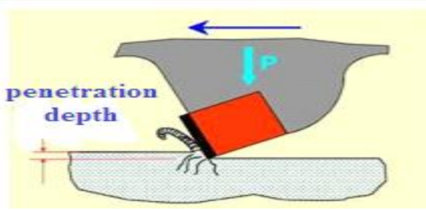

Fig 2.15: Rock shear by the bit

B) Erosion:

Although in practice there are few rocks that can be destroyed only by erosion, high velocity mud flow, which in most rotary drills removes drill cuttings, can increase the effects of rock destruction. by the action of the bits. Some bits, either fixed cutter or roller cone, called jet bits, are also adapted for this purpose.

2.2.2.2. High temperature synthetic diamond (TSP):

The TSP (thermally stable polycrystalline) is a cutting structure formed of PDC cutters protected at the back by TSP and / or diamonds called Quatro cut. It also consists of synthetic diamonds but without cobalt for the purpose of eliminating through acidification and without carbide substrate, the TSPs are thermally stable up to 1200oc.

TSPs can be grouped together to form mosaic structures of the PDC dimension. This structure increased the speed of travel and extended bit life in soft, abrasive formations and in the intercalations of harder clays and rocks where PDCs were not available. not profitable.

TSP has many advantages over other types of diamond:

- It is more temperature resistant than the PDC.
- Thanks to its polycrystalline structure, it is more impact resistant than natural diamond (with the exception of carbonado which is also polycrystalline).
- Its irregular wear produces sharp faces while the natural diamond dulls. As a result, the performance of the TSPs decreases little or not during the life of the bit.

Fig 2.16: thermally stable polycrystalline bit (TSP)

2.2.3. Impregnate bits:

The body is made of a matrix of tungsten carbide impregnates with synthetic diamonds inside. The abrasive structure is resistant to high pressures and temperatures, and therefore these bits are used in very hard formations with low forearm and high abrasiveness, As the wear of the matrix, the exposed diamonds come off and new cutters appear.

Due to the small size of the synthetic impregnate diamonds, the speed of advancement obtained by this tool is very low. [7]

Figure 2.17: Diamond impregnate (baker huge)

2.2.4 Hybrid bits:

The term "hybrid" comes from the combination of PDC and natural diamond cutting technology mounted on the same bit. A secondary element of diamond impregnate tungsten carbide is placed behind the PDC tooth. These second elements are generally called "impregnate". Each impregnate goes with a specific PDC located at a critical point, potentially exposed to wear. Hybrid bits are found on both steel bodies and dies.

In both cases, the impregnated ones contain many small natural diamonds on the exposed face in contact with the formation during the severe drilling conditions. [7]

Figure 2.18: hybrid drill-bit with PDC and TCI features together (baker huge)

Table 2.1: Different main features of the bits types

Characteristics	Unit	Diamond	PDC	Carbide tungsten	Steel
Hardness	Kg/mm^2	6000-9000	5000-8000	1475	558
compression Resistance	10^3 psi	1260	890	780	238
thermic Conductivity (25°)	W/cm.°C	5.2	5.43	1.00	0.48
Density	g/cm^3	3.52	3-3.25	14.95	785
fusion Point	°C	3650	-	2860	1530
The crushing Resistance	Bars	80000	-	50000	15000
Young Module	10^6 psi	105-152	132	92	29

3. The Usage of diamond bits:

Like any bit choice, the decision to drill diamond must be based on a cost analysis. Some drilling situations suggest the economic use of a diamond bit:

- ✓ When the life of the wheel bits is very short due to wear of bearings or teeth, or breakage of teeth.
- ✓ When forward speed is very low (1.5 m/h or less), due to high mud density, or insufficient hydraulic power from the rig.
- ✓ In diameter six inches or less, where the life of roller cone is limited.
- ✓ For inclined ascents in directional drilling.
- ✓ When the weight on the bit is limited.
- ✓ In turbodrill, where the high rotational speed optimizes the advancement of the diamond bit.

The usage of the diamond bit is limited in some very hard fractured formations where diamonds can be exposed to violent shocks. Flint or pyrite-containing formations reduce the life of the diamond bit when it's crumbling and rolling under the bit, damaging the diamonds.

4. IADC classification of diamond bits: [6]

This classification is based on four characters that classifies all diamond bits.

- **The first character:** Type of diamonds and matrix:
  - **D**: natural diamond bit with a tungsten carbide die;
  - **M**: PDC bit with tungsten carbide matrix;
  - **S**: PDC bit with steel matrix;
  - **L**: TSP bit with tungsten carbide matrix;
  - **O**: other types of bit that will be developed in the future.
- **The second character:** bit Profile: The bit profiles are coded using nine digits from 1 to 9 which represent the usual shapes of diamond tools.
- **The third character:** Hydraulic characteristics:
  - **R**: for radial output of the fluid;
  - **X**: for outlet with central groove;
  - **O**: for other types of fluid outlet.
- **Fourth Character:** Diamond Size and Density: nine digits (1-9) symbolize the type, size and density of diamonds. The size of the natural diamonds is based on the number of stones per carat, while the size of the synthetic diamonds is based on the size of the cutter. The density of diamonds gives a relative indication of their number in order to distinguish heavily loaded bits from weakly loaded ones

5.2.4. Attack of drill bit by the rock

5.2.4.1. Reactions of the rock on drill bit:

At a given moment the bit is in equilibrium under the action of the external forces constituted by the load and the engine torque and under the action of the reaction system that the rock opposes to the bit.

The knowledge of these reactions is necessary for the determination of the stresses to which the various elements constituting the bit are subjected; the knowledge of these constraints is itself very useful for the choice of shapes and dimensions, and the mechanical characteristics of the different parts of the bit. Any percussion provoked voluntarily to better destroy the rock must be able to be supported by the part of the bit which transmits it.

In particular roller cone bit, which include bearings, will have to withstand fatigue phenomena, which are involved in the operation of the rolling blocks due to the periodic variation of loads and stresses.

5.2.4.2. Wear of the active parts of the bit:

As already indicated, the contact under load and a relative movement of the rock and the bit cause wear by abrasion and friction of the active parts of this one.

Other wear may intervene fiat maintain in contact with the active parts of the bit with the cuttings, previously detached from the virgin rock; these wears thus depend on the conditions of evacuation and recovery of cuttings. The drilling mud can itself erode parts of the bit.

6. Determination of tool wear: [6]

6.1 Wear of the milled teeth and insert bits:

This wear is due to abrasion by the rock. It is expressed in 1/8 of the height of the tooth.
The symbol T (Tooth; Teeth) is used.
0: no loss;
T1: 1/8 of the height of the tooth is worn, T2, T3 ......, T8:
all the tooth is worn. For a broken tooth, BT (Brocken Teeth) is noted. The wear of the insert bit is due to the loss of the cutting elements either by breaking or by heating.

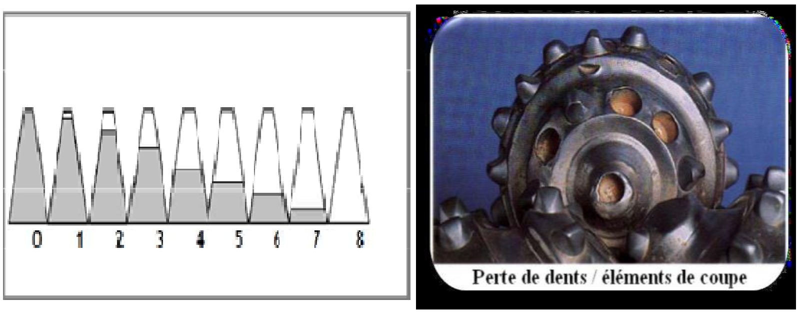

Fig 2.19: the height of the teeth/picot (IADC)

6.2 Wear of fixed cutter bits PDC:

- **Analysis of the wear of the PDC:** During the ascent of the Bit, the bit man (specialist of the bits) inspects it and makes an analysis of the wear of the bit according to the codification IADC (International Association of Drilling Contractors). It is a very difficult operation because it is subjective; it differs from one person to another.

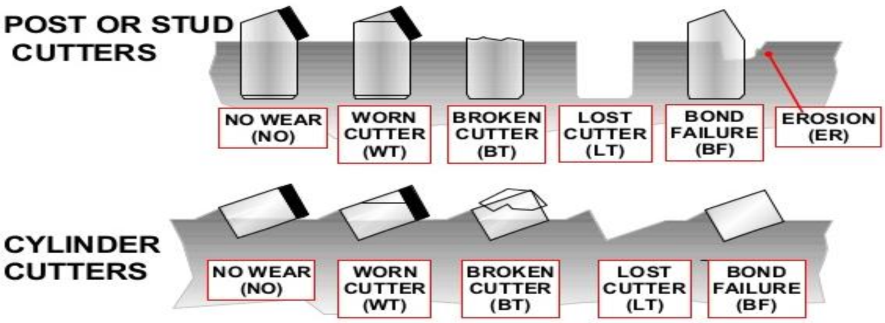

Fig 2.20: fixed cutter main characteristic(IADC)

.This wear is due to the loss of the cutting elements either by breaking or by heating

0:no loss

1; 2; ...; 8: all stakes are lost.

This wear leads to the formation of a conical hole. The symbol O or I is used.

6.3. Wear detection

objective determination is very important because it will serve to:

• Select the bit best suited to the type of training to be drilled;

The old way of accounting for bit wear only considered the overall wear of the cutting elements, the condition of the bearings and the diameter of the bit. Currently, the method used introduced in 1987 is more complete. It applies to both roller cone bits and diamond bits.

there are eight (08) columns of information are used to report bit wear (see table below). The first 4 columns relate to the cutting structure.

Tab 2.2: information for bit evaluation wear

Cutting Structure				B/S	G	Remarks	
Inside rows	**Outside rows**	**Characteristic of the wear**	**location**	**Bearings / seals**	**Calibration** 1/16 in	**Other features**	**Reason for the ascent**
1	2	3	4	5	6	7	8

- **The first column** indicates by a number from 0 to 8 the wear of the cutting elements of the inner rows (ie 2/3 inside the cutting elements).
    - For diamond bits, 0 indicates that the bit has not lost height and 8 indicates a total loss of available height.
- **The second column** also indicates by a number from 0 to 8, the wear of the cutting elements of the outer rows (outer 1/3 of the cutting elements).
- **The third column** uses a two-letter code to indicate the main characteristics of the wear of the cutting structures. (see table).

table 2.3: Codification of cutters wear

BC: Cone broken.	**LN: Loss of chess.**
BT: Broken teeth.	**LT: Loss of teeth.**
BU: Tool blocked.	**OC: Eccentric wear.**
CC: cracked cone.	**PB: Pinch tool.**
CD: Cone blocked.	**PN: Duse blocked.**
CI: Interference between cones	**RG: Peripheral wear.**
CR: Torus tool.	**RO: Damaged seal.**
CT: Chipped teeth.	**SD: Arm Damage (cone)**
ER: Erosion.	**SS: Wear with auto sharpening.**
FC: Flattened teeth.	**TR: Wear between teeth.**
HC: Warming up.	**WO: Whistled tool.**
JD: Damage by scrap	**WT: Used teeth (SS / FC).**
LC : Loss of cone.	**NO: without wear.**

- **The fourth column** uses a letter or number to indicate the location of the wear reported in the 3rd column

- **The fifth column** uses a letter or number (depending on the type of bearing) to indicate the state of the bearings.
  X: Is used for bits without bearings (PDC, diamond, ... etc).
- **The sixth column** indicates diameter loss in 1/16 inch.
  I: indicates that there is no loss of diameter.
- **The seventh column** is used to support any additional wear, in addition to that reported in column This column is not limited to cutting structures only. It uses the same codes as the Column 3.
- **The eighth column** indicates the cause of the ascent of the bit.(tab 4)

Tab 2.4: reason of pulling

BHA: BHA change.	**FM: formation change.**
DMF: Engine failure of the bottom.	**HP: Trouble drilling.**
DSF: BHA problem.	**HR: Number of hours.**
DST: Drill stem test.	**PP: Pump pressure.**
DTF: Problem bit background.	**PR: rate of penetration.**
LOG: Electrical logs.	**TD: Final depth / casing installation.**
RIG: Repairing the ADF.	**TQ: Couple.**
CM: Mud reconditioning.	**TW: Unscrewing string.**
CP: Beginning of coring.	**WC: Weather problem.**
DP: Drilling a plug.	**WO: BHA whistling.**

7. conclusion:

To obtain optimum performance of the drilling bits, it is necessary to gather a set of factors that best promote the conditions of attack of the rock by the bit and which best protect the bit from its attack by the rock.

Achieving and using the bit best suited to the destruction of a given rock is the most important performance factor.

The constructers present a whole range of different types of bits which are important to know the particular characteristics. It is also important to bear in mind that a poor bit choice can lead, at the same time as a less good rock attack, to a faster or accidental destruction of the rock by the bit.

The economical drill bit is not necessary the one which provide a higher rate of penetration ROP. we've take in consideration it’s lifetime, service time as well as the well type (well calibration, realized trajectory, etc.). the reason is not only to get the target faster as possible as to the casing shoe point, it’s also about being able to measure the geological layers limits, run in hole the casing, completing the well.

CHAPTER III

EVOLUTION OF MECHANICAL SPECIFIC ENERGY MODEL

1. Introduction:

Optimized drilling is a system of pre-selecting the magnitude of controllable drilling variables between footage and drilling cost [10]. It is considered that with the increasing demand to drill wells, the area of research on the optimization of the drilling operations is going to be one over which scientist will be working on.

2. Objectif of study:

The objective of this thesis is to attempt to determine the best controllable drilling parameters to apply in each section of the well when drilling. The first step will be to model the drilling process and get the output as the rate of penetration. The next step will be to optimize the rate of penetration by optimizing the input variables to the model by applying the mechanical specific energy model

In the other hand, this research is to identify, characterize, and suggest changes in technical drilling of petroleum-related hydrocarbons carried in zone A1 of Hassi Messaoud West field. Thus, develop and mold mathematically a drilling optimization model aiming performance improvement and drillability enhancement. This thesis was developed based on the following specific objectives:

- Address the geological similarity of Hassi Messaoud West field;
- Study techniques and new researches concerning drilling optimization with regard to rate of penetration (ROP) modeling, specific energy (SE) surveillance, and analysis of drilling mechanics parameters;
- Analyze these studies using combined Hassi Messaoud West field operational information and data sets, proposing performance improvements;
- Suggest possible alternatives to improve drilling efficiency by combining ROP modeling and SE surveillance techniques/
- Dissert a final methodology linked to mathematical modeling, based in the studied literature and suggestions to enhance the drillability and performance in deferent sections.

3. ROP modeling concept:

Rate of penetration (ROP) modeling has been introduce in the industry for decades as a bit to quantitatively reduce drilling costs by drill-bit selection and by determining the optimal combination of mechanical and hydraulic operating parameters to be used while drilling to guarantee optimum activity. This sub-chapter summarizes the main research developments in terms of ROP modeling from 1958 to date, highlighting the main classical literature which are still used as reference in the industry.

4. Background research:

A lot of research on modelling and optimization of drilling parameters has been done. This section looks at past research on optimization of drilling. Most of the drilling models developed use different models separately for the different drilling parameters. For instance one model is developed for optimizing the weight on bit and the rotary speed, a different model is used for optimizing bit hydraulics and yet a different model for formation drillability. The following is the progression of modelling of optimization in drilling from the 1950s when research on optimization of drilling parameters started.

John Speer in 1958 developed five relationships between weight on bit, rotary speed, hydraulic horsepower, and effect of weight on bit (WOB) on formation drillability and how the optimum rotary speed is related to the weight on bit. He combined the five relationships into a chart for determining optimum drilling techniques from a minimum of field test data. Speer Identified five factors that affect bit performance as: Weight on bit, rotary speed, hydraulic horsepower, type of bit, and properties of the circulating medium (Speer, 1958).

Regression analysis of past drilling data to obtain constants in a drilling rate equation was proposed by **Graham** and **Muench** in 1959. They derived empirical mathematical expressions for bit life expectancy, drilling rate as a function of depth, weight on bit and rotary speed. They then applied regression on past drilling data to determine drilling constants that enabled them to determine optimum weight on bit and rotary speed combinations.

$$\boldsymbol{ROP = C_{for} D^{k} N^{0.584}} WOB \qquad (1)$$

Cunningham (1960) addressed a way to represent rate of penetration (ROP) as a function of two specific drilling parameters, running several tests under atmospheric and overbalanced conditions with roller-cutter drill-bits in shale and granite formation types. The drilling conditions applied on the tests were 15 to 50 [psi] hydrostatic pressure, 50 to 400 [rpm] rotary speed, 20 to 700 [lbf] weight-on-bit (WOB), weighted brine and tap water as drilling fluid, with 1.25 and 7.875 [in] OD drill-bits. The final ROP equation relation *(ROP_{calc})* was empirically derived, by means of its relation to the WOB over the outer drill-bit diameter $\frac{wOB_{sf}}{OD_{bit}}$ used (directly proportional to it) and to the rotary speed (RPM) applied (squarely and directly proportional to it).

The constant was defined, for this specific case and experiments, to be around 0.45 and always less than or equal to 1 . The constant , regardless of not having been defined, was stated to be a general constant dependent on drill-bit dullness not varying much, since the formations used in the test are considered to be non-abrasive. Equation (2) details the mathematical relationship of these detailed findings .[9]

$$\boldsymbol{ROP_{calc} = k \cdot \frac{WOB_{sf}}{OD_{bit}} \cdot (RPM_{sf}\,)^{a_6}} \qquad \textbf{(2)}$$

Maurer in 1962 developed a drilling-rate formula for roller corn bits derived from the mechanisms of creating ‘craters’ on the rock. The formula was based on the condition that there is perfect cleaning of the hole where all rock cuttings are removed from below the drill bit. Maurer stated his formula as “the drilling rate is directly proportional to the rotary speed and to the bit weight squared, and inversely proportional to the bit diameter squared and to the rock strength squared”. This relationship was incorporated into Bourgoyne’s drilling parameter for formation strength (Maurer, 1962). [9]

$$\boldsymbol{ROP = k \cdot \frac{RPM_{sf}\cdot\left(WOB_{sf}-WOB_{sft}\right)^2}{OD_{bit}^2\cdot S^2}} \qquad \textbf{(3)}$$

Galle and Woods in 1963 modelled rate of penetration based on the best constant weight and rotary speed for the lowest drilling cost for roller cone bits. They applied their model in several field tests which showed reduction in drilling cost. In their model they showed procedures for, the best combination of constant weight and rotary speed, the best constant weight for any given rotary speed and the best constant rotary speed for any given weight, (Galle et al., 1963). [9]

$$\boldsymbol{ROP = C_{for} \cdot \frac{WOB^{k_1}N^{k_2}}{\left(0.93h^2+6h+1\right)^p}} \qquad \textbf{(4)}$$

Grant Bingham in 1965 did compression tests on rocks in an attempt to relate drilling rate to the properties of the rock. He found out that the threshold force required to initiate drilling in a given rock at atmospheric pressure could be correlated to the shear strength of the rock. He did experiments with various rocks to determine their threshold strength. He presented his results in a graph of critical shearing stress against the square root of apparent intercepts (threshold strength) for these rocks and the plot could be approximated by a straight line (Bingham, 1965).

In 1974, **Bourgoyne and Young** developed an optimal drilling model using multiple regression approach. They considered most of the factors that affect rate of penetration and combined them in one mathematical equation. They then applied multiple regression approach to find the regressor constants that they used to predict the rate of penetration. Their model combined findings from many models developed previously into one model by using synthesis of previous field data. [25].

$$\boldsymbol{ROP = e^{\left(a_1+\sum_{j=2}^{8} a_j \cdot x_j\right)}} \qquad \textbf{(5)}$$

- Formation strength coefficient a_1,
- Formation depth; $x_2 = 10000 - \mathrm{h}$
- Formation compaction ;$x_3 = \mathrm{h}^{0.69}\left(G_p - 9\right)$
- Pressure differential across the hole bottom; $x_4 = h(G_p - \rho_c)$
- Bit diameter and weight on bit; $x_5 = ln\left(\frac{w}{d} - \frac{\left(\frac{w}{d}\right)_t}{4-\left(\frac{w}{d}\right)_t}\right)$
- Rotary speed; $x_6 = ln(N/100)$
- Bit wear;$x_7 = -t_w$
- Bit hydraulics. $x_8 = \frac{\rho q}{350\mu d_n}$

Teale (1965) analyzed the work done by a drill bit in order to advance into the rock or formation when excavating an infinitesimal volume of rock, and consequently, the necessary energy in terms of volume removed instead of mass removed, naming it the specific energy (SE) necessary in a rock drilling process. It was then established an equation to address the total work done by the forces acting on the drill-bit, considering its translational axial and rotational movement within a specific time range, stating also that the maximum mechanical efficiency would occur with a minimum imposed SE. The total work performed by the axial and radial force, in order to allow excavating a specific volume of rock, is represented by equations (6). [15]:

$$Es = \frac{WOB}{A_b} + \frac{120 \cdot \pi \cdot RPM \cdot T}{ROP \cdot A_b} \qquad (6)$$

After extensive researches over twenty years, **Rabia** (1985) simplified the equation for SE, stating that the ROP is more sensitive than SE for WOB and rotary speed changes. It was concluded that an increase in the SE (dependent on the drill-bit type and design rather than just rock properties) results in an increase in the cost per foot, and that cumulative cost per foot is directly related to drill-bit performance. The tests were conducted three different 12.25 [in] roller-cutter TCI bits in the Middle East.

Some year after, following the achievement of Rabia et al. (1985), **Pessier**and **fear**. (1992) addressed some interesting studies and summarized, mathematically and theoretically, the importance and possibility of converting the torque shown in the SE equation in terms of WOB and drill-bit sliding friction factors (considering the drill-bit as a flat cylinder and touching the borehole just in the bottom of the hole as per Figure 21). Thus, the SE formulation defined in equation (6), developed by Teale et al. (1965), was also validated for hydrostatic pressure environments and started to be called mechanical specific energy (MSE) instead of just SE) as per equation (7) and (8).They have been widely used in bit selection, drilling efficiency quantification, drilling performance monitoring, drilling parameters optimization, ROP improvement and so on.

$$MSE = WOB \cdot \left(\frac{13.33 \cdot \mu \cdot RPM}{D_b \cdot ROP} + \frac{1}{A_b} \right) \qquad (7)$$

$$\mu = 36 \cdot \frac{T}{WOB \cdot D_b} \qquad (8)$$

Another important interpretation was that hydraulics appear to have a high impact on penetration rate. The deeper the drilling activity, the less effective would be the hydraulic energy reaching the bottom of the hole due to pressure losses across the drill-string and the BHA. In addition, there is heating as a source of energy loss that should not be taken out of consideration on those calculations. The first changes done in the SE equation accounted for using torque and ROP in field units (units being [ft- lbf] and [ft/ h], respectively), as per equation (29).

But was from the year 2005 with **Dupriest** (2005 and 2010), that the surveillance of SE started to be effectively used for improving of drilling performance. It was asserted that drillbit efficiency lays between 30 to 40% as also per Teale, which stated that calculated SE's were roughly three times the rock crushing strength. It was found that this relates to the drill-bit depth-of-cut (DOC) in a proportional manner, and that the low drilling-related efficiency is a consequence of basically three main factors: drill-bit balling, bottom-hole baling and vibration (evidenced when drilling hard formations with high compressive strength and using inadequate WOB and rotary speed).The usage of PDC drill-bits does decrease the problematic of bottom-hole balling which is more evidenced in TCI drill-bits type due to its different drill-bit crushing action. In terms of vibration, not much was concluded rather than emphasizing that these parameters alone is not enough to guarantee a correlation with ROP.[14]

$$\boldsymbol{MSE = 0.35 \cdot \left(\frac{WOB}{A_b} + \frac{120 \cdot \pi \cdot RPM \cdot T}{ROP \cdot A_b}\right)} \qquad \textbf{(9)}$$

- *Hydraulic effect:*

The hydraulic energy is ignored as it is hardly aid in actual rock-broken in conventional rotary-drilling. Recently some researchers think that hydraulic energy also aids in actual drilling for certain formations, then they add the hydraulic term to the MSE function.

Hydraulic energy has an influence on drilling efficiency, but its role is complex. In conventional rotating drilling, bit hydraulics mainly accounts for the removal of cuttings from the bottom hole by jet-erosion, and the jet from bit nozzles could hardly aid in rockbroken especially in the deep and hard formations. Therefore, the MSE model is suitable for high pressure jet drilling and soft formation drilling. [12]

5. Result of background research:

A lot of research work has been done in the area of modelling and optimization, most of them aimed at reducing cost. The early models concentrated on modelling a few parameters that affect drilling rate while assuming or holding the other factors constant. Later a comprehensive and detailed modelling involving most of the parameters that affect rate of penetration were included. Currently optimization models have been developed that are capable of achieving real-time-optimization of the parameters affecting rate of penetration.

6. Modeling theory:

The aim of this study is to model a drilling rate penetration using the parameters applied to make drilling possible. After creating the drilling rate model, the parameters will be optimized by computer program using Exceland MatLab software to dothe modeling part of calculations of the rate of penetration.

6.1. Mechanical specific energy (MSE):

In this part, a new mechanical specific energy model for conventional drilling is established based on the evaluation of MSE models and the analysis of ROP performance, meanwhile a method for real time optimization of drilling parameters based on MSE for rotating drilling in the hard formation is also presented.

6.1.1. Definition:

Mechanical specific energy (MSE) has been defined as the mechanical work done to excavate a unit volume of rock. Teale (1965) initially proposed the MSE model for rotation drilling system. it could provide an objective assessment of the drilling efficiency and an objective bit to identify the bit founder.

This model(MSE) has utilize effectively in laboratory in order to evaluate the efficacity of drilling bit. It is evidently then to drill a volume has given which it has to a certain quantity of minimum energy will be require. Thisquantity will be depend on the type of drilling bit has utilized and the rock nature.[8]

6.1.2. Principe of MSE theory:

The MSE theory provoke a tactic to expect or analyze the performances of drilling bit . the Es is based on the fundamentalprinciples correlate with the quantity of energy required to carry out an unitary volume of rock and drilling bit efficacity in order to destroy this rock [8].

The Es parameter is an utile measure in order to identify the puissance has require in (bit torque and RPM) on particular bit type in order to drill with ROP has given in a particular rock type.

This theory is not new but still very effective .it has been used in a quick evaluation of drilling bit performance throughout the years. The equation (6) gives the relation between thespecific energy and the mechanicals parameters(Teale) [8] it has derivedto the rotation drilling in the atmospherics conditions.

$$Es = \frac{WOB \ \cdot ROP + 60 \cdot 2\pi RPM \cdot T}{ROP \cdot A_b}$$

$$Es = \frac{WOB}{A_b} + \frac{120 \cdot \pi \cdot N \cdot T}{ROP \cdot A_b} \qquad (6)$$

In the above model, torque at the bit is a main variable. Although torque at the bit can be easily measured in the laboratory and with Measurement While Drilling (MWD) systems in the field, the majority of field data is in the form of surface measurement. While in the absence of reliable torque at the bit measurements, the calculation of MSE based on this model contains even large sources of error. Therefore, it is only used qualitatively as a trending tool.

In 1992, Pessier and Fear provided a simple method of the calculation of torque at bit while in the absence of reliable torque measurements and optimized Teale's model.

$$MSE = WOB \cdot \left(\frac{13.33 \cdot \mu \cdot N}{D_b \cdot ROP} + \frac{1}{A_b}\right) \qquad (7)$$

- **Coefficient of Sliding Friction μ:**

In actual drilling process, leakage and torque losses play important roles in the performance of the rate of penetration .so theSliding Friction Coefficientμ was been introduce to trythe torque like an experimentmight as well the weight on bit function , this coefficient will be utilize in the next steps to calculate the specific energy values which impose in several cases where the torque measures is reliable calculateasfollowing[8] :

$$\mu = 36 \cdot \frac{T}{WOB \cdot D_b} \qquad (8)$$

The above model's parameters are easy to be obtained on the ground, and its calculation precision has been improved, as a result, it has a common usage in the drilling industry. In this model, the torque of bit is calculated through WOB. However, WOB is always read in the weight indicator on the ground, which is not the bottom hole actual WOB. As for directional and horizontal drilling,

- **The Maximum efficiencyEff_m:**

Tealehas presented concept of minimum specific energy and maximum mechanical efficiency. Minimum specific energy will be reach when the specific energy is near or equal to the compression effort of the rock (CCS)has been drilled.

The maximum efficiency (EFF_{max})of whatever drilling bit type is calculated byequation ()

$$EFF_{max} = 100 \cdot \frac{Es_{min}}{Es} \qquad (10)$$

Where:$E_{S\ min}$= minimum specific energy (Rock durability).

- **Confined compressive strength (CCS):**

Teale's laboratory experiment showed that MSE was numerically close to the unconfined compressive strength (UCS) of the formation at maximum drilling efficiency. However, the tests were conducted at atmospheric conditions. In the real drilling process, MSE is numerically close to the CCS of the formation at maximum drilling efficiency. In other words, when drilling achieves a maximum drilling efficiency, the minimum MSE is reached and is roughly equal to the CCS of the rock drilled

$$MES_{min} = CCS \qquad (11)$$

Therefore, MSE can be used to detect the peak drilling efficiency by surveilling MSE to see if the MSE(min) is roughly equal to the CCS of the rock drilled.

The mechanic couple associate with a particular bit type to drill with ROP has given in particular rock type or the compression resistance (CCS) is calculated by using the following equation (12) which was derived from equation (7) and equation (10):

$$T = \frac{CCS}{EFF_m} - \frac{4 \cdot WOB}{\pi \cdot D_b^2} + \frac{{D_b}^2 \cdot ROP}{480 \cdot N} \qquad (12)$$

By substitution the Es efficiency term and mechanic couple in function of WOB and resolve the equation (6) to ROP. the count of penetration will be calculating by the coming equation (13).

$$ROP = \frac{13.33\mu \cdot N}{D_b\left[\frac{CCS}{EFF_m \cdot WOB} - \frac{1}{A_b}\right]} \qquad (13)$$

We have examined the MSE theory.Pessier has concluded that the sliding friction μ, maximum efficiency (Eff_{max}), WOB and RPM have a reasonableness that will be define for each bit type in function of the apparent durability of the rock. the laboratory work was being start by the searchers to confirm and measure their reports. the research on the solution confined reasonably precis resistance against the pressure in the apparent durability of the rock was been started yet.

7. optimization part:

7.1. Drilling cost optimization:

Drilling optimization is usually conducted using models for estimation of ROP as well as cost per foot.

Drilling costs tend to increase considerably with depth; it is a good practice study past data and information from previous wells to address time and costs of future drilling operations insimilar regions. When good and reliable data are available for a specific region or location, it is possible to predict the relationship between costs and depth, which are reduced as more successful wells are drilled in nearby regions. This improvement is related to the learning process, mathematically described by learning curves, and, with a minimal amount of gathered data, acurve can be drawn, drilling engineers to predict well costs for subsequent wells. [13]

$$C_f = \frac{C_b + C_r(t_t + t_c + t_b)}{\Delta h} \qquad \textbf{(14)}$$

7.2. MSE Drilling optimizationof mechanics parameters:

Real-time optimization of drilling parameters during drilling operations aims to optimize WOB, RPM for obtaining maximum ROP. The process is not only formation specific but also drilling system specific. Fig.1. shows a classic drill-off curve. The point at which the ROP stops responding linearly with increasing WOB is referred to as the founder point where the ROP is maximized. The corresponding WOB at this point is taken to be theoptimum WOB. Fig. 4 shows field data from three drill-off tests with an insert bit. It indicates that the bit is prone to founder with high RPM, and the optimum WOB decreases obviously with the increase of RPM of bit. Moreover, the founder point changes greatly with the change of RPM of bit. [17]

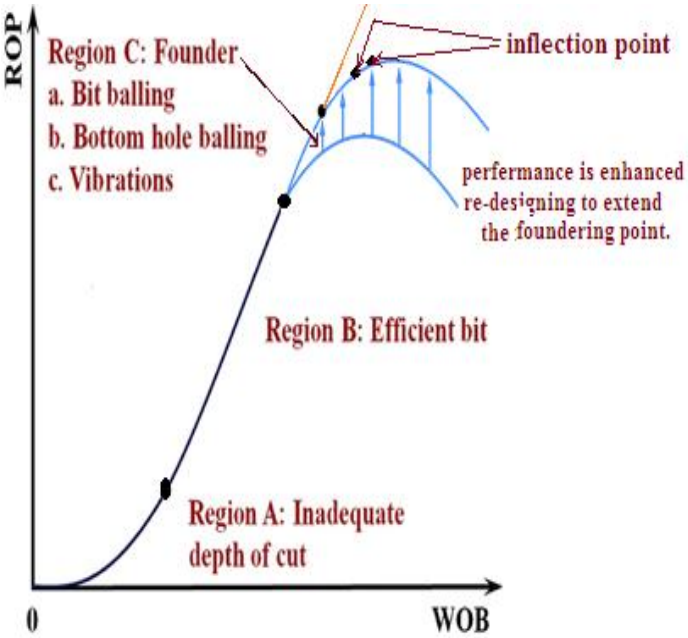

Fig 3.1: Relationship between the traditional ROP versus WOB plot. [10]

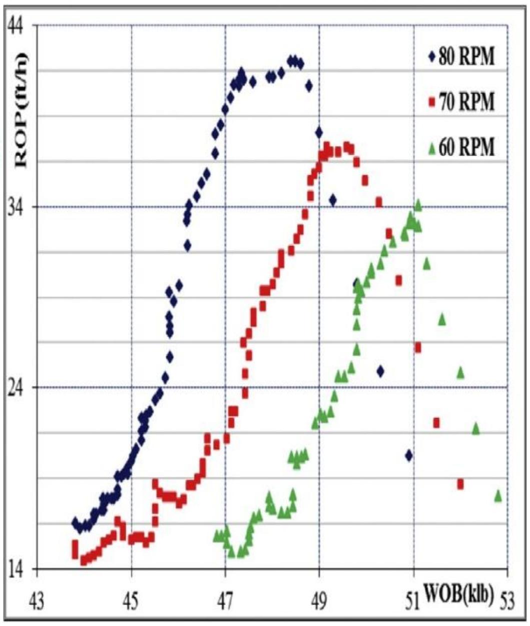

Fig 3.2: Field data from three drill-off tests. [10]

Asaforementioned, MSE is the amount of energy required to destroy a unit volume of rock. When a bit is operating at its peak efficiency, the ratio of energy to rock volume will remain relatively constant. The minimum MSE is reached and it correlates with the CCS of the formation. This relationship is used operationally by observing whether the MSE(min) is roughly equal to the CCS of the formation while adjusting drilling parameters such as WOB or RPM to maximize ROP. [10,11]

If the MSE(min) remains roughly equal to the CCS of the formation while increasing WOB, the bit is assumed to be still at its peak efficient. If the MSE(min) increases significantly and is much higher than the CCS, the bit has foundered. The causes of founder are bit balling, bottom hole balling and vibrations. If the causes of founder are not addressed when they occur, overall drilling performance will suffer and tools will be damaged.

We consider the conditions of application of MSE theory in conventionaldrilling well as there is no change of weight between the surface and the bottom. [17]

We extract α value about$\alpha = CCS/EFF_m$according to equation (12) which define the torque, so it can be write as the coming equation (15):

$$\alpha = \frac{CCS}{EFF_m} = \left(\frac{13.33 \cdot \mu \cdot N}{D_b ROP} + \frac{1}{A_b}\right) \cdot WOB \qquad (15)$$

the first meter drilled can give us the following: μ, N, ROP, et le WOB.in this case, can simply calculateα. the α values will be utilizing for the next calculation of the optimal ROP by using the equation (5). For its running, the optimal ROP will be used to determine the new α value, and so on. The following organigram represents the calculation approach.

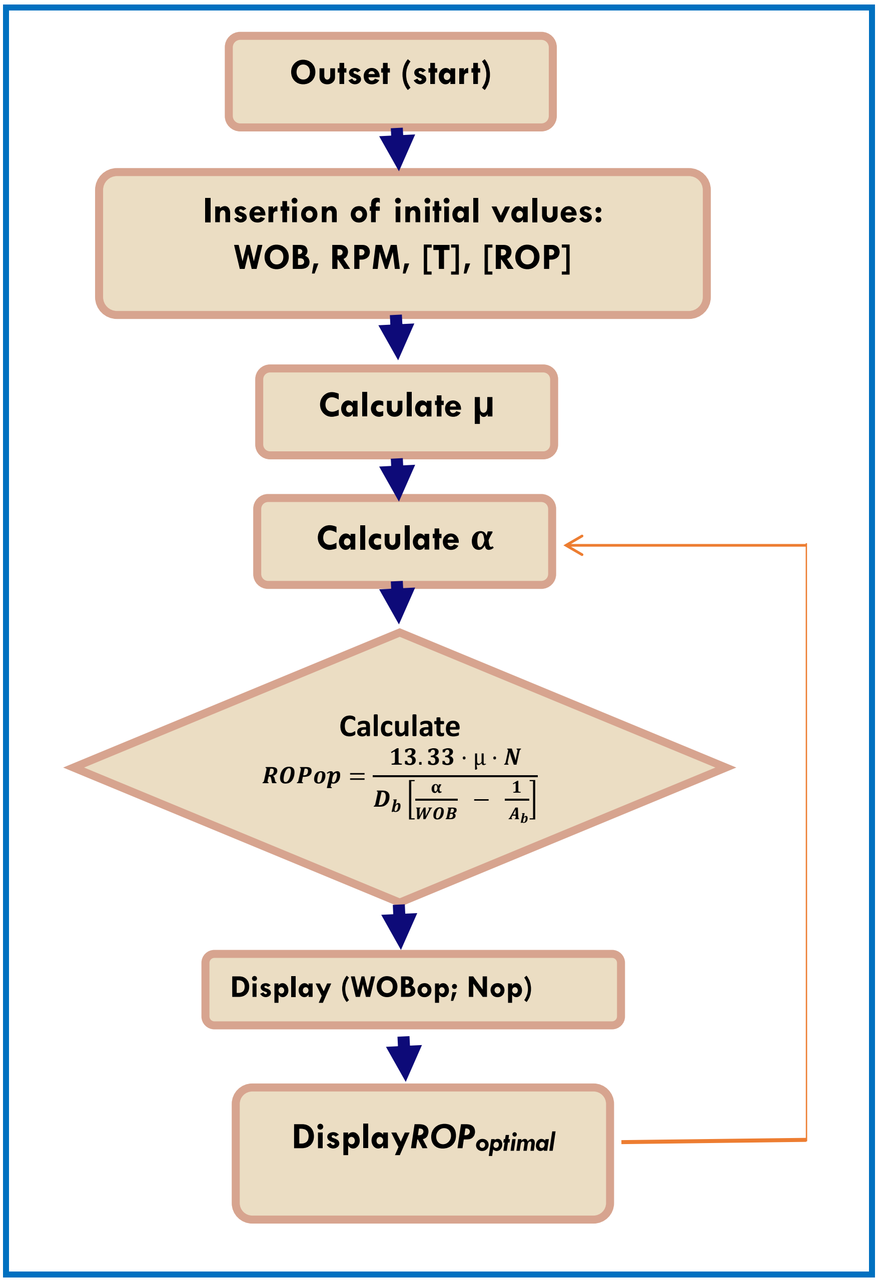

Fig 3.3: diagram of $ROP_{OPtimal}$ Modelled [26]

MSE should be kept as low as possible and ROP as high as possible in order to increase the efficiency of the process; which can be obtained by varying WOB, rotary speed, and mud flow within normal operating limits. Other than identifying performances limiting factors, MSE can be used as a quantitative measure for assessing costs-benefits associated with redesign of drilling process.

8. Vibrations types of drill bit and drill string

Moreover, the tool is also able to monitor in real time the vibrations which allows increasing ROP, the components life and the hole quality.

All the vibrations involved in the drilling process are represented in figure 3.4.

Bit balling and bottom hole balling are terms used to describe build-up of material on the bit and bottom hole that inhibits transfer of a portion of the WOB to the cutting structure. They usually occur in soft formations, and it can be relieved by increasing flow rates and reducing WOB. When drilling in hard formation with a PDM, bit balling and bottom hole balling are unlikely to occur, while vibrations are very common. [4,11]

Down hole vibrations include three modes which are represented in figure 3.4: whirl (lateral), stick-slip (torsional) and bit bounce (axial). They amplify loads downhole, resulting in a host of bit and bit failures that not only increase the number of trips required, but also the costs of bit repair and replacement. Actually, these vibrations in rotating drilling with PDM could be effectively eliminated by adjusting WOB or RPM on the surface. [20]

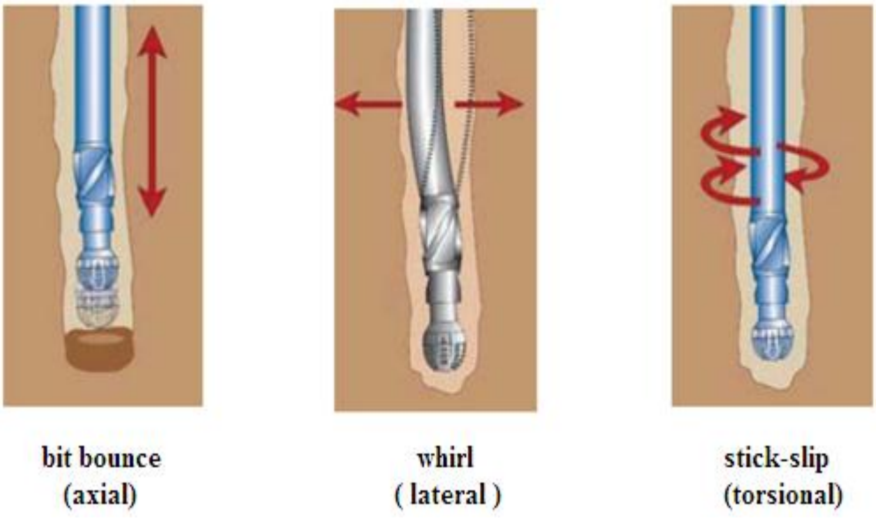

Fig 3.4: types of drill string vibration [20]

8.1. Axial vibration:

Axial vibrations (bit bounce) consist in the movement of the drill string along the hole axe; among which the most dangerous on the bit.

8.2. Lateral vibration:

The lateral vibration(whirl), induced by a movement perpendicular to the hole trajectory, if detected, requires immediate intervention to avoid damages to the equipments. The whirl consists in a eccentric rotation of the bit (fig 3.5):

Fig 3.5: types of whirl vibration [20]

In the **forward** whirl the bit rotates clockwise and causes the area of the collar that comes in contact with the hole to wear; in **the backward** whirl the center of the collar rotates around the center of the hole at a higher speed than expected, inducing the increase of the bending cycles and the consequent fatigue failure, in **Chaotic whirl** the bit has a mixture attitude in forward and backward. [4,20]

The major consequence of the whirl is a reduction of the efficiency and a larger hole diameter.

8.3. Torsional vibration:

The stick-slip is a torsional vibration associated with a high torque and a fluctuation of RPM caused by the surface rotation of the drill string associated with its downhole deceleration due to the friction of the equipment with the hole walls. Also, in this case it is requested an immediate intervention to avoid the ROP reduction and bit damages. [20]

8.3.1. Stick-slip type oscillations:

This type of vibration is an important class effecting of ROP(fig6.), it's associate stick-slip phenomenon, for example, the PDC bit usually manifests in transversal sense, within the general lateral vibration and the oscillation have conduct. But it can be existed if the roller cone bit type has utilized. [20]

8.3.2. Effect of stick-slip on ROP:

In the figure (6), The black line represents the rotary table/tope drive (RPM in surface) which is variable from 45to 65(r/min) and the other one represents the rotary table/tope drive in the downhole. we observe that RPM can arrived three to five time from its nominal value and with one to five time of oscillation period. Through this period sometimes about 55(r/min) of RPM, and that which is causing the torsion of drill string .it very dangerous on breaking the drilling bit.

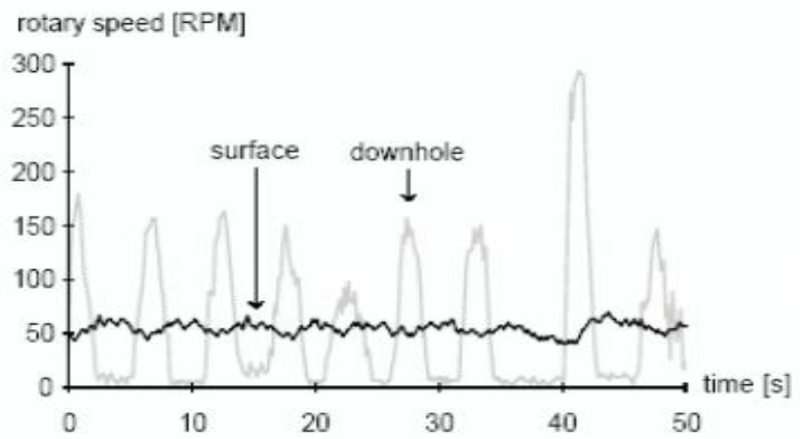

Fig 3.6: effect of stick-slip on ROP

8.4. the general effect of vibrations on ROP:

MSE can be related to effects of dysfunction shown in Figure .7. If the MSE increases when a change is made, the performance is moving further way from the efficient performance, which would be the dashed blue line. If it decreases, the performance is moving closer to the dashed line. For example, the curve for whirl shows that if WOB is increased, the ROP performance moves closer to the predicted line, which means that in efficiency due to whirl is decreasing, and we would expect the MSE to go down. [20]

This is used as adiagnostic. If the WOB is increased, and the MSE declines, we know that whirl was the cause of dysfunction to start with. As shown in **Figure .7**, there is no other dysfunction that improves as WOB is increased (e.g., moves closer to the dashed line).

In order to identify some of the other forms of founder, it is necessary to observe additional data, or to have more information about the drilling conditions.

Regardless of the cause of dysfunction, the manner in which the driller uses the MSE to maximize real time performance is the same. To get this performance, the driller must conductstep tests by changing one parameter at a time (WOB, RPM or Flow rate). [17]

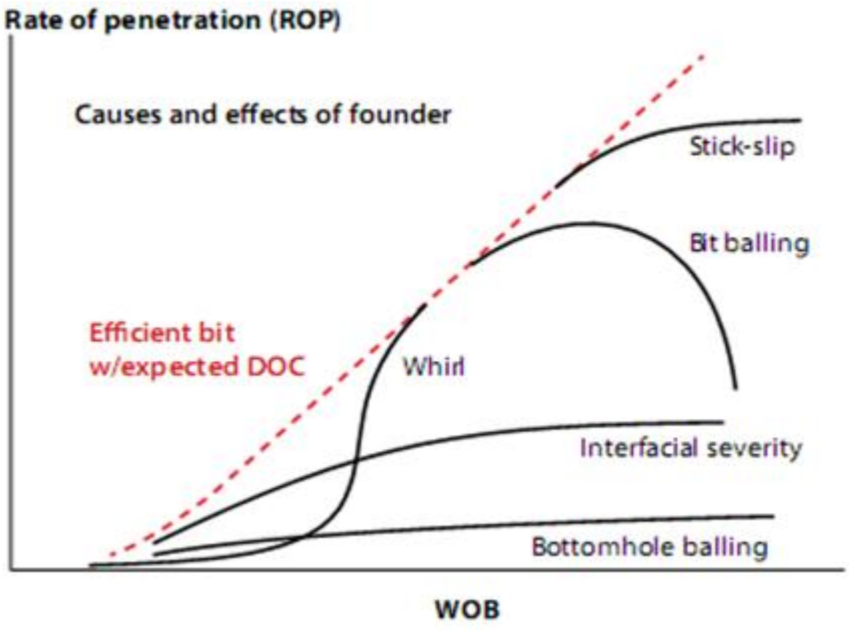

Fig 3.7: effect of vibration types on founder point

- If the MSE declines the dysfunction is getting better and performance is improving. Continue with more of the same change (i.e., even higher WOB);
- If the MSE increases, the dysfunction is becoming worse and performance is declining. Change the parameter in the other direction (i.e., reduce the WOB);
- If the MSE stays the same performance is on the straight-line portion of the drill off curve in Figure of founder point. Continue increasing WOB to founder.

9.Conclusion:

Most of the models have been developed for use in the oil fields where the formation is mainly homogeneous. This study has adapted the MSEdrilling optimization model of Pessier. Data from one well OMM-302 is used in the case study of this model. and that will be represent in the following chapter.

CHAPTER IV

CASE STUDY, APLLICATION OF MECHANICAL SPECIFIC ENERGY THEORY

1. Introduction:

This chapter is including the case of study which is contain the application of specific energy model of Pessier as we have presented it in the previous chapter. So, we gave a short resume of drilling well OMM-302 Bis programs and its operation, geological description and location, this well is situated in Hassi Messaoud field zone A1. the application of optimization is based on drilling parameters data that was saved during the drilling operation. [23]

2. Well objectives:

OMM-302 Bis is a vertical development well to be drilled in the 1A zone of Hassi Messaoud field; The proposal of well Bis is following the good petrophysical parameters in the sector (in particular in the D5, D4 and D2) revealed by the interpretation of the well logs OMM302, and confirmed by an excellent history of production,

The well has several objectives which are:

- Final Depth: 3474 m (3538m TVD, -3384m TVDSS)
- Target: Cambrian (R2).
- Expected Reservoir Pressure: **300** kg/cm^2
- Do not exceed global NPT< 5%.
- Achieve logging acquisition objectives.
- Complete all operations referring to SONATRACH HSE standards.

3. Geographical situation:

Hassi Messaoud field is located 800 km southeast of Algiers, between the meridians 5°30 6°00 and the parallels 31°00 and 32°00N (Fig. 1). It is 350km from the Algero Tunisian frontier and 80 km East of Ouargla.

Hassi Messaoud field is considered as the largest oil field in the Triassic province. Due to its size and its reserves, it is the largest Algerian oilfield and the area is around 2200 Km^2.

It is limited to:

- NW by the deposit of Ouargla, Guellala, Benkahla and HaoudBerkaoui.
- SW by the deposit of el Gassi, Zotti and El Agreb.
- SE by the deposit of Rhoude-El-Baguel and Mesdar.
- East by the deposit of Ghadames.

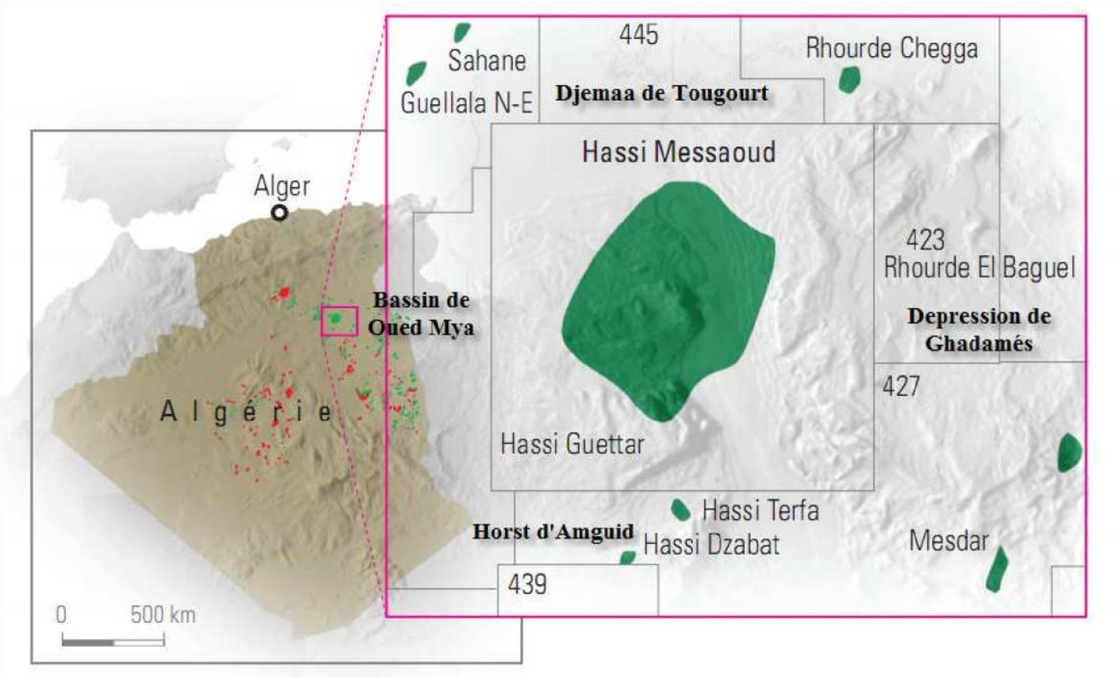

Fig 4.1: Location map of the Hassi Messaoud field

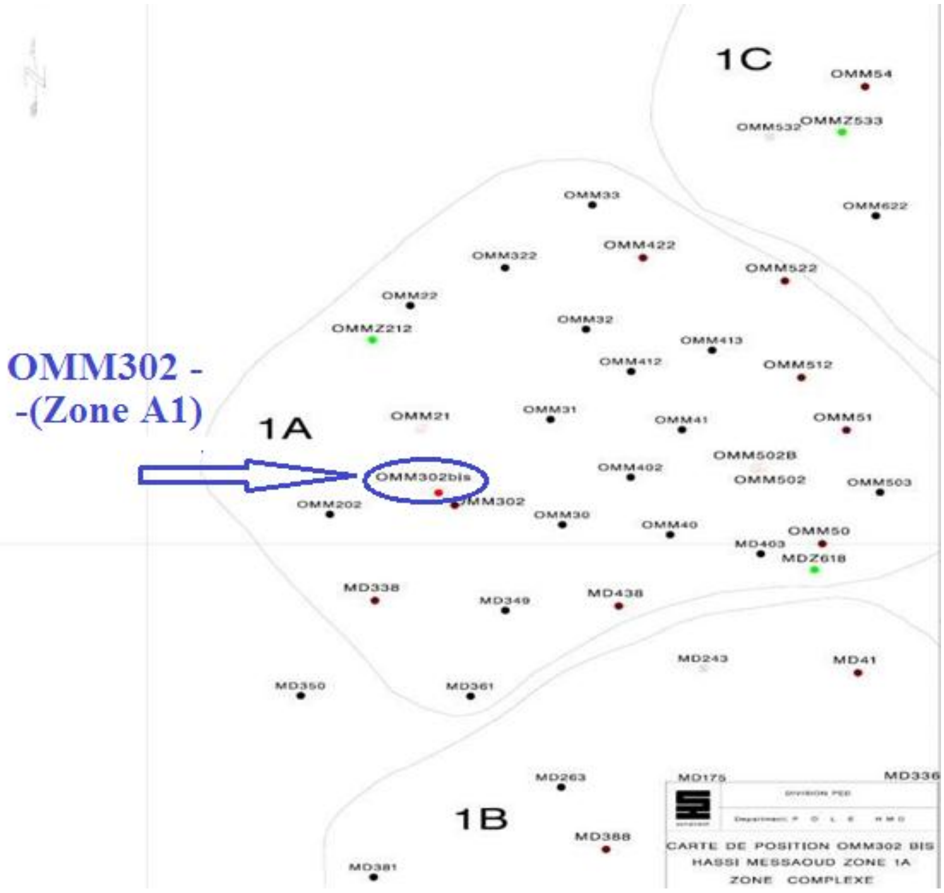

Fig 4.2: Situation of OMM-302 Bis well in (1A) zone

4. Well description:

The table below shows several characteristics and information of OMM-302.

Table 4.1: well description

	OMM-302 Bis	
Field	**HMD**	
Well Classification	Development	
Operator	SONATRACH	
Drilling Contractor	SONIPEC	
Drilling Rig	**SPEC-232**	
Surface Location	LSA	X = 792658,038 Y =130579,695
	Latitude	31°43'55.08000" N
	Longitude	5°47'13.63856" E
	UTM Zone 31	X = 764 077,023
		Y = 3 513 837,983
Well Located in coordinate system	UTM Zone 31on North Sahara, Clarke 1880 (This system will be used as reference in all documents)	
Elevations	Ground Level	143,231m Above Mean Sea Level (AMSL)
	Rotary Table Elevation	10,5 m above Ground Level (AGL)
	Rotary Table Elevation	154m Above Mean Sea Level (AMSL)
Well TD	3474 m TVD	-3320 m TVDSS

5. Mud program: [23]

The INVERMUL Oil Base drilling fluid system and operating procedures are designed to achieve the following objectives:

- Provide effective hole cleaning while drilling the 26" hole and avoid losses into the surface unconsolidated formation.

High viscosity Spud Mud will be used to drill the 26" hole. Drilling hazard in this interval will be mainly due to a Total Loss of Circulation problem into the unconsolidated sand of “Mio Pliocene” and Limestone of “Eocene & Senonian Carbonate”. LCM pills and/or cement plugs may be required. Upon approaching the casing point the mud fluid loss will be controlled and the YP will be reduced to ±30 to facilitate casing running and cementing respectively. Top cement job through the annulus will be performed if required.

To provide hole cleaning, Bentonite spud mud is recommended to be used. Enough time should be allowed to the mixed Bentonite in order to ensure full hydration.

- **Minimize ECDs** by controlling the amount of Low Gravity Solids (LGS) build-up in the fluid and by optimizing flow rates.
- **Provide efficient** hole cleaning characteristics to minimize annular loading of cuttings.
- **Effectively seal** porous zones, minimize fluid loss to the formation and provide a good filter cake.
- Avoid reservoir damage.

Table 4.2: Mud properties

Properties	36''/26" Section	16" Section	$12^{1/4"}$ Section	$8^{1/2"}$ Section	6" Section
Mud system	Bentonitic	OBM	OBM	OBM	OBM
Mud weight (SG)	1,05	1,25	2.02 before LD2	1,40	(as per DP)
Y_P, Ib/100 ft2	40 - 60	18 - 24	10 - 14	10 - 12	10 - 12
HPHT FL ML	API ± 20 at TD	<10	<10	<10	<4
LGS %	< 5	< 5	< 5	< 5	< 4
Hydraulic analysis 3 diff Y_p	Required	Required	Required	Required	Required
Pump flow Rate (l/min)	3500	2800	2600	1800	800

6 . Geological context:

The Fig 4. shows more details in Appendix I.

6.1. Stratigraphical aspect:

Hassi Messaoud field is as wide mole, which an important part of the Paleozoic stratigraphic series is absent, removing any witnesses of geological history for 230 million years.

6.1.1. Paleozoic:

The Paleozoic formations are unconformably overlie the basement; it is the Panafricain unconformity. From the top to the bottom, :

A. Cambrian: (3440 m)

Essentially consists of heterogeneous sandstone, fine to very coarse interspersed by argillaceous siltstones laminae, micaceous. Average thickness is 590m.

B. Ordovician: 3328m

Regionally, the Ordovician is composed of several lithological units with incomplete series. For Hassi Messaoud field, from the top to the bottom we have only four (4) lithological units:

- **Alternance Zone: 3378m**

The average thickness is 20 meters. An irregular alternance of black silty clay fine isometric quartzitic sandstone and abundance of Tigillites and some Lingulidae (Ordovician-Actual), the mineral fraction comprises of glauconite and siderite.

- **Clay of El Gassi:**

The average thickness is about 50 meters. This formation consists of silty clay, soft with black and green color, rarely red. This clay can be carbonated or glauconieuse containing a fauna (Graptolites) indicating a marine depositional environment. This is mostly encountered on the peripheral areas of the field.

- **El Atchane Sandstone:**

The average thickness varies from 12 to 25 meters. This formation consists of fine to very fine sandstone grey-beige to dark grey. This sandstone can be clay with several silty clay laminae.

- **Hamra Quartzite:3324m**

The average thickness varies from 12 to 25 meters. It is fine quartzite sandstone, silty light grey to beige with rare intercalated silty clay, micaceous and soft of glauconite, anhydrite and several Tigillites.

6.1.2. Mesozoic:

A. Trias: 2779 m

It unconformably overlies the Cambrian in the center and the Ordovician to the flanks of the structure. It is a very diverse set result from the transgression with lagoon marine character accompanied by with eruptive lava. It is divided into four (4) units:

- **Eruptive Triassic:**

The thickness varies between 0 and 92 meters. Locally we find eruptive lava interbedded with Trias sandstone, this indicates the presence of several volcanicoutpourings intercalated into the clastic facies. These flows have often occurred inHercynian valleys.

- **Triassic Shaly sandstone:**

Its average thickness is 35 meters. It is the first deposit of the Paleozoic relief and divided into several units, which differ according to the lithology and logging responses. Found, locally on eruptive lava filling the deep Hercynian erosion valleys:

Upper sandstone: fine sandstone with argillaceous cement.

Lower sandstone: consists ofsandstone with fine to medium abundant argillaceous cement.

- **ShalyTrias:**

The average thickness is 113 meters. It consists of dolomitic clays or silty intercalated with brown-red salt bench.

- **SalifereTrias:**

The average thickness is 340 meters. Plays the role of cap rock, it consists of massif salt bench present, at the top, intercalations of anhydrite and clay benches slightly silty and dolomitic, it consists of three (3) units:

- **SalifereTrias « 3 » or « ST3 »(3024m): thickness is 202 meters.**

  At the base of salifereTrias, it consists of massif salt bench present at the top intercalations of anhydrite and clay benches slightly silty and dolomitic.

- **SalifereTrias « 2 » or « ST2 »(2825m): thickness is 189 meters**

It consists of massif salt bench with intercalations of anhydrite and gypsiferous clay.

- **SalifereTrias « 1 » or « ST1 »(2779m): thickness is 46 meters**

Consists of salts with predominance of anhydrite and dolomitic clay.

B. Jurassic: (1953m)

The average thickness is 844 meters. It is a group of clayey sandstone with an intercalation of limestone at the top (Malm) and alternance of lagoon and marine facies at the base (Dogger and Lias).

- **Lias: (2519m)**

The average thickness is 300 meters. The transition from Trias to Lias is characterized by a dolomitic marls zone known as "Horizon B" which is a seismic landmark. The Lias is divided into five (5) distinct levels intercalated between them through the entire thickness:

Dolomitic Lias «DL3 »: (2749m)

Thickness of 31 m, it consists of grey marl with grey dolomite stringers.

SalifereLias «SL2 »:(2704m)

Thickness of 58 m, it consists of translucent salts and brown red clay laminae.

Dolomitic Lias «DL2 »: (2645m)

Thickness of 55 m, it consists of intercalation of massive dolomite benches fine grained, greyish with slightly grey dolomitic marl laminae.

SalifereLias «SL1 »:(22574m)

With an average thickness of 90 m, it consists of brown clays with salt and anhydrite white stringers.

Dolomitic Lias «DL1 »: (2519m)

Thickness of 66m, it consists of dolomite benches and anhydrite with clay and limestone laminae.

2) Dogger: (2176m)

The average thickness is 320 meters. The Dogger is divided into two (2) formations, the Dogger lagoon at the base and clayey Dogger at the top.

- **Dogger Lagooner: (2281m)**

It is represented by a Lagoonseries at the base essentially anhydrite and dolomite about 210m thick.

- **Dogger Clays :(2176m)**

Thickness of 107 m, it consists of soft clay, silty with fine sandstone laminae and argillaceous carbonate cement.

3) Malm: (1953m)

The average thickness is 226 meters. It is characterized by clay deposits and marl with interbedded limestone and dolomite benches accompanied by anhydrite traces.

6.2. Cambrian litho-stratigraphic (reservoir characterization):

Cambrian is the main reservoir of Hassi Messaoud west located distinct sedimentary groups of lithozone R2). (Fig. 2).

This division is based on petrographic, petrophysical and wireline logging criteria.

The average thickness of Lithozone R2 is 100 meters. The lithozone R2 consists of sandstone medium to coarse micaceous poorly sorted with abundant argillaceous cement and interbedded siltstones. Stratifications are often oblique.

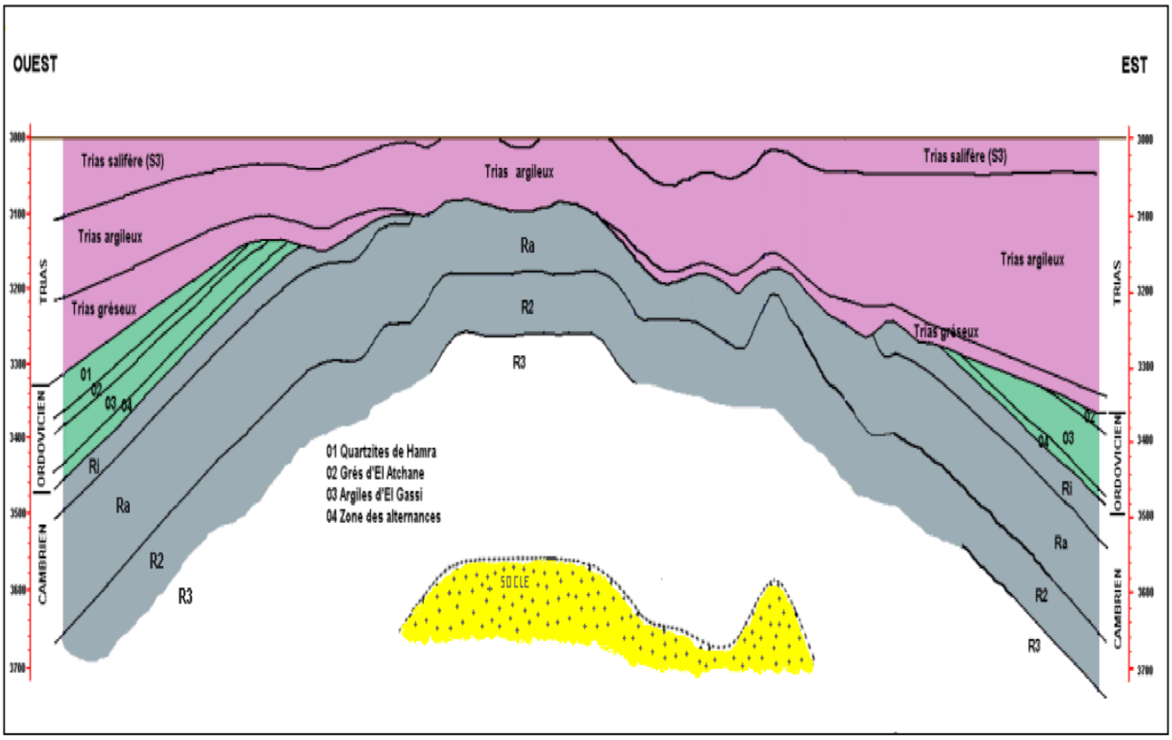

Fig 4.3: Hassi Messaoud field structure presented as vast flat anticlinal dome with general direction North-Est – South-West

7. Application of MSE theory in Field case:

As described in the previous chapter, there are several methods for optimizing drilling parameters. For our memory, we chose the ROP optimization method by the theory Energy

Specific (Es). This method takes the hydraulic parameters as optimal parameters and tries to use the mechanical parameters measured on the surface in the cabin of the Mud logging.

To verify the new mechanical specific energy model, drilling data of a 80m section of a vertical well have been used to calculate the profiles of CCS and MSE with depth. The drilling data, including WOB, surface RPM, ROP, mud flow rate, were recorded for every 1-m step from 2402 m to 2480 m,and for more details see table 4.7 in Appendix 4.2.

We applied the MSE theory in section of 12**.1/4"** from 2400 to 2481 m which has drilled by PDC, the drilling parameters was recorded in table 4.3. All the parameters in this table recorded as initial parameters.

Table 4.3: drilling data was saved during the process [23]

Depth (m)	WOBmin (ton)	WOBmax (ton)	RPMmin (rpm)	RPMmax (rpm)	Rotary Torque (ft.lb)	ROP (m/h)
2402-2406	2.14	16.55	60.52	80.59	7485.76	6.62
2411	13.4	17.69	79.23	84.28	8806.78	11.54
2416	15.01	18.69	7945	83.27	8195.03	10.86
2421	13.63	18.99	76.2	83.27	11853.54	6.6
2426	12.98	18.76	45.79	129.81	10845.53	7.34
2431	12.4	17.56	113.69	124.19	10069.42	6.32
2436	14.7	18.21	123.25	123.29	8909.27	6.79
2441	15.1	17.42	116.63	123.31	9187.24	5.84
2446	13.5	17.78	123.25	123.3	8661.6	7.16
2451	12.58	17.74	123.26	124.24	8254.05	7.39
2456	14.25	17.69	123.24	123.29	8886.79	5.87
2461	11.6	18.16	123.26	123.3	8522.15	5.2
2466	12.98	18.65	117.83	129.89	9122.32	6.43
2471	4.77	17.69	123.29	129.89	8677.11	12.98
2476	13.76	17.78	129.61	129.88	8430.38	5.38
2481	13.76	20.43	124.17	129.9	8229.23	5.93

7.1. Data analysis:

In this section (2402-2481 m), as seen in Figure (24), The data collected shows that there is an indirect relationship between RPM, WOB and ROP. The ROP is very sensitive to changes by WOB than RPM.

the applied WOB is very low and less than 20 ton, the applied RPM is variable between 50-100 rpm then became stable after 2430 m with 128 rpm, Severe vibrations were observed in first 30 m in this section. Which result of low ROP.

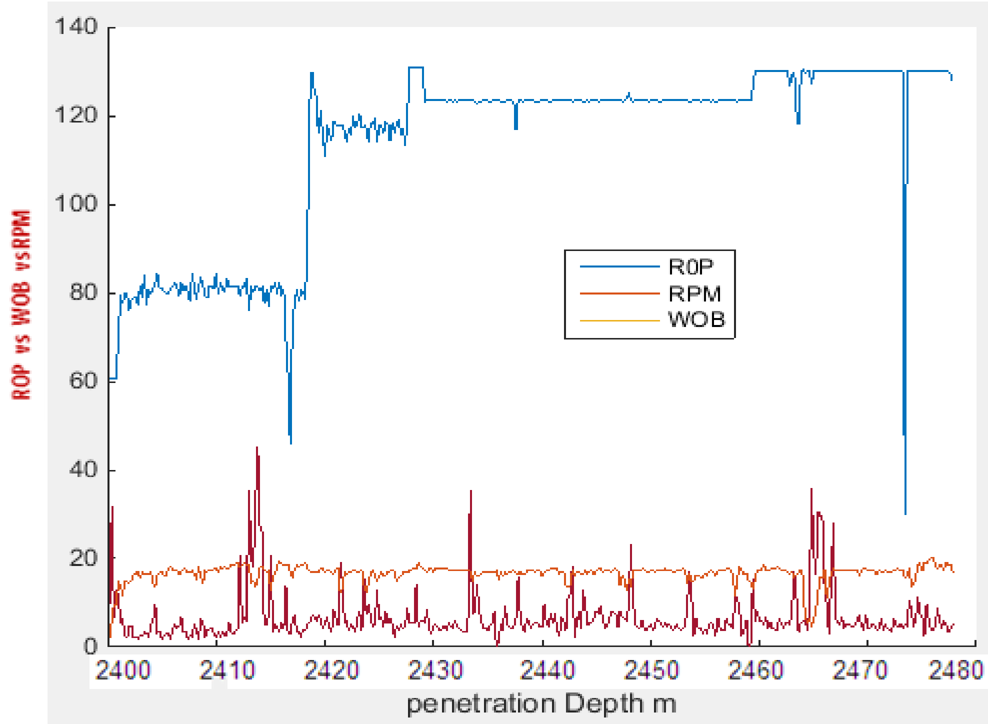

Fig 4.5: correlation between ROP, RPM, WOB

7.2. Result and discussion:

From the methodology section, several variables are needed as input to the model. Some of the variables are parameters that are captured as the well is drilled. Some of the variables need to be calculated using mathematical formula while others need to be got using field measurements under special conditions.

Table 4.4: Variables needed for the model

Variables measured while drilling	Variables to be calculated
Depth	$\alpha = \frac{CCS}{EFF_m}$
Rate of penetration (ROP)	Sliding friction(μ)

Weight on bit (WOB) and rotary torque	ROP_{opt}
Rotary speed (RPM)	Section(area)

The initial parameters that were mesured during the drilling operation of 12.1/4"from 2402 m of depth to 2481 m .

Table 4.5: the initial parameters for the first meter

Depth (m)	WOB (ton)	RPM (rpm)	Rotary Torque (ft.lb)	ROP (m/h)
2402	2.14	60.52	2254.75	9.76

After using the MSE theory for optimization, the table (**4.6**) gives the final result of $ROP_{optimal}$, optimum WOB and the optimum RPM each range as five meters ,the optimum ROP values which have a superior error on 5% not acceptable , where the optimum values which have an inferior error of 5% are all acceptable

Table 4.6: Result of optimization parameters

Depth (m)	RPMop (r/min)	WOBop (ton)	ROP (m/h)	ROPop (m/h)	Error (%)
2406	61.56	2.2	6.62	10.21	4.46
2411	86.66	14.1	11.54	12.01	3.72
2416	88.65	16.1	10.86	11.3	3.93
2421	81.44	17.23	6.6	6.79	2.89
2426	121.65	18.11	7.34	7.94	2.79
2431	122.02	17.01	6.32	6.65	4.99
2436	123.02	18.13	6.79	7.02	3.31
2441	121.44	16.67	5.84	5.93	1.6
2446	122.42	17.79	7.16	7.39	3.05
2451	121.86	16.98	7.39	5.53	1.93
2456	123.01	17.99	5.87	5.97	1.82
2461	123.29	17.18	5.2	5.42	4.17
2466	123.29	15.12	6.43	6.71	4.18
2471	126.29	7.011	12.98	13.49	3.76
2476	128.29	17.012	5.38	5.59	3..59
2481	128.29	18.51	5.93	6.14	3.35

7.2.1. The ROP modelled:

Figure (6) show the plot for the modelled ROP values, obtained by using the MSE optimized model. In comparison, the original data sets are equally plotted on the same figure,

Original data sets are in 'Red', while modelled are in 'yellow'. They all show similar trends even though there are slight deviations at some data points along the depth,

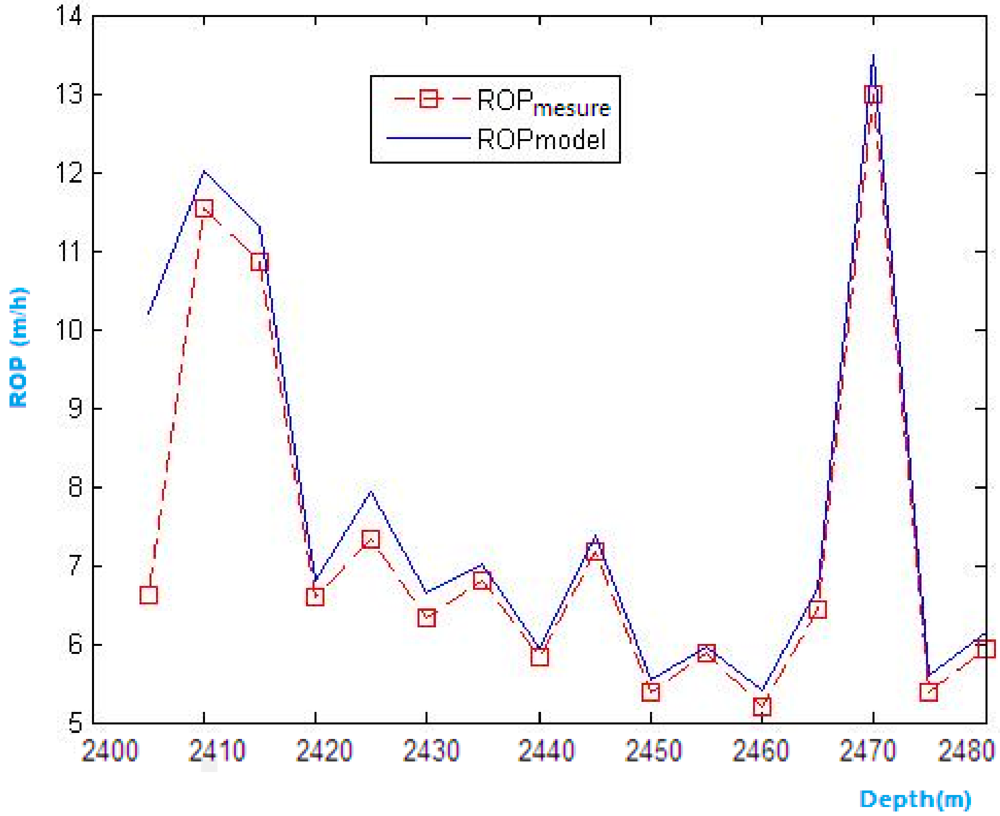

Fig 4.6: ROP_{op} vs ROP_{mesure}

7.2.2. Effect of WOB and RPM on the optimum ROP

The Optimum weight on bit and optimal rotation s peed were used to calculate optimal the rate of penetration, figures (7) and (8) compare the ROP optimized with optimum WOB and optimum RPM at each data point of depth. We observe that there is a clear improvement in the penetration speed when the weight on the bit (WOBop)Optimum and optimal rotational speed (RPMop) are used.

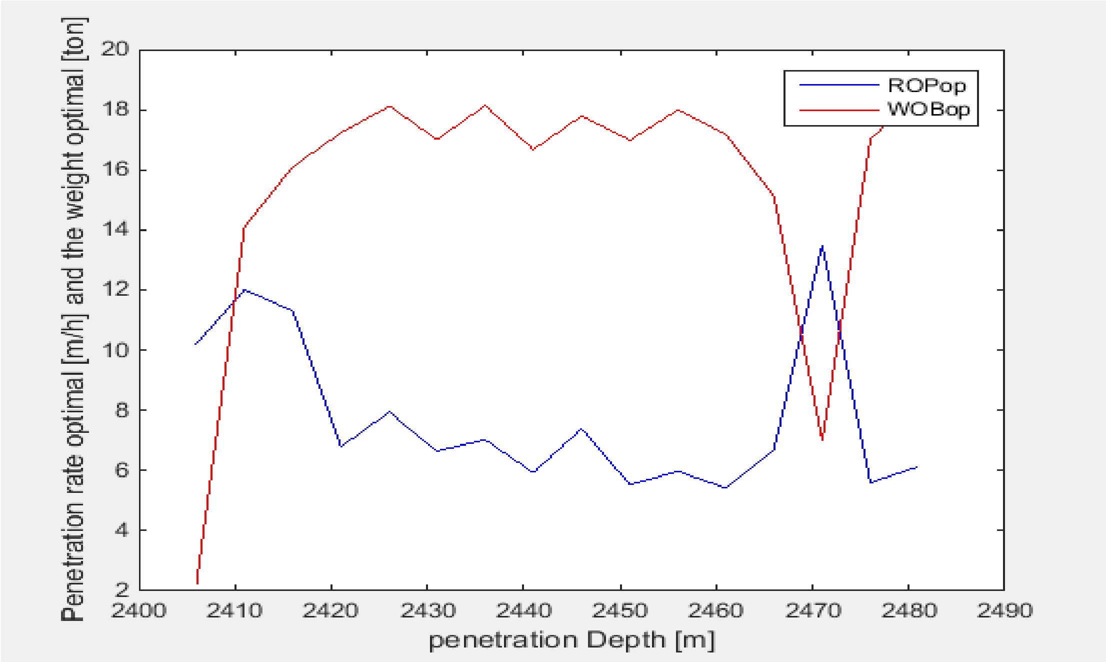

Fig 4.7: ROPop vs WOBop

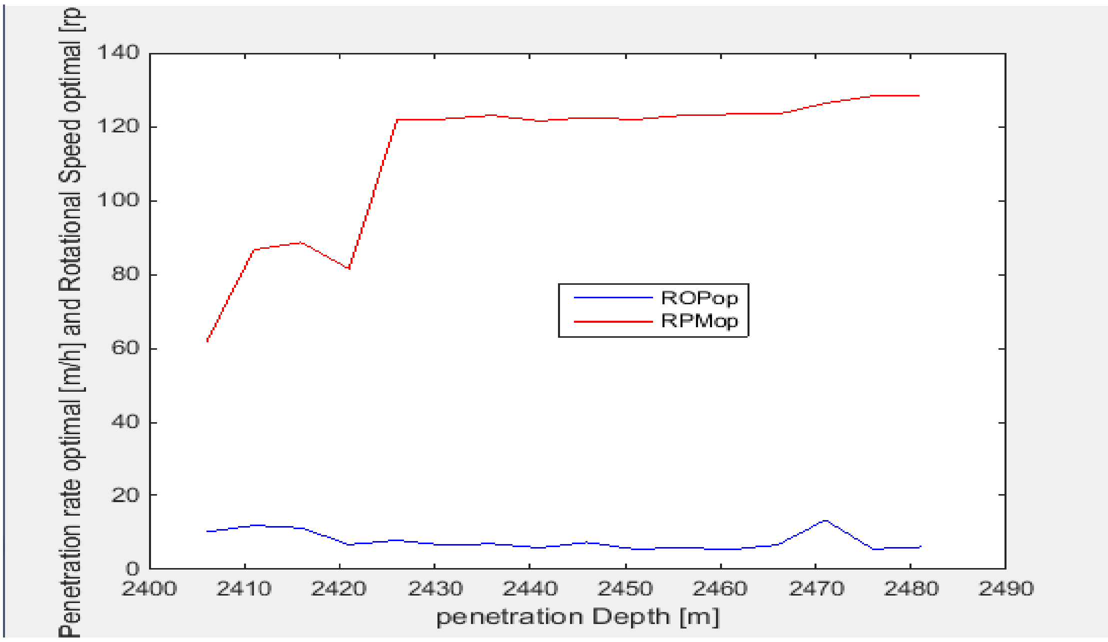

Fig 4.8: ROP_{op} vs RPM_{OP}

7.2.3. The analyze of optimum WOB and optimum RPM values:

Results of optimization of RPM and WOB on This section of the hole shows that the RPM is higher than the optimum value and WOB is below the optimum value. The maximum WOB is given by the manufacturer on the bits data sheet. Where the WOB applied is below threshold (maximum), optimizing WOB results to an optimum WOB which is closer to the threshold value than the minimum value (Figure 9).

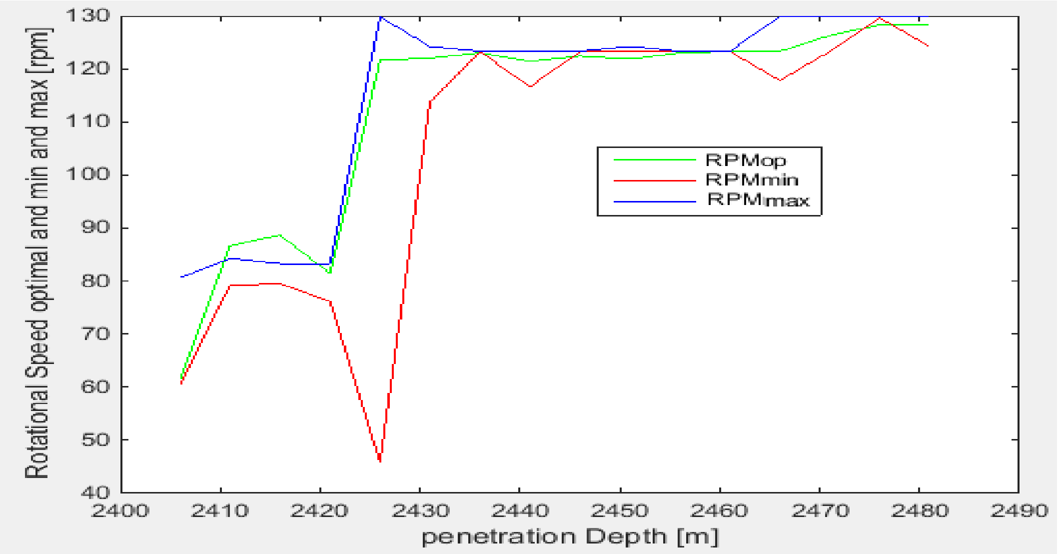

Fig 4.9: Comparison of optimum RPM

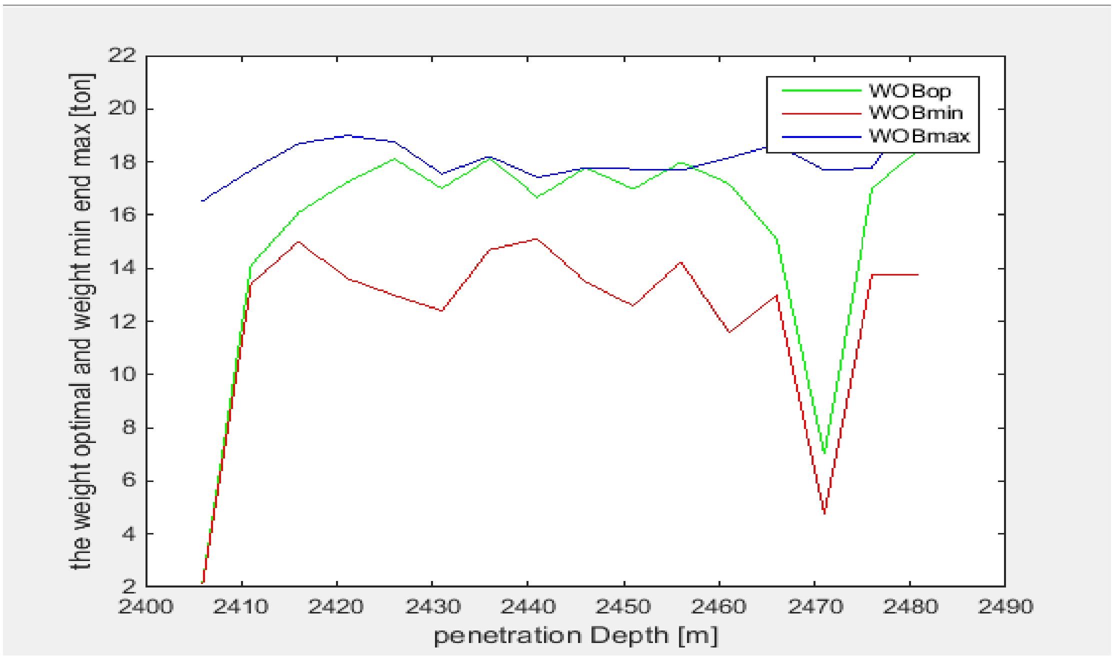

Fig 4.10: Comparison of optimum WOB

8. Solving problems:

The effect of the rotary torque is very sensitive on the rate of penetration, the figure (11) shows that the rotary torque is very high and can reach 18000 ft.lb in first 30 m section which the whirl or stick-slip vibrations set on and the reason of that is WOB and RPM are not controllable

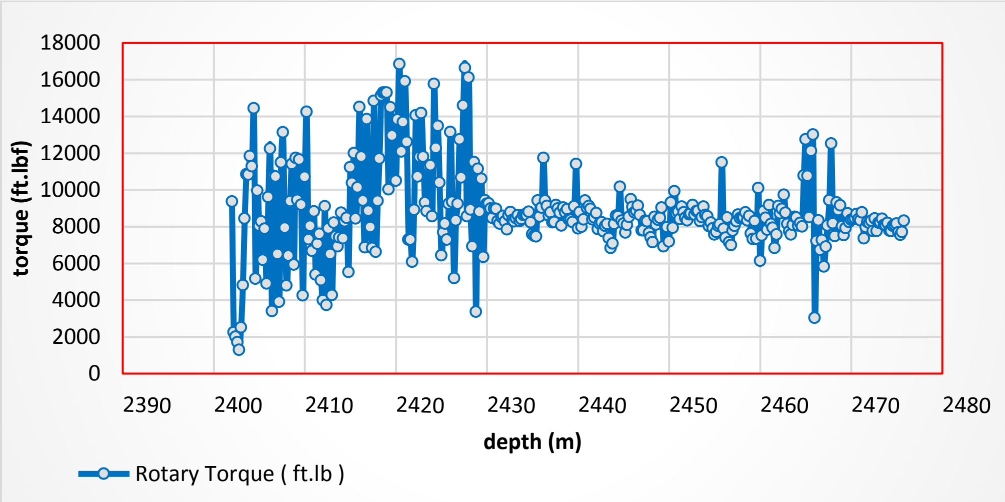

Fig 4.11: Effect of rotary torque

In terms of vibration, it was stated that lateral vibration, or whirl, could be mitigated by increasing the WOB, bent housing configurations versus more straight ones, using near bit stabilizers, and even increasing the drill-bit gauge length.

For torsional vibration or stick-slip, efficiency is enhanced by a decrease in torque (achieved by reducing the WOB) or an increase in rotary speed.

For axial vibration or bit bounce, a reduction in WOB was helpful, considering that it is more frequent when encountering stringers (known as small formation layer of different geology within a formation type) or drilling hard formations.

9. Conclusion:

The analyze of results of ROP modelled in 12,1/4" section shows that its values are much higher than the previous values, the optimize value is around 15 m/h which is acceptable that depending the compressive strength of the formation has been drill in this section.

The Es specific energy method can be applied in vertical wells in order to optimize the rate of penetration using the program developed by MATLAB. According to the interpretation of the OMM-302 well, several days were earned which correspond from 5% to 30% improvement in time and total cost of drilling.

General conclusion:

Management of penetration rate is critical in order to ensure a steady and cost-effective drilling operation. This thesis also demonstrates that variations in ROP are combined effect of several factors either mechanicals or hydraulics. Hence these factors need to be managed well in order to mitigate huge variations.

Adequate WOB, RPM, bit type and bit torque are all necessary to avoid several bit related problems in order to increase drilling efficiency. These problems can be mitigated to some extent by focusing on the design of the hoisting system, rotary torque and power transmission systems.

From our work we affirm that the optimization by the mechanical specific energy is a reliable and effective model in the prediction field and the analysis of penetration rate performance, we are hoping that these will help contribute and provide amelioration in the optimization domain.

For a more accurate modelling to be done, good data needs to be used, hence proper data acquisition and monitoring systems need to be used on the rigs. A good model will lead to improved determination of the best parameters to be used which will be lead to improvement in drilling performance.

Recommendation:

The proposed model can estimate rate of penetration as a function of many drilling variables such as weight on bit, rotary speed, flow rate, nozzle diameters, drilling fluid density and viscosity, bed height and cuttings concentration in the annulus with a reasonable accuracy .

To increase the accuracy of model, it is necessary to use data from more than a single well. Also, these data should be from a single formation .

Because of the structure, geometry and the number and size of their nozzles of PDC bits, the pump-off force play an effective roll on the weight on bit.

Furthermore, the ROP optimized value can be reach as maximum by considering the other effects such are hydraulic (pressure and flow rate), bit type, bit wear and BHA type, the modelling part can be more effective.

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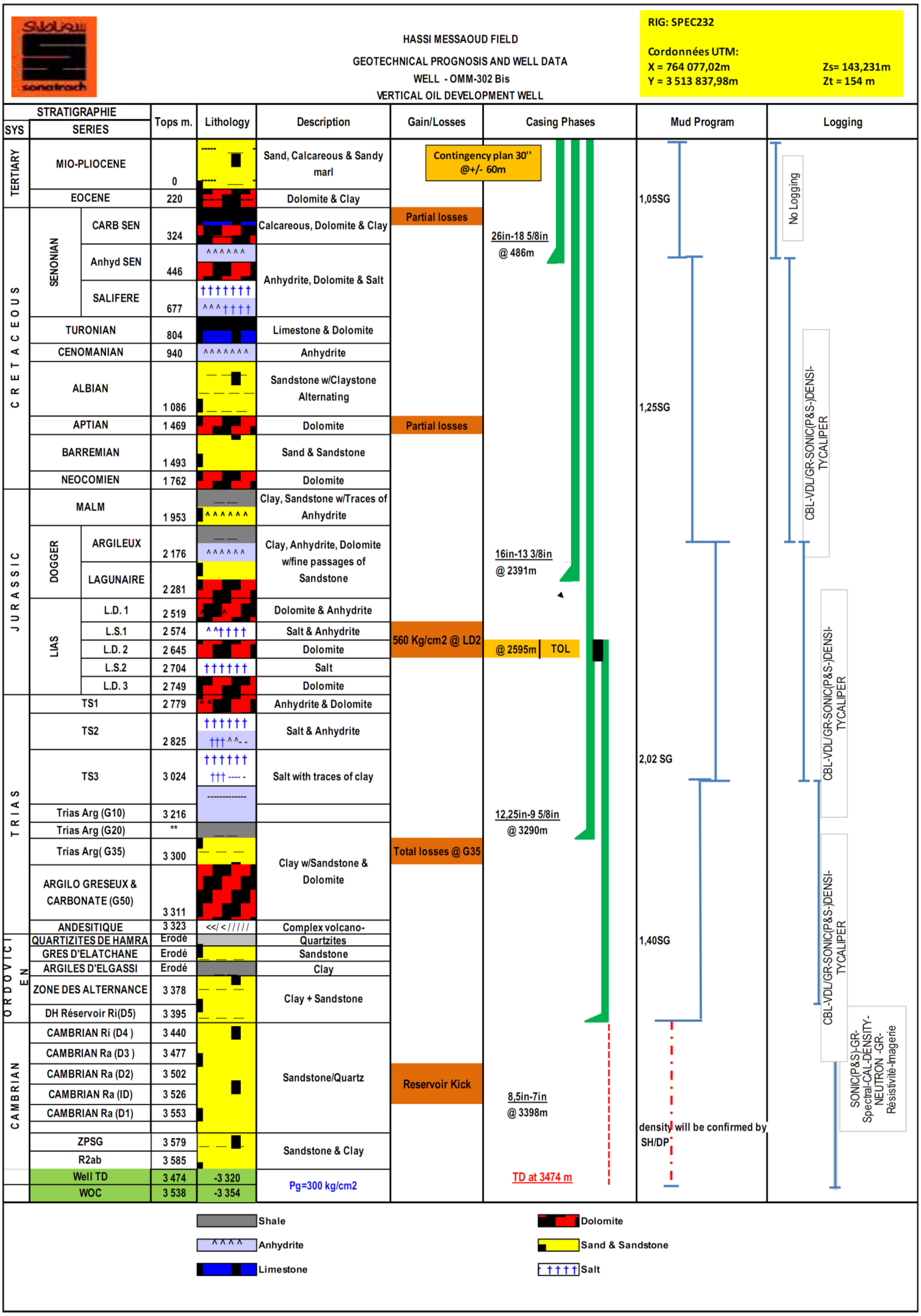

Fig 4.4: Well schematic and stratigraphy [23]

Table 4.7: The recorded parameters during the process

ROP (m/hr)	Drilled Time (Hr)	Rotary Torque (ft.lb)	SPP (psi)	Mud Flow In (l/min)	RPM (rpm)	WOB (ton)	Vert Depth (m)
6.82	89.42	9372.63	2619.16	2961.36	168.68	17.28	2402
2.05	2.52	8840.98	2696.7	2398.83	79.37	17.34	2411
2.14	2.79	4001.58	2717.51	2394.48	84.47	17.85	2412
2.72	3.08	4288.77	2734.09	2394.48	83.27	17.67	2413
4.34	3.36	8774.53	3108.33	2586.04	81.42	19.19	2414
35.33	3.56	11245.25	3062.66	2588.22	76.2	18.74	2415
27.33	3.6	14525.32	3079.05	2586.04	80.54	18.03	2416
20.59	3.78	8878.96	3029.14	2581.69	81.47	12.98	2417
5.63	3.97	9417.72	3025.82	2588.22	79.26	18.74	2418
6.11	4.21	15301.42	3023.24	2586.04	73.04	15.55	2419
4.14	4.47	10514.24	3034.3	2592.57	79.78	18.36	2420
6.94	4.74	15909.02	2919.92	2542.5	125.84	17.07	2421
5.34	4.91	14064.87	2925.63	2538.15	110.74	16.98	2422
6.51	5.08	9325.16	2889.53	2535.97	117.79	17.63	2423
5.78	5.2	15776.11	2892.48	2538.15	113.96	16.38	2424
6.8	5.38	7706.49	2890.09	2535.97	118.27	16.67	2425
9.74	5.51	9363.13	2897.82	2540.33	114.14	14.03	2426
6.13	5.71	10678.01	2900.58	2538.15	117.93	16.13	2427
6.49	5.89	8947.78	2903.71	2538.15	114.3	17	2428
5.04	6.1	8824.37	3015.88	2588.22	115.89	15.95	2429
5.53	6.28	9265.82	3047.56	2586.04	130.95	17.54	2430
5.8	6.43	8309.34	3033.93	2586.04	130.97	17.83	2431
4.99	6.63	7851.27	3048.85	2588.22	123.29	17.02	2432
4.92	6.84	8473.1	3047.56	2586.04	123.29	17.76	2433
6.07	7.03	8674.84	3082.37	2588.22	123.28	17.16	2434
3.17	7.26	7511.87	3117.36	2594.75	123.29	17.27	2435
14	7.4	11755.54	3108.52	2590.39	122.71	15.91	2436
3.63	7.61	8240.51	3087.89	2588.22	123.27	17.2	2437
5.13	7.78	8060.13	3069.47	2570.8	123.28	15.1	2438
4.67	7.98	8257.12	3060.08	2579.51	123.27	16.93	2439
4.44	8.12	8805.38	3044.06	2568.62	123.28	17.18	2440
5.23	8.32	9140.03	3078.31	2596.92	123.29	17.38	2441
9.72	8.53	7867.88	3082	2592.57	123.3	16.04	2442
7.57	8.71	8150.32	3084.02	2596.92	123.31	17.67	2443
3.62	8.93	8601.27	3084.02	2590.39	123.29	17.07	2444
5.66	9.05	7682.75	3085.31	2592.57	123.26	16.2	2445
4.91	9.2	8786.39	3086.6	2594.75	123.26	17.47	2446
7.5	9.4	7799.05	3084.21	2592.57	123.28	17.09	2447
6.12	9.59	7162.97	3080.16	2594.75	123.29	17.51	2448
8.24	9.78	9042.72	3082.73	2596.92	123.26	17.2	2449
4.19	10.13	8810.13	3087.52	2572.98	123.27	17.47	2450
5.21	10.37	8354.43	3085.31	2572.98	123.25	16.8	2451

ROP (m/hr)	Drilled Time (Hr)	Rotary Torque (ft.lb)	SPP (psi)	Mud Flow In (l/min)	RPM (rpm)	WOB (ton)	Vert Depth (m)
3.84	10.8	8639.24	3065.42	2568.62	123.27	17.54	2453
4.19	11.02	7580.7	3057.13	2564.27	123.27	17.42	2454
2.59	11.22	7886.87	3047.37	2568.62	123.28	14.81	2455
4.1	11.44	7784.81	3044.43	2566.45	123.31	15.79	2456
2.5	11.66	8520.57	3051.98	2566.45	123.28	17	2457
6.49	11.86	7625.79	3058.61	2564.27	123.3	17.29	2458
10.57	12.05	6142.4	3034.11	2564.27	123.29	11.6	2459
-0.01	12.25	9192.25	3053.63	2564.27	123.26	16.78	2460
6.04	12.45	9123.42	3041.29	2564.27	129.89	17.31	2461
4.12	12.64	8162.18	3040.74	2564.27	129.89	17.45	2462
4.18	12.83	8508.7	3038.16	2564.27	129.9	18.05	2463
17.24	13	12766.61	3045.16	2564.27	126.52	16.55	2464
6.41	13.15	3040.35	3004.46	2564.27	127.85	17.42	2465
16.36	13.22	5831.49	3044.24	2564.27	127.18	4.77	2466
9.68	13.27	8185.92	3040.19	2562.09	129.89	15.42	2467
5.29	13.42	8029.27	3040.19	2564.27	129.86	17.69	2468
5.23	13.61	8378.16	3032.64	2562.09	129.87	17.58	2469
7.35	13.8	8352.06	3042.58	2564.27	129.9	17.18	2470
4.27	14	8202.53	3027.85	2562.09	129.9	17.69	2471
6.41	14.21	8233.39	3027.3	2564.27	129.87	16.2	2472
3.6	14.43	8214.4	3023.61	2555.56	129.89	17.04	2473
4.29	14.62	8169.3	3021.59	2562.09	129.9	17.78	2474
4.69	14.81	9301.42	3063.58	2562.09	129.87	17.67	2475
2.41	14.96	8413.77	3047	2562.09	129.92	18.89	2477
3.79	15.15	8356.8	3044.43	2559.92	129.9	20.16	2478
4.68	15.19	7815.66	3026.01	2559.92	129.88	20.43	2479
5.27	15.51	7713.61	3070.76	2577.33	129.89	17.39	2480