بسم الله الرحمن الرحيم

Sudan University of Science and Technology

College of Petroleum Engineering and Technology

Department of Transportation and Refining Engineering

Drilling Optimization using Simulation

الحفر الأمثل باستخدام المحاكاة

Prepared by:

- **Awad Hashim Awad Bakhet**
- **Ayman Imadeldien Marhom Elhusein**
- **Salah Eldein Mohammed Ibrahim**
- **Saadia Mohamed Ahmed Ali**
- **Mohamed Elkheir Elsheikh Suliman**

Supervisor:

Dr. Yousef Bagadi

November 2020

الاستـهلال

قال تعالى :

"وَمَـا أُوتـِيـتُمْ مِنَ الْـعِـلْمِ إِلَّا قَـلِـيـلًا "

صدق الله العظيم

Dedication

إلى أمهاتنا اللاتي سهرن و ربين إلى آبائنا ؛ إلى أسرنا

Acknowledgment

We were intending to conduct a full optimization that includes Well design and the effective drilling parameters , but due to lack of wells design softwares we satisfied with conducting an optimization only for effective parameters .

Also the project was mainly targeted Al-rawat oil filed but we didn't get the data So we targeted Heglig oil filed since it's data was the only data we get .

Our Thanks to our Supervisor , colleagues and teachers whom Stand by our side till we complete this project.

Abstract

Drilling is much expensive process , in this project we aim to reduce cost and time required to accomplish the drilling .

Time and cost are functions on ROP so increasing ROP can save cost and time .

We simulated the actual well conditions and run series of optimization to obtain the optimum effective parameters (bit type , WOB & RPM and hydraulics) which helps to drill a well by minimum cost and time taking the safety side in consecration.

The results of Combining all effective optimized parameters can give better results and saves more time and cost. It saved 194945$ of cost and 72 hrs of time.

The simulator was used is an old version , using an upgrade version is recommended .

Key Words drilling optimization , Payzone , WOB & RPM , ROP , cost analysis and bit selection.

التجريد

الحفر عملية مكلفة جدا ، في هذا المشروع ونحن نهدف إلى خفض التكلفة والوقت اللازم لإنجاز الحفر.

الوقت والتكلفة هي دوال في معدل الاختراق وزيادة معدل الاختراق يمكن أن يوفر التكلفة والوقت.

اجرينا محاكاة الظروف الفعلية الآبار و من ثم اجرينا سلسلة من عمليات التحسين للحصول على المعاملات الفعالة المثلى (نوع سكين الحفر ،الوزن المسلط على سكينة الحفر ،الهيدروليك) مما يساعد على حفر بئر بالحد الأدنى من التكلفة والوقت مع مراعاة عامل السلامة .

الكلمات المفتاحية: الحفر الأمثل ،الوزن المسلط على السكين ،معدل الاختراق ،تحليل التكلفة .

من نتائج عمليات المحاكاة ،عند القيام بجمع المعاملات المؤثرة في معدل الإختراق تحصلنا على نتائج أفضل وتوفير للوقت والتكلفة الكلية.

وتم توفير (194945 دولار) من التكلفة الكلية ،و(72 ساعة) من الزمن الكلي.

برنامج المحاكاة المستخدم قديم من اصدار سنة (1996م) ،ونوصي باستخدام اصدار حديث للحصول علي نتائج أفضل.

List OF CONTENTS

Chapter (1)
Introduction

Chapter2

LITERATURE REVIEW

Chapter 3

Methodology

Chapter 4

Results and discussion

Chapter 5

Conclusion and recommendations

LIST OF FIGURES

LIST OF TABLES

Nomenclature & Abbreviations

Roman Symbol		field units
a_1	Formation strength parameter	
a_2	Exponent of the normal compaction trend	
a_3	Under-compaction exponent	
a_4	Pressure differential exponent	
a_5	Bit weight exponent	
a_6	Rotary speed exponent	
a_7	Tooth wear exponent	
a_8	Hydraulic exponent	
f_1	Formation strength function	
f_2	Formation normal compaction function	
f_3	Formation compaction function	
f_4	Pressure differential of hole bottom function	
f_5	Bit diameter and weight function	
f_6	Rotary speed function	
f_7	Tooth wear function	
f_8	Hydraulic function	
x	Drilling rate of penetration independent parameter	
x_2	Normal compaction drilling parameter	
x_3	Under-compaction drilling parameter	

x_4	Pressure differential drilling parameter	
x_5	Bit weight drilling parameter	
x_6	Rotary speed drilling parameter	
x_7	Tooth wear drilling parameter	
x_8	Bit hydraulics drilling parameter	
Cf	Drilling cost	$/ft
Cr	Fixed operating cost	$/hr
Tb	Total rotating time,	hrs
Tc	Total non-rotating time	hrs
Tt	Trip time	hrs
ΔD	Drilled footage	ft
$\frac{dD}{dt}$	Rate of penetration	ft/hr
K	constant of proportionality	ft/ hr
A	constant	ft^{-1}
D	total depth	ft
ROP	rate of penetration	ft/min
Sc	compressive strength of the rock	
Wb	Weight on bit per inch of bit diameter	1,000 lb/in
Wtb	threshold bit weight at which the bit start to drill	1000lbf/in(N/m)

T	time	hrs
d	Bit diameter	in
dn	Bit nozzle diameter	in
gp	Pore pressure gradient	lb/ga
h	Fractional tooth wear	
H1	Constants that depend on bit type	
N	Rotary speed	rpm
q	Flow rate	gal/min
W/d	Weight on bit per inch of bit diameter	1,000 lb/in
μ	Mud viscosity	Cp
μe	Effective viscosity	Cp
dp	Particle diameter	
ρp	Particle density	
P	Pressure	psia
Q	Flow rate	gpm
Ps	Surface Pressure Loss	psi
SE	Surface Pressure Coefficient	
ρ	Mud Density	lb/gal
L	Surface equipment equivalent length of drill pipe	ft
Ldp	Length of drip pipe	ft
Yp	Yield Point	Ibs/100ft
Pv	Plastic Viscosity	cp
Ldc	length of drill collar	ft
ID	Internal diameter	in
OD	Out diameter	in
Pc	Circulation Pressure Loss	psia
Vn	Nozzle velocity	ft/sec

Dn	Nozzle diameter	In
Va,V‘‘	Average velocity	ft/sec
RN	Reynolds number	
F	Frictional factor	
Dop	Outer diameter of the drill pipe or drill collar	in
Dh	Diameter of the hole	in
Dp	Diameter of the Pipe	in
De	Equivalent Diameter of the Drill Collar	in
n	Power law index	
A	Nozzles Area	$inch^2$
Cd	Discharge coefficient	
Pdc	Pressure Drop across Drill Collar	psia
τH	The formation abrasiveness constant	
tb	bit run time	
τB	bearing constant	hr
B1,B2	Bearing wear parameter	
W	Weight on bit	Ib

Abbreviations

BHA……………………………………..…..	bottom hole assembly
WOB……………………………………..…	Weight on bit
RPM…………………………………………	Revolution per minutes
ROP …………………………………………	Rate of penetration
HPH…………………………………………..	Hydraulic horse power
BHHP …………………………………………..	Break Hydraulic Horse Pump
PDC…………………………………………	Polycrystalline diamond bit
IADC……………………………….	international Association of drilling

Chapter (1)
Introduction

1.1 Background:

Drilling is one of the most expensive operations in oil exploration and development. In oil industry time is money so all researchers in drilling field focus on optimization parameters which has direct effect in drilling cost . According to (Cunha 2002) drilling costs may represent up to 40% of the entire exploration and development costs .

The main target of drilling optimization is to drill a well-bore with minimum cost , less time and in a safe way . Drilling cost mainly depend on rate of penetration (ROP) and it is the Main parameter that has direct effect on drilling cost .

To optimize drilling operation we need accurate data to get to the optimum drilling parameters .

Generally we optimize the controllable variables such as mud type, hydraulics , bit type , weight on bit (WOB) , rotary speed (RPM) and casing design . By optimizing these variables we can drill well-bore with the minimum cost and safe time and money and achieve the objective of drilling optimization.

1.2 types of drilling optimization techniques and types of costs :

Many types of drilling optimization techniques and cost represented on table NO.(1.1)

Table 1.1 drilling optimization techniques & drilling costs types

Drilling optimization techniques	Drilling costs
Cost per foot equation	Pre-spud costs
Time value of money	Casing and cementing

Expected value method	Drilling-rotating costs
Lagrangian multiplier	Drilling-non-rotating costs
multiple regression	Trouble costs
Confidence intervals	
Lagrange's interpolation formula	

In this project we attend to use the cost per foot equation which is the most used technique :

$$C_f = \frac{C_b + C_r(t_b + t_c + t_t)}{\Delta D} \text{.............. (1.1)}$$

Where:

Cf = drilling cost, $/ft

Cb = cost of bit, $/bit

Cr = fixed operating cost , $/hr

Tb= total rotating time, hrs

Tc = total non-rotating time , hrs

Tt= trip time , hrs

ΔD = drilled footage , ft

1.3 Problem statement :

The time necessary for drilling dependent on ROP . There for predicting & optimizing ROP is one of most important parts of the drilling operation ,because when ROP decrease the time &cost will increase , so we will use the effective parameters to obtain high ROP.

1.4 Objectives :

The main objective of this project is to apply drilling optimization on real data of “heglig ” oilfield to determine:

- Optimum drilling parameters.
- Minimize cost per foot.
- Optimum ROP.
- Analyzed the different variable and how it effect in ROP.

1.5 Factors affecting on ROP :

The factors are affecting on ROP can be classified into two main groups represented in table No (1.2)environmental factors can’t be changed or controlled , so that in optimization we calculate the optimum values of controllable factors.

Table 1.2 factors affecting ROP . Fear, M.J (1999)

Enviroment factors	**Controllable factors (a`lterable)**
Depth	Bit wear state
Formation properties	Bit design
Mud type	Weight on bit
Mud density	Rotary speed
Others mud properties	Flow rate
Bit size	Bit`s hydraulic
	Bit nozzle size

The most important variables that affect the ROP are :

Bit type.

Formation characteristics .

Bit operation conditions .

1.6 Types of drilling bits :

There are several types of drill bit manufactured for different situations and conditions . Basically there are two types of drill bits ; fixed-cutter and roller-cone bits .

1.7 Rules of drilling bit selection :

Several rules of Thumb are often used for initial bit selection :

Rules of Thumb #1 : if the formation hardness is known , then use the IADC charts or Bourgoyne et al ,(1986) .

Rules of Thumb #2: Bit cost consideration plays a vital role for selecting initial bit type and features .

Rules of Thumb #3: selection of tri-cone roller bits . This a good choice for an initial bit type which is used for the shallow portion .

Rules of Thumb #4: selection of diamond bits which perform

Best in non-brittle formations (having a plastic mode of failure) and bottom portion of well (due to longer bit life ,minimize high-cost tripping operations)

Rules of Thumb #5: selection of **PDC** drag bits , which perform best in uniform sections of carbonate formations .

Rules of Thumb #6: PDC drag bits should not be used in gummy formations (gluey , shales) tending to case bit balling .

Rules of Thumb #7: Carefully evaluate a dull bit when it is removed from the well . Maintain carefully well-written records of used bits for future references .

1.8 Operation condition :

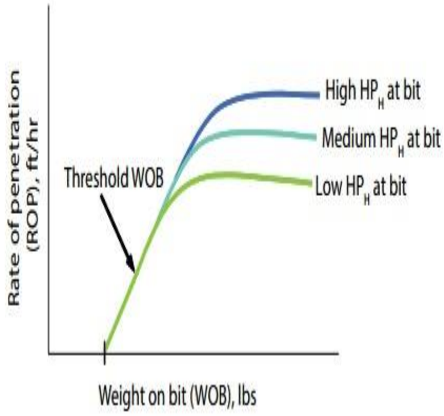
to evaluate the bit performance the ROP depends on :

1.8.1 weight on bit :

A certain minimum WOB is required to overcome the compressibility of the formation . Fig. 1.1 . Experimental study shows that once this threshold is exceeded , ROP increase linearly with WOB . However there are certain limitations to the WOB which can be applied to hydraulic horsepower (HPH) at the bit ,type of formation ,hole deviation ,tooth life .

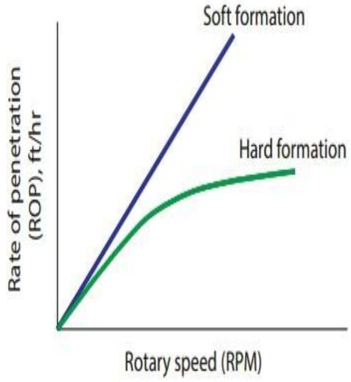
1.8.2 Rotary speed :

an optimum speed must be determined because ROP is affected by the rotary speed of the bit . The RPM influences the ROP since the teeth must have time to penetrate and sweep the cutting into the hole fig. 1.2



(Bourgoyne et al,1991)

Fig.1.1: WOB Vs ROP



(Bourgoyne et al,1991)

Fig.1.2: RPM Vs ROP

1.8.3 Mud properties:

Mud properties play a vital role while drilling. They create a hydrostatic balance around the cutting area to restrict an influx of formation fluids into the wellbore and clean the bottom-hole.

1.8.4 Hydraulic efficiency :

Hydraulic efficiency (jetting impact) is directly related to HPH. So it is recommended to allow a minimum flow rate to ensure that the bit face is kept clean and the cutting temperature is kept to minimum. This requirement for flow rate may poorly affect the optimization of HPH.

1.9 Drilling cost analysis:

The major factors controlling the costs of drilling wells are the abnormal rig market conditions ,well depth , diameter, casing design and well type .it is recognized that there are many factors affecting well .

Cost must be taken into consideration to accurately estimate the cost of specific well , as a result drilling costs increase non-linearly with depth (fig. 1.3)

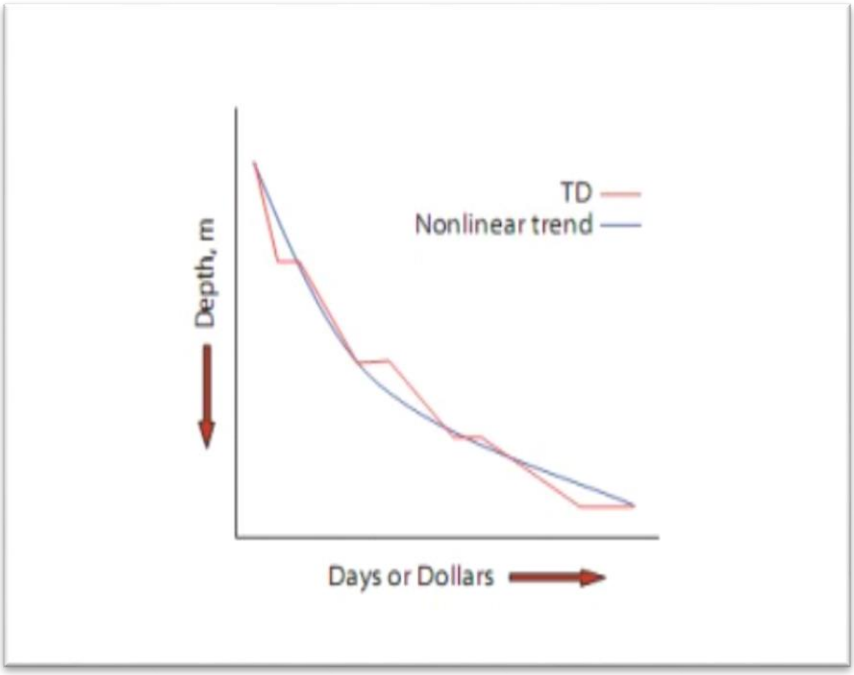


Fig 1.3 Drilling cost as function of well depth, Hossain (2015)

1.10 Drilling time estimation :

The estimation of drilling and completion time is a depended variable which is governed by different a activities while drilling .

An estimation of drilling time can be based on historical ROP data where the drilling program will be set for the area .

for a given formation , ROP is inversely proportional to both compressive strength and shear strength of the rock . In addition rock strength tends to increase with depth of burial . When a major unconformities are not present in the subsurface lithology ,the ROP usually decrease exponentially with depth . Under these conditions ROP can be related to depth as:

$$\frac{dD}{dt} = Ke^{-AD} \ldots\ldots\ldots\ldots 1.2$$

Where:

$\frac{dD}{dt}$ = rate of penetration , ft/hr

K= constant , ft/ hr

A= constant , ft^{-1}

D= total depth , ft

It is noted that constants A,K must be determined from the previous filed data . Now the drilling time can be obtained by integrating and solving the Eq- (1.2) for a given depth .

Weight on bit and rotary speed

Murer (1962) developed a theoretical equation for rolling cutter bits relating ROP to bit weight , rotary speed, bit size, and rock strength . For these condition, the equation can be written as :

$$ROP = \frac{K}{S^2 c}\left[\frac{Wb}{db} - \left(\frac{Wtb}{db}\right)t\right]^2 N \ldots\ldots\ldots\ldots 1.3$$

Chapter2

THEORETICAL BACKGROUND & LITERATURE REVIEW

2.1 Theoretical Background:

There are many techniques that utilized for reduction of drilling operation cost. This can be achieved by optimize time of operation since time is always money in drilling operation. Time taken to drill any well in drilling operation can be represented by Penetration rate (ROP). Therefore Drilling Rate of Penetration plays main role in drilling optimization. Drilling Model must be developed to come out with rate of penetration.

Drilling models are always find the best mathematical relationship between ROP and other drilling parameters that have important effect on it. Because of the uncertain drilling variables there is no direct or exact mathematical relation for rate of penetration and other drilling parameters, and also their relationship are complex and nonlinear. Penetration rate can be affected by many parameters such as:

Weight on bit (WOB), bit hydraulic, bit type, rotary speed (N), formation characteristic and mud properties etc, are the parameters affecting rate of penetration. Here, are lots of models that have been proposed for rate of penetration such as Bourgoyne and Young model, Artificial Neural Network (ANN), Bingham model and Warren model, etc.

First step is to review the background in several rate of penetration models but before that there is one method lowering drilling cost, which is cost per foot analysis. That aimed to optimize the rate of penetration. It is based on the optimum drilling operation condition of bit run and the criteria of bit selection or respected bit selection.

If drilling rate is high the drilling cost will be reduce from the drilling cost equation so ROP can play main role to reduce the cost . So, we can choose one of the models to optimize ROP. There are common models used to optimize ROP.

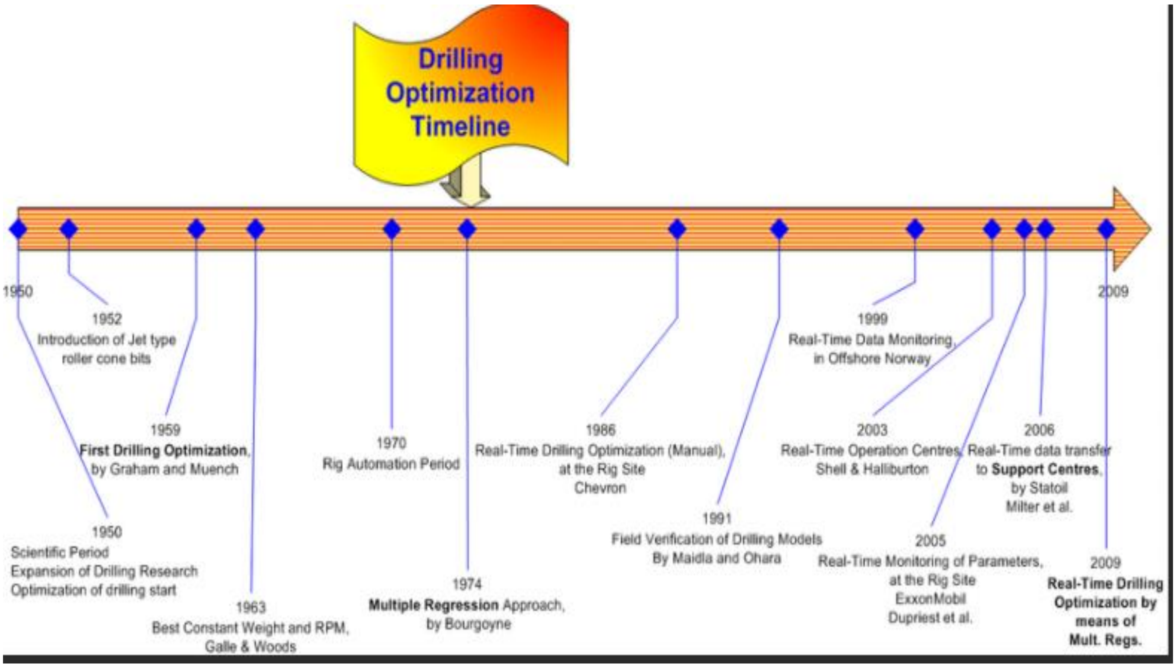


Figure.2.1: Time line for drilling optimization (Eren and Ozbayoglu,2015).

2.2 ROP Models:

2.2.1 Overview of ROP Correlation Models:

Warren, T.M (1984) developed a model for predicting ROP for roller-cone bits under low-borehole-pressure conditions. This model accounted for both cuttings generation and cuttings removal. Drilling data obtained under high- borehole-pressure conditions were analyzed to determine the reasons of the reduction in ROP as the borehole pressure increases. In some cases, the reduced ROP is caused by a buildup of rock debris under the bit. When this occurs, the ROP can be improved by an increased level of hydraulics. In other cases, the reduction in ROP seems to be caused by a local catering effect that is much less responsive to increases in hydraulics. Comparison of model predictions to the observed ROP can help to identify the mechanism that limits the ROP and provide insight into ways to improve it, Batee (2010).

$$R=\left(\frac{aS^2d^2b}{N^bWOB^2}+\frac{c}{Ndb}\right)^{-1} \ldots\ldots (2.1)$$

Where:

a,b,c=bit constant for warrens constant

S =confined rock strength,psi

Dimensional analysis was used to isolate a group of variables consisting of the modified impact force and the mud properties to incorporate into above equation to account for the cutting removal .These factors were combined with equation until an equation was obtained that matched the experimental data .The resultant expression for ROP is, Batee (2010):

$$R=(\frac{aS^2db^3}{NWOB^2}+\frac{b}{Ndb}+\frac{cdb\gamma f\mu}{Fjm})^{-1} \ldots \ldots (2.2)$$

Where:

γf=fluid specific gravity

μ=mud plastic viscosity ,cp

Fjm=modified jet impact force, klb

Bingham model is a simple model which is a modification of Maurer Model (an experimental model which is applicable to low value of weight on bit (W) and rotary speed (N). Also this is a simple model .This model neglects the depth of drilling so the answer often has less reliability.

$$R=k(\frac{w}{ab})^{a5} * N^e \ldots \ldots (2.3)$$

Bourgoyne and Young's model (1991) introduces penetration rate as a function of eight variables such as sediments compaction and strength, pore pressure, bit weight, rotary speed, bit hydraulics, teeth wear, etc. The model mathematically is expressed by: Batee (2010)

$$R= f1* f2* f3 * f4* f5* f6 * f7* f8 \ldots\ldots(2.4)$$

Where, ROP is rate of penetration (ft/hr), $f1$ is the function of the formation drill ability (mud type, bit type, formation strength), symbolize the impact of compaction on the penetration rate represent by $f2$, $f3$&$f4$, signifies the overbalance on ROP, $f5$&$f6$ respectively model the effect of bit weight and rotary speed on ROP, effect of tooth wear and bit hydraulic represent by $f7$&$f8$ respectively.

BYD creators proposed multiple regression method to find the unknown coefficients, but applying multiple regression method is not reliable that it can procedure to meaningful results physically, and also number data point limit is affecting this method. So, recently there are many new mathematical techniques applied to calculate these unknown coefficients, to reach the meaningful result. Example of these methods is Nonlinear least square data fitting with trust –region method is a technique applies to the problem.

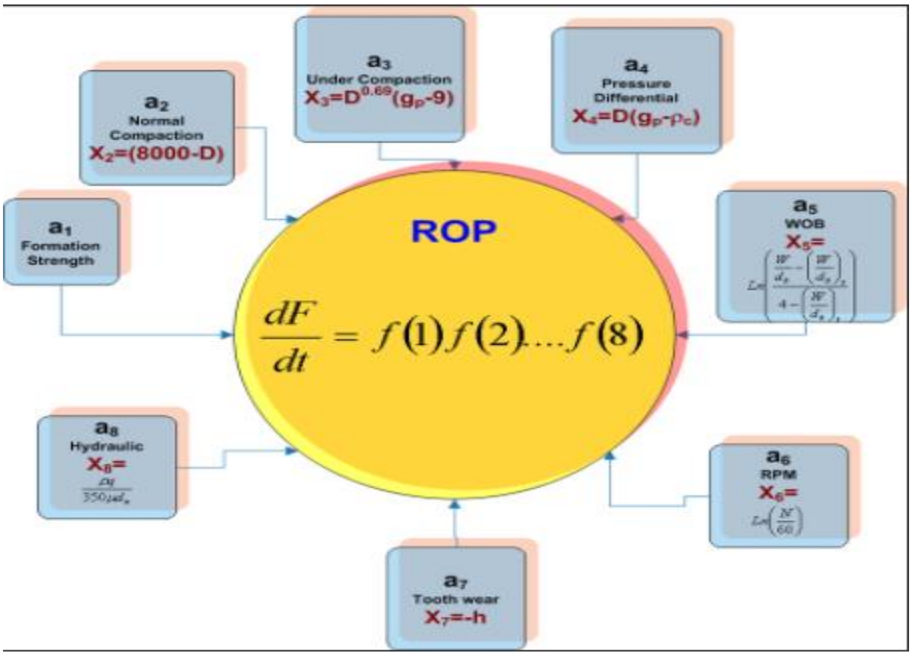


Fig.2.2: Bourgoyne and Young's model

Bahari(2007) Writing computer program and applied three methods rather than multiple regression method to solve Bingham‟s constants on nine wells data of Khangiran gas field, he compared result of each method and that trust-region method is the best.it can be applied easily to predict penetration rate when a few data points are present and when the drilling parameter are not in the recommended ranges.

Bahari et al (no date), they proposed method solves two Deficiencies, physically meaningless coefficients, and the decrease in accuracy. In their method, their practical data sets were nine wells of "Khangiran" Iranian gas field, they applied Genetic Algorithm GA to determine constant coefficient of Bourgoyne and Young model. Simulation result confirm that suggested approach not only provides meaningful results but also leads to more accuracy in comparison with conventional methods.

In both papers Bahari Used Bourgoyne and Young Model to Forecasting the Rate of Penetration.

Bataee et al (2010): calculate and predict the proper model of ROP for roller cone bit and PDC bits in each well by using the ROP models (Bingham model, bourgoyne and young model, warren model) and verify the validity of each model with field data .the application of present study are predicting the proper penetration rate, optimizing the drilling parameter, estimate the drilling time of well eventually reducing the drilling cost for future wells.

Bielstein and Geiorge(1950) recorded preliminary tests to determine the effect of various factors affecting the rate of penetration of rock bits. They also established the importance of the number and design of cutting elements in rate of penetration. Findings that the magnitude of the various effects on the rate of penetration varies with changes in the type of formation drilled.

The effect of hydraulic factors affecting the rate of penetration is explored .

Effects of rotary speed and bit weight were investigated, and it was found that the rate of penetration increased with increasing rotary speed and bit weight, with the rate of change in the two factors being principally a function of the formation being drilled.

Carlos M. C. Jacinto, et al (2013), used Bayesian Network (BN) inference approach for targeting the elicitation process and subsequent combination of models; and a Dynamic Evolving Neural-Fuzzy Inference System (DENFIS) in their research to optimization of the cost of drilling wells in environments of high complexity and risk such as those related to the pre-salt region offshore Brazil.

In order to reduce costs it is necessary to accurately plan offshore oil drilling operations. The time required to successfully drill a well has to be estimated fairly precisely, since most of the costs associated are tied to the rental of equipment required for the operation as reported by Gandelman (2012); however, each operation has unique properties that make this task highly difficult. Many properties vary, such as rock type, rock porosity, gas presence, pressure, drill bit wear rate among others. All these properties affect the ROP, as well as many other parameters which are controlled by a drilling operator: weight on bit(WOB), revolutions per minute(RPM), bit type, bit diameter, bit wear rate, hydraulic horsepower per square inch(HSI).

Most of the work in the planning phase is restricted to adjusting bit type and diameter, RPM and WOB in order to achieve an acceptable ROP. To optimize this work many systems using artificial neural networks (ANN) were proposed in the past to predict the rate of penetration (ROP) for the project planning phase such as Bilgesu et al. (1997) and -15-

even choose automatically some parameters such as RPM and WOB in Fonseca et al. (2006). Unfortunately for the available data on the Brazilian pre-salt layer these systems did not achieve a reliable result due to the poor quality and scarcity of data. To overcome these problems they investigated two alternative approaches: a Bayesian Network (BN) inference approach for targeting the elicitation process and subsequent combination of models; and a Dynamic Evolving Neural-Fuzzy Inference System (DENFIS) Carlos M. C. Jacinto, et al (2013).

Eckel(1967) was able to establish from laboratory and field experience that the rate of drilling using mud was increased from 30 to 70 percent of those obtainable with water under the same conditions. Eckel (1967) further stipulated that viscosity is a significant factor affecting the rate of drilling. Eckel (1967) used oil emulsion in his experiments and he observed that the rate of drilling was improved due to their lubricated properties.

Eckel(1967) concluded that mud rheological properties have significant effect on the rate of penetration.

Fear (1999), produce numerical correlation between ROP and drilling parameters after that use this correlation to generate recommendations for maximizing ROP. The data used are:

mud logging .

geological information .

bit characterization .

(bit/rock) inter action considered to minimize the general cost of drilling because it significantly affected.

In addition to torque and drag managed dependent on bit type and down hole tools which chosen to raise ROP with the new drilling technologies. In summary rock properties that influence ROP include: at least: mineralogy, strength, density, porosity and permeability. Also weight on bit (WOB), rotary speed, flow rate independence between mechanical and hydraulic drilling.

Environmental factor affected in ROP are: Formation properties and types, mud density types and properties.

Controllable factors affected in ROP are: Bit wear state, deign, rotary speed, hydraulic horse power, weight on bit, flow rate and bit nozzles.

Application of method**:** It is used as check list, so data assembled as to minimize ROP by the effect of variable of both environmental and controllable factors.

Galle et al., (1969) presented a pioneer work that created a major breakthrough in drilling technology, mainly when referring to optimization aspects. They assumed that rate of penetration was affected by only two parameters, weight on bit and rotary speed. In their paper, also, it is assumed that all other variables involved, like bit selection, hydraulics, drilling fluid properties, etc., were properly selected. They defined an analytical model to predict rate of penetration (ROP) as a function of weight on bit, rotary speed, type of formation, and bit tooth wear.

Gregorio (May 2004) evaluate the benefits and practical application of the drilling simulation technology. They have found in the literature that is possible predict the drilling performance on the basis of a combination of theoretical and lab drilling models. Different companies are developing and using drilling simulators in the planning and drilling of oil wells. The results show that a drilling simulator can accelerate training, increase the use of the best technology, and shorten the drilling learning curve. After a set of wells is drilled, the experience can be captured and retained. The drilling simulator can generate a complete model of the drilling process, so the engineers can run multiple scenarios quickly and update the plans with the new data to predict the consequences of their decisions. The research has shown the software accuracy in the prediction of the unconfined rock strength based on drilling and lithology data (compared with unconfined rock strength estimated from electric logs).

The drilling parameters analysis showed that WOB and ROP are critical in drilling optimization. The research shows that using the maximum WOB available and reducing rotational velocity of the bits increase their performance in the Aloctono block.

The use of DROPS® drilling simulator software as an optimization tool allowed selection of new mud and bit programs with better cost per meter, ROP, and drilling time.

Humphrey (2013), optimum conditions for drilling were determined by estimating pore pressure and fracture pressure from conductivity data, selecting a suitable mud with an appropriate density based on the result of the conductivity data analysis, studying the rheological properties of mud samples (3 samples), calculating the pressure losses in the mud circulatory system and finally applying the maximum horsepower criterion for optimization.

Based on the results of conductivity data analysis, experimental analysis of the drilling mud rheology and pressure loss calculation in the mud circulatory system, conditions for optimum hydraulic horsepower across the drill bit in the problematic zone is presented in his case study. His study shows that pressure loss in the mud circulatory system depends on the mud and the circulating flow rate. Also, the operating conditions obtained in his study shows that the flow rate exceeds the minimum flow rate required for drill cuttings removal. One unique aspect of his project work is the integration of experimental work designed to generate rheological data for theoretical computation.

The disadvantage of this project work that is focused on the application of optimization using the maximum horsepower criterion only in an over pressure zone for bottom hole cleaning and for showing the effect of mud rheology on pressure losses in a mud circulatory system.

Irawan, et al (2012), used Bourgoyne and Young model in there project in order to derive equations to perform the ROP estimation using the available input data. This model has been selected because it is considered as one of the complete mathematical drilling models in use of the industry for roller-cone type of bits (Bahari and Baradaran, 2007).

The rate of penetration for the field had been predicted based on constants for every data vs. Depth. Finally, optimized weight on bit had been calculated for several data points. In the end, drilling simulator (Drill-Sim 500) was used to prove the results based on actual field data.

The penetration model for the field is constructed using the results from statistical method. In the end, the result from analysis is used to determine optimum values of weight on bit that give optimum drilling operation.

Mostofiet al (2010) used two term ROP model (1981), three term ROP model for tri cone bit (1987) and Horeland and Hoberock modified model (1993) to include differential pressure effect, bit tooth wear, hole cleaning issue in the analysis. In their model 2 sets of information required to develop it, Geological Drilling Log GDM and bit constants, linearization method seems to provide better results. And then best bit runs are introduced.

Roman and David (no date**)**, He reviewed papers share one common failing: The technique used to optimize drilling are too limited in scope. They are concerned only with finding the weight, speed, time schedule.

That corresponding to a minimum value of the drilling cost per foot for each bit used .He seek in his two part paper to remedy that failing by developing techniques which are less limited in scope and by demonstrating the superiority of a method which established an optimal policy for the entire well rather than for each bit used .Part one explore two methods. The first method minimizes the cost per foot drilled during a bit run ,and the second the cost of selected interval .Part two examine the third method ,which minimizes the cost over a series of intervals .These techniques may be selected in accordance with the amount of drilling data available.

Equation used in this model is suggested by Galle and woods, they are not capable of explicitly accounting for changes in mud properties, hydraulics or bit type.

Reza et al., (1986) developed a drilling model using dimensional analysis. The parameters included in the three equations of penetration rate, rate of bit dulling and rate of bearing wear are weight on bit, rotary speed, flow rate, bit diameter, bit nozzle diameter, bearing diameter, mud kinematics viscosity, differential pressure, temperature, and heat transfer coefficient. They developed dimensionless models for roller cone, PDC and diamond bits.

Winters, W.J et al., (1987) developed a model, which relates roller cone bit penetration rates to the bit design, the operating conditions, and the rock mechanics. Rock ductility is identified as a major influence on bit performance. Cone offset is recognized as an important design feature for drilling ductile rock. The model relates the effect of cone offset and rock ductility to predict the drilling response of each bit under reasonable combinations of operating conditions. Field data obtained with roller cone bits can be interpreted to generate a rock strength log. The rock strength log can be used in conjunction with the bit model to predict and interpret the drilling response of roller cone bits.

2.3 Summary of Literature Review:

As we can see most of pervious literatures used, Bourgoyne and young model, warren model and artificial neural networks (ANN) for predicting optimum ROP with more accuracy than Bingham model because this model neglects the depth of drilling so the answer often has less reliability. The validity of each model varying according to available field data.

In this project we will use **Payzone** Software to optimize the drilling parameters under study and then compare the Theoretical results gained from software with the actual field parameters.

Chapter 3

Methodology

The base of this project is to simulate the actual well data and then run a multiable simulations to obtain the optimum bit , WOB & RPM and hydraulic .

We will simulate the real data and match it with the software to insure more acurate simulations and results .

3.1 The project methodology is consists of the following steps:

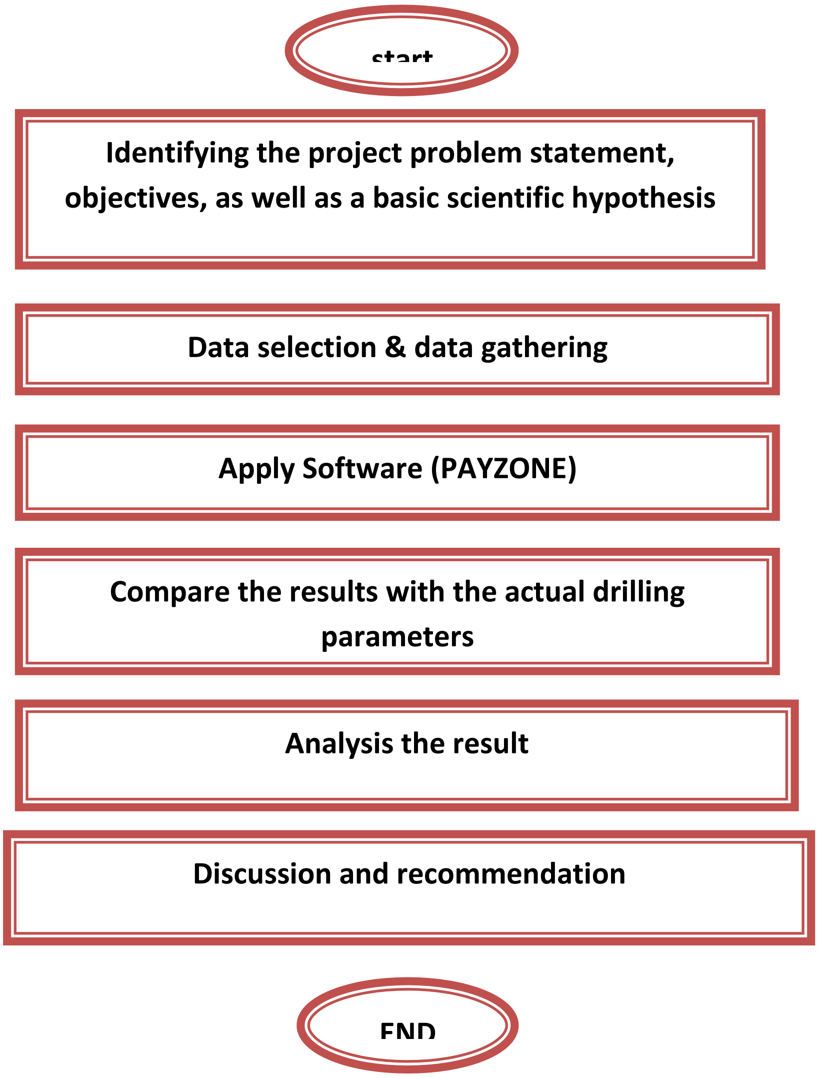


Figure (3.1) Research Methodology Flow Chart

3.2Payzone drilling simulator

The simulator (called "Payzone" for short), is a computer program that receives: a description of a series of rock layers (lithology), a description of one or more drill bits, and a set of operating parameters such as weight on bit, bit rotary speed, mud flow rate and other required information, as input. The simulator then calculates the rate of penetration and the rate of wear of the bit. From this information, a plot of drilled depth versus time is obtained.

3.3 model building :

To implement a proper optimization we need to know how to optimize the various parameters . as mentioned at chapter one a lot of variables should be considered in optimization process , so that we need to build a model for each system involved in drilling operation .

3.2.1 hydraulic model:

The hydraulic is playing a major role in bottom hole cleaning and cutting removal . to assure an effective cutting removal and transportation to the surface which maximize the ROP we must maximize the jetting force and the bit hydraulic horse power .

The most used models in hydraulic optimization are :

1- Bingham model .

2- Power law model .

Surface loss (P1) = $E\ x\ p^{0.8} x\ Q^{1.8} x\ PV^{0.2}$………..…. 3.1

Model		Laminar flow (V′< Vc)	Turbulent flow (V′> Vc)
Bingham	Pipe flow	$P = \frac{L \times PV \times V'}{90{,}000 \times D^2} + \frac{L \times YP}{225 \times D}$	$P = \frac{8.91 \times 10^{-5} \times \rho^{0.8} \times Q^{1.8} \times (PV)^{0.2} \times L}{D^{4.8}}$
	Annular flow	$P = \frac{L \times PV \times V'}{60{,}000 \times De^2} + \frac{L \times YP}{225 \times De}$	$P = \frac{8.91 \times 10^{-5} \times \rho^{0.8} \times Q^{1.8} \times (PV)^{0.2} \times L}{(Dh - OD)^3 (Dh + OD)^{1.8}}$
Power law	Pipe flow	$P = \frac{KL}{300D} \times \left(1.6V' \frac{1.6V'(3n+1)}{(D \times 4n)}\right)^n)$	$P = \frac{8.91 \times 10^{-5} \times \rho^{0.8} \times Q^{1.8} \times (PV)^{0.2} \times L}{(Dh - OD)^3 (Dh + OD)^{1.8}}$
	Annular flow	$P = \frac{KL}{300De} \times \left(\frac{2.4V' \times (2n+1)}{(De \times 3n)}\right)^n$	$P = \frac{8.91 \times 10^{-5} \times \rho^{0.8} \times Q^{1.8} \times (PV)^{0.2} \times L}{(Dh - OD)^3 (Dh + OD)^{1.8}}$

Where the average velocity of flow in the pipe for both Power law and Bingham calculating from:

$$V' = \frac{24.5Q}{D^2} \text{.........................} \quad (3.2)$$

Table No(3.1)

Average velocity of flow in the annular for both Power law and Bingham calculating from:

$$V' = \frac{24.5Q}{Dh^2 - OD\text{^}2} \text{...} \quad (3.3)$$

Critical velocity of pipe flow for Power law model:

$$Vc = \left(\frac{5.82 \times 10^4 \times K}{\rho}\right)^{\frac{1}{2-n}} \times \left(\frac{1.6 \times (3n+1)}{(D \times 4n)}\right)^{\frac{n}{1-n}} \quad \text{.......} \quad (3.4)$$

Critical velocity of annualr flow for Power law model:

$$Vc = \left(\frac{5.82 \times 10^4 \times K}{\rho}\right)^{\frac{1}{2-n}} \times \left(\frac{1.6 \times (3n+1)}{(De \times 4n)}\right)^{\frac{n}{1-n}} \quad \text{.......} \quad (3.5)$$

Critical velocity of pipe flow for Bingham model:

$$Vc = \frac{97PV + 97\sqrt{PV^2 + 6.2\rho De^2 YP}}{\rho De} \text{.........................} \quad (3.6)$$

Critical velocity of annular flow for Bingham model:

$$Vc = \frac{97PV + 97\sqrt{PV^2 + 6.2\rho De^2 YP}}{\rho De} \text{........................} (3.7)$$

Where De = Dh-DO

Pressure drop across bit = Pbit = Pstandpipe – system loss…. (3.8)

Nozzle Selection:

$$TFA = (0.00096 \times Q)\sqrt{(\frac{\rho}{pbit})} \ldots\ldots\ldots\ldots\ldots\ldots (3.9)$$

$$dn = 32\sqrt{(\frac{4TFA}{(3\times\pi)})} \ldots\ldots\ldots\ldots\ldots\ldots (3.10)$$

$$Vn = 33.36\sqrt{(\frac{Pbit}{\rho})} \ldots\ldots\ldots\ldots\ldots\ldots (3.11)$$

3.2.1.1 Suitable hydraulic model Selection :

Selection of the hydraulic model is based on the fluid type & behavior as shown at figure No(3.1)

3.2.2Hydraulic criteria :

Significant increase in penetration rate can be achieved through the proper distributing the power of drilling fluid to bit. This is felt to be due mainly to improved cleaning action at bottom hole. Three criteria exist for optimizing bit hydraulics. They are:

1)the maximum hydraulic horsepower criterion

2)the maximum jet impact force criterion, and

3)the maximum nozzle velocity criterion

$k = P(Qi)n$ ……(3.12)

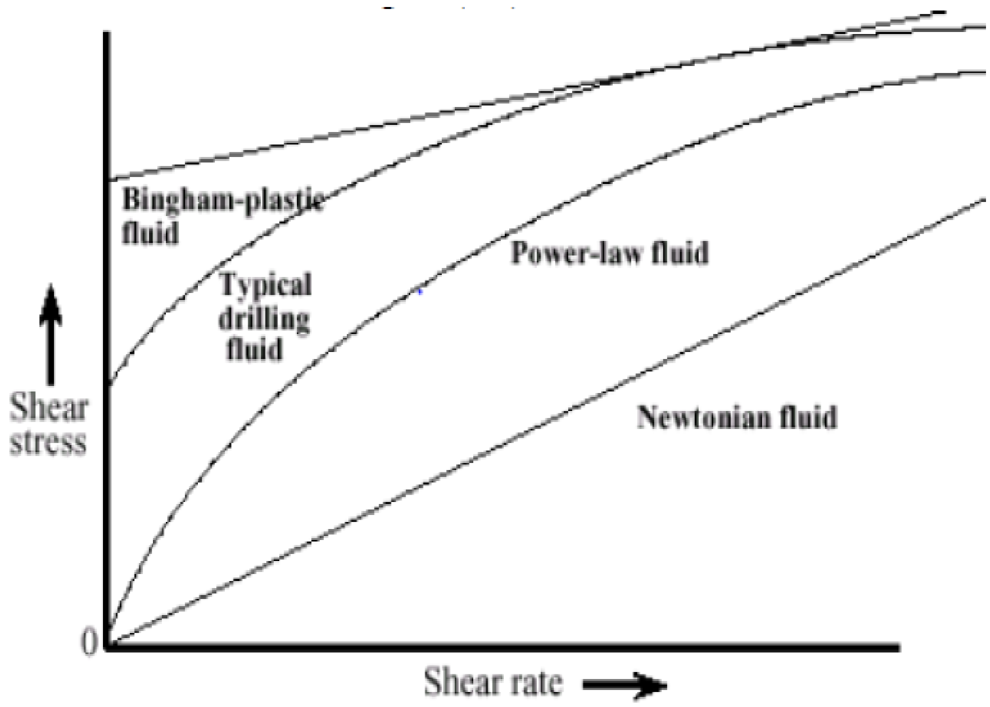
$Pbit = n/(n+1) \times Ps$……(3.13)

BHHP=$\frac{Pbo \times Qopt}{1714}$……(3.14)

IF =(Qopt×√ (ρ ×Pbo))/ 58 ……(3.15)

TFA=0.0096×Qopt×√(ρPbo) ……(3.16)

dno=32×√((4×TFA)/(3×pi)) ……(3.17)



(netwas group oil.us)

Fig.3.2: Rheological model shear rate Vs shear stress

Maximum bit impact f+orce can be obtained as follow :

$Pbit = n/(n+1) \times Ps$ ……(3.18)

IF =(Qopt×√ (ρ ×Pbo))/ 58 ……(3.19)

BHHP=$\frac{Pbo \times Qopt}{1714}$ ……(3.20)

Optimum flow rate is obtained by plotting circulating

pressure versus Q.

The intersection of optimum Pc with the curve gives

the optimum flow rate .

Slip velocity:

$$Vs = 174.7dp \times \frac{(\rho p - \rho f)^{0.667}}{\rho f^{0.333} * \mu e^{0.333}}.$$

$$\mu e = \left[\left(2.4v' \frac{2n+1}{(Dh-ODp)*3n}\right)\right]^{n} \times \frac{200K(Dh-ODp)}{v'}.$$

Equ No.(3.21)

Transport velocity:

Vt = Va – Vs ……(3.22)

Drill Cuttings Concentration:

$$C_a = \frac{1}{60} \times \frac{(ROP \times Dh^2)}{(Va - Vs) \times (Dh^2 - ODb^2)} \ldots (3.23)$$

3.2.3Optimization of bit selection :

$$J2 = \left[\frac{60}{N}\right]^{H1} \times \left(\frac{1}{1+\frac{H2}{2}}\right) \times \left[\frac{\left(\frac{W}{db}\right)_m - \left(\frac{W}{db}\right)}{\left(\frac{W}{db}\right)_m}\right] \ldots\ldots (3.24)$$

$$\tau_H = \frac{t_b}{J2 * h_f\left(1 + \frac{H2}{2} h_f\right)} \ldots. (3.25)$$

$$J3 = \left[\frac{60}{N}\right]^{B1} \left(\frac{4db}{W}\right)^{B2} \ldots. (3.26)$$

$$\tau_b = J2\, \tau H\, hf\, \left(1 + \left(\frac{H2}{2}\right) h_f\right) \ldots. (3.27)$$

$$\frac{db}{dt} = \frac{1}{\tau_b}\left(\frac{N}{60}\right)^{B1} \left(\frac{W}{4db}\right)^{B2} \ldots. (3.28)$$

3.2.4 Optimization of Bit Weight and Rotary speed:

Bearing Failure:

Rotating time calculation:

$$Tr = \frac{bB}{NW^{1.5}} \ldots\ldots (3.29)$$

Tooth wear:

$$H_f = \frac{-\sqrt{1+2C_1\left(\frac{T_r\left[10^3 A_f (PN*QN^3)\right]}{-D1W+D2}\right)}}{C_1} \ldots (3.30)$$

Footage drilled:

$\Delta D=Y=$

$$\left(\frac{K(W-M)N^{\lambda}(-DW+D2)}{10^{-3}Af(PN+QN^3)}\left[\frac{C1}{C2}Hf+\frac{C2-C1}{C2^2}\ln(1+C2Hf)\right]\right.$$

Equ No (3.31)

Tooth Failure:

$$T_r = \frac{(-DW+D2)}{(10^{-3}A_f)(PN+QN^3)}\left[1+\frac{C1}{2}\right] \ldots (3.32)$$

Footage drillied:

$\Delta D=Y=(W-M)N^{\lambda}Tr(\frac{2K}{2+C1}(\frac{c1}{c2}+(C2-C1/c_2^2)\ln(1+C2)))$

3.2.5 ROP Models:

Warren, T.M (1984) model:

$$R=\left(\frac{aS^2d^2b}{N^bWOB^2}+\frac{c}{Ndb}\right)^{-1} \ldots \ldots ()$$

$$R=\left(\frac{aS^2db^3}{NWOB^2}+\frac{b}{Ndb}+\frac{cdb\gamma f\mu}{Fjm}\right)^{-1}$$

Bingham model:

$$R=k(\frac{w}{ab})^{a5} * N^{e} \ldots\ldots ()$$

3.3 Prediction of drilling cost, drilling rate and drilling time based on depth:

Penetration rate varies with compressive strength and shear strength of the rock penetration rate can be related to depth by:

$$\frac{dD}{dt} = ke^{-2.303a_2D} \ldots. (3.33)$$

$$k \int_{t=0}^{td} dt = \int_{0}^{D} e^{-2.303a_2D} \ldots. (3.34)$$

Integrating and Solving for td yields

$$t_d = \frac{1}{-2.303a_2D} (e^{-2.303a_2D} - 1) \ldots. (3.35)$$

Trip time depends on depth of the well, used rig and drilling practice can be calculated as follow :

$$t_t = 2\left(\frac{t_s}{l_s}\right) D \ldots. (3.36)$$

Depth of next trip is:

$$D = \frac{1}{2.303a_2} ln[2.303a_2kt_b + e^{2.303a_2D_i}] \ldots. (3.37)$$

Chapter 4

Results and discussion

4.1Review :

In this chapter we focus on applying filed data "heglig 50 well" in payzone simulator , and results will be discussed and analyze the effect of different drilling parameters (bit selection , WOB & RPM , hydraulic) on ROP .

Fig.4.1: Payzone simulator interface

4.2 Data entry:

The data for the given well "heglig 50" was analyzed and the required data was selected . the data had been entered into the simulator as shown on figure (4.2) bellow :

File Edit Module Window

طبقاتي العزيزه.pzr

New Layer | Delete Layer | Edit Layer

			Rock Properties							Fluid Properties	
#	Depth	TH	Type	FG	S	W	GA	Res	Por	Type	PPG
0	0-1233	1233	Soft Sand	11.00	999	1	1	0.01	20	-	8.40
1	1233-1620	387	Shale	11.00	99	1	1	0.10	20	-	8.40
2	1620-1833	213	Soft Sand	11.40	999	1	1	0.10	20	Water	8.60
3	1833-2823	990	Soft Sand	11.50	999	1	1	0.01	20	Water	11.50
4	2823-3446	623	Shale	11.60	450	1	1	0.10	15	-	8.60
5	3446-4292	846	Limestone	11.90	250	1	1	0.10	20	Oil	8.70
6	4292-4780	488	Shale	12.00	99	1	1	1.00	1	-	8.70
7	4780-6840	2060	Soft Sand	12.20	400	1	1	0.10	10	Oil	9.00
8	6840-6938	98	Soft Sand	12.00	380	1	1	0.10	10	Oil	9.10
9	6938-7951	1013	Soft Sand	11.00	70	1	1	0.10	15	Oil	9.20

Fig.4.2: lithology input

4.3 conditions of the drilling simulation :

The conditions were set as the follow in figures(4.3) below:

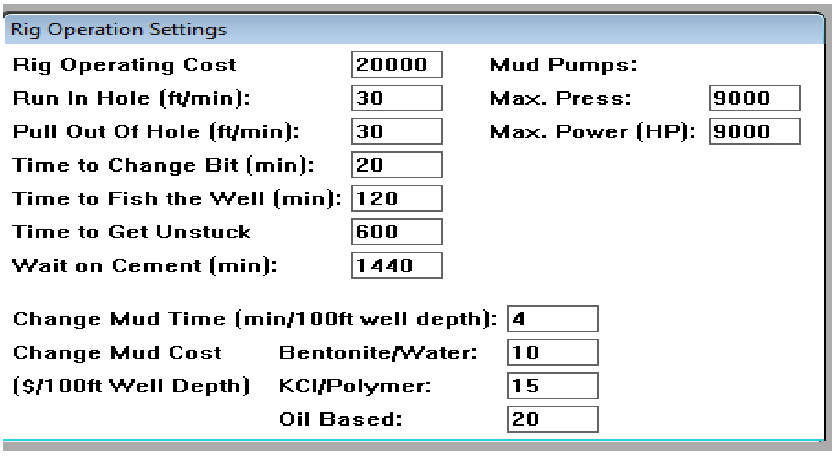


Figure (4.3) Rig operation settings

Here we state the conditions of the rig , pumps and rig operations we state the time of run in & out of hole , time to get unstuck also time required to change mud. as the follow in figures(4.4) below:

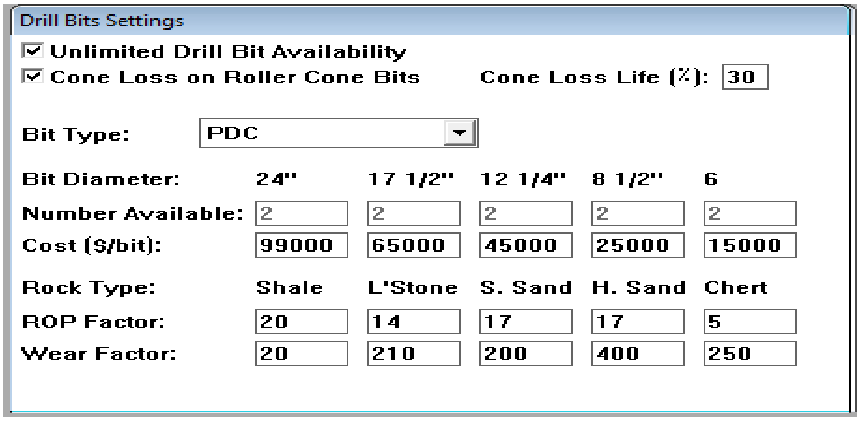


Fig.4.4: Drill bit settings

Here we input the ROP & wear factors for different bits and different formations.

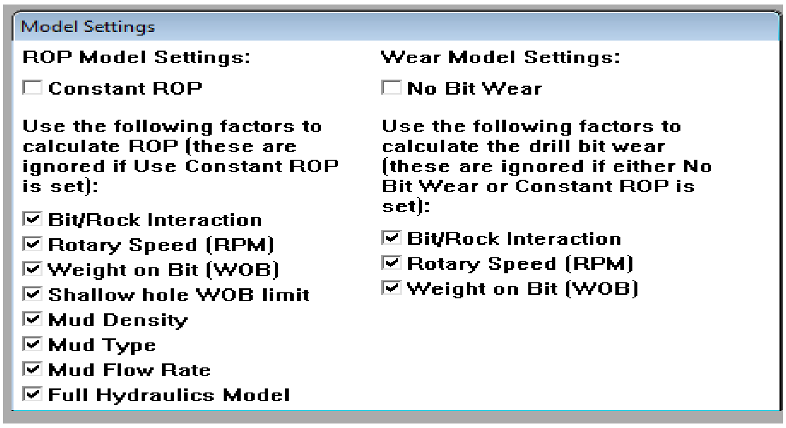


Fig. 4.5: Model settings

The ROP models we took in consideration all parameters that influence the ROP.

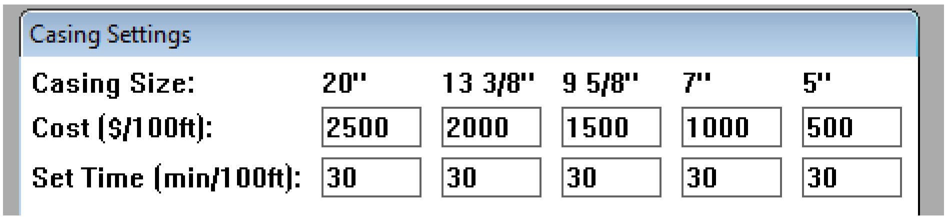


Fig. 4.6: Casing settings

Standard costs for casing costs and setting cost related to setting depth

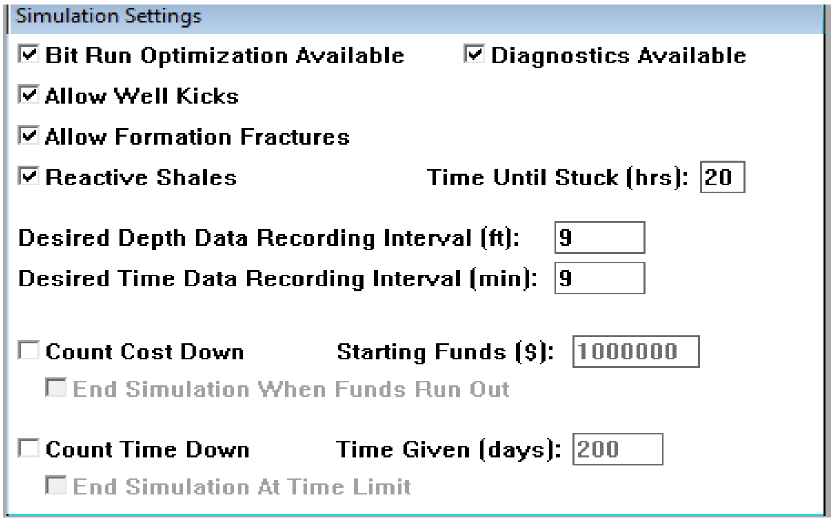


Fig. 4.7: Simulation settings

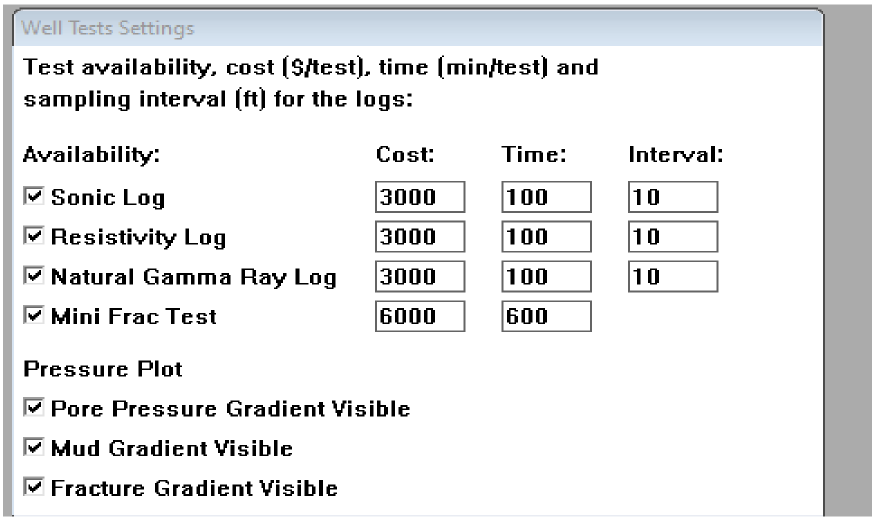


Fig. 4.8: well testing settings

Available tests and it's cost and time and interval of tests.

4.4 Real data simulation :

The basic concept of drilling optimization is to simulate the actual given data from the previous well and then run a series simulation operation to estimate the optimum drilling parameters that reduce cost and time .

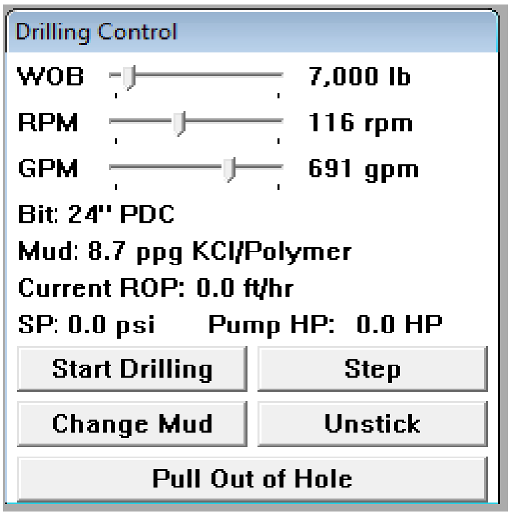


Fig4.9 drilling control window

For higlig 50 and from the actual drilling parameters the simulation result is shown in figure (4.10) and table (4.1) bellow.

Table 4.1:Time &Cost For Heglig 50 well

Well Depth:	7954 ft
Time Taken:	294 hrs 57 min
Well Cost:	$630108
Cost Per Foot:	$79

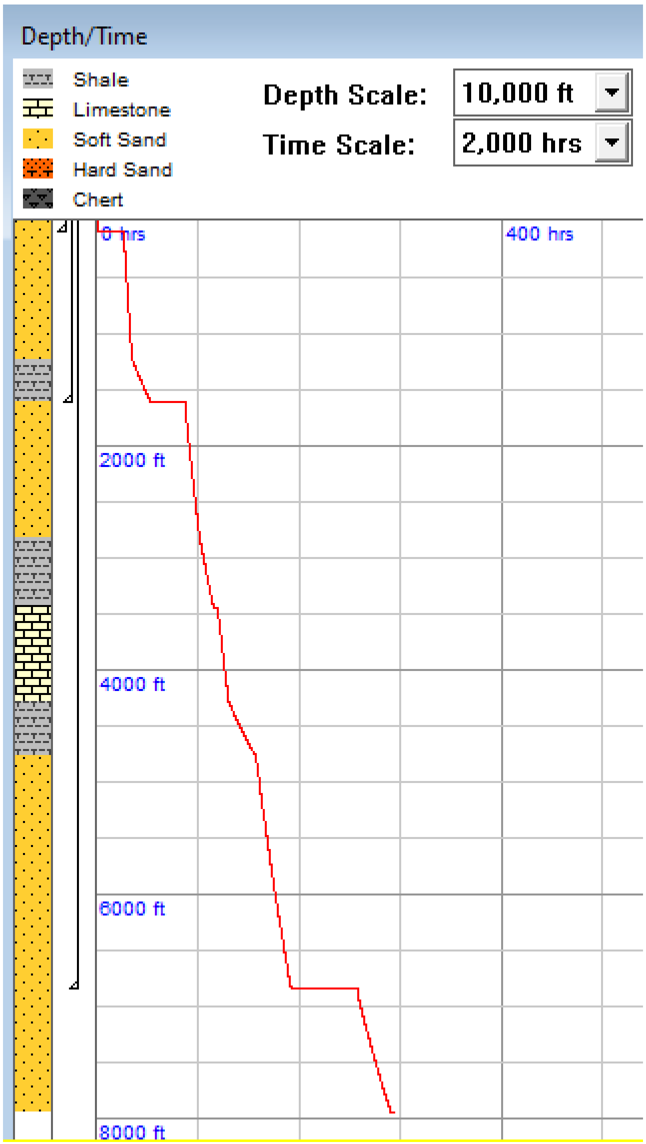


Fig. 4.10: Time Vs Depth for heglig 50 actual data

4.5 Drill bit selection optimization:

In figure below ,we notice that when an optimization process performed to choose a drill bit, the cost reduced by 75202$ and time by 16 hours , cost per foot was reduced from 79$/ft to 70$/ft .

This leads us to the fact that choosing a suitable drilling bit for the type of formation to be drilled is a very important and necessary process, Milled tooth bit reduced the cost due to the fact that it is specially designed for soft formations drilling.

We made a number of scenarios to choose the optimum bit type. the Milled tooth bit showed a results in figure(4.11) ,table (4.2) below that can minimize both time & cost of the drilling .

Table.4.2: Time & Cost For optimized bit

bit selection optimization.pzz	
Well Depth:	7953 ft
Time Taken:	279 hrs 15 min
Well Cost:	$554906
Cost Per Foot:	$70

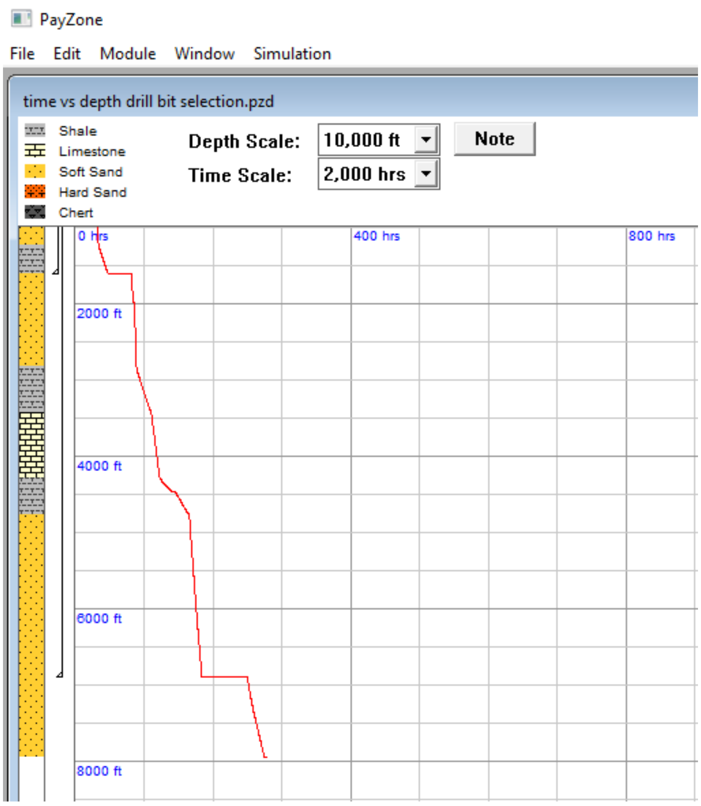


Fig 4.11: Time Vs depth for Bit selection optimization

4.6 WOB & ROP optimization :

Drilling with an appropriate amount of WOB and a suitable RPM can increase the rate of penetration and thus reduce both cost and time required to finish the drilling .

RPM is lnearly proportional to the ROP , but at at the same time it affects the bit wearing and reduces it's life time . soft formation should be drilled with relatively high RPM and solid formation with modreatly low RPM.

In the other hand increasing WOB can increase ROP until a ceartin point aafter it any inceasment reduces the ROP . We ran a series of simulations using diffrent values of WOB & RPM . it is a step by step operation by fixing the value of one variable and changing the value of the other one .

We found that rising WOB in the intermediate hole to 13 klb and rising the RPM to 120 will achieve better ROP and then less cost and time are obtained .

The over all cost reduced by 91871$ and time reduced by 85 hours , cost per foot reduced to 77$/ft instead of 79$/ft as shown in Table.4.3 bellow .

Table.4.3: Time &Cost For Optimized WOB &RPM

optimization of WOB and ROP only.pzz	
Well Depth:	7952 ft
Time Taken:	209 hrs 57 min
Well Cost:	$538237
Cost Per Foot:	$68

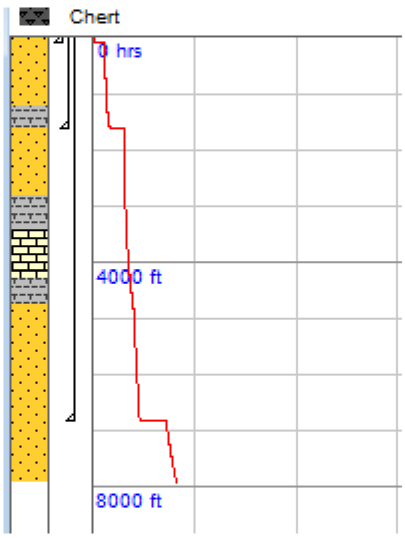


Fig. 4.12: Time Vs Depth for WOB & RPM optimization

4.7 Hydraulic optimization:

Designing a suitable hydraulic system and completing the drilling operation at an appropriate pumping rate is an important process that helps in cleaning the bottom hole ,thus drilling faster and reducing the cost .As cleaning the bottom hole prevents the stuck pipe problem , it also saves the bit from damage and wearing which gives the bit longer life , maintain high ROP and less cost per foot .

As shown in figure (4.13) ,table (4.4) below it was founded that using a bit with nozzles size of 13 inches instead of 15 inches bit , this reduced cost by 21418$, also we saved 20 hours of time .

Table 4.4: Time &Cost For Optimized Bit Nozzles Size

optimization of nozels only.pzz

Well Depth:	7953 ft
Time Taken:	275 hrs 9 min
Well Cost:	$608690
Cost Per Foot:	$77

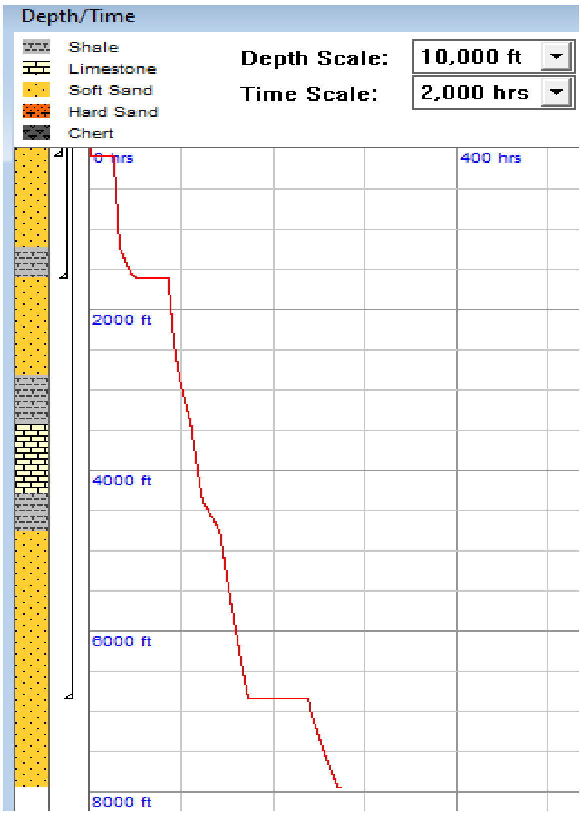


Fig.4.13: optimization of Bit Nozzles Size

4.8 combined effect of optimized parameters on ROP:

By including the effect of all optimized parameters and runing the simulation it was founded that the drilling cost was reduced to 435103 and this saves 194945$ of cost and time required to finish the well is reduced by 72 hours .

Cost per foot reduced from 79$/ft to 55$/ft .As we can see by combining the effect of optimized parameters we can make reduction in both time and cost as shown on fig4.14 and table 4.5 bellow.

Table .4.5:Time &Cost For Combined Optimization

nozel 13.pzz	
Well Depth:	7953 ft
Time Taken:	222 hrs 58 min
Well Cost:	$435163
Cost Per Foot:	$55

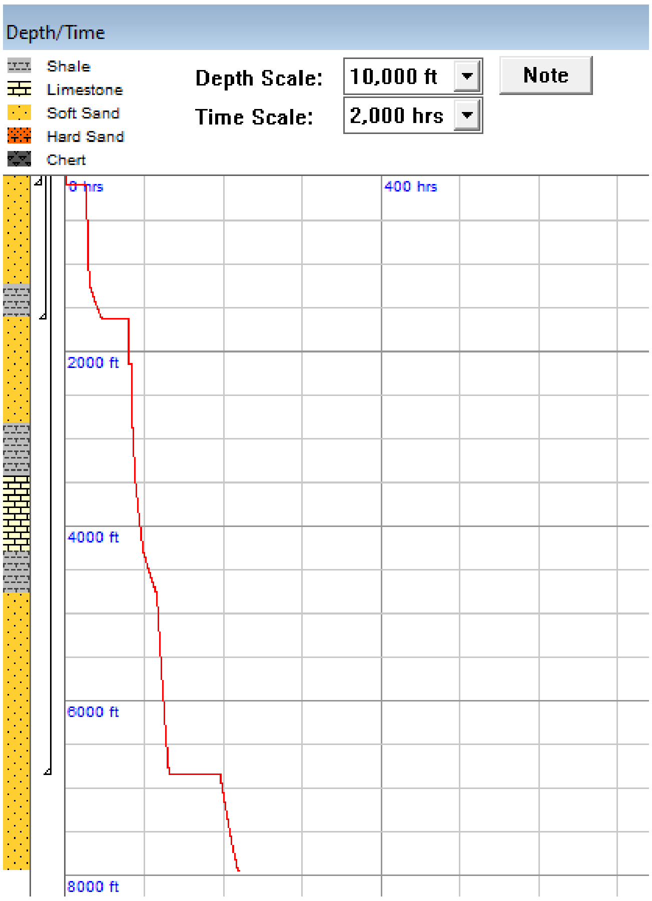


Fig. 4.14: Time Vs Depth for Combined optimized well

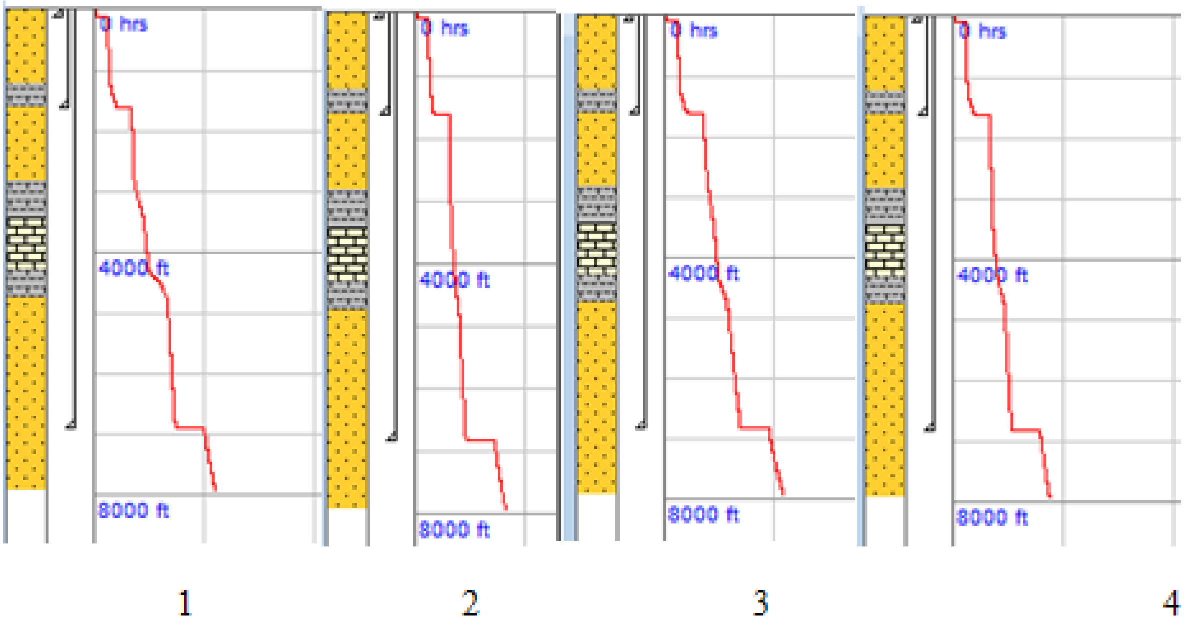


Fig. 4.15 Time Vs depth for all effective drilling parameters

1-represents bit selection optimization.

2- represents WOB & RPM optimization.

3- represents hydraulic optimization.

4- represents combined models optimization .

4.9 Case Study :

in this project we use payzone simulator to study the different effect of drilling parameters and optimize it to reduce the high cost and time for Heglig 50 well .

4.9.1Input data:

The actual data of heglig 50 well was entered into the simulator , including the lithology data as shown in fig.4.2

4.9.1.1: Actual well simulation:

A simulation process was run with the same drilling parameters of actual well data to simulate heglig50 well .

4.9.1.2: Bit selection optimization :

A simulation process was run using different bit types , and using the actual drilling parameters to study the effect of bit type on ROP .

4.9.1.3: WOB & RPM optimization :

The actual drilling parameters was considered constant , an simulation process was run using different values of WOB and RPM.

4.9.1.4 :hydraulic optimization:

An simulation was run to estimate the effect of hydraulics on the drilling process ,the actual conditions of the well was considered constant and nozzels size was changed to find the optimum nozzels size that increase the ROP .

4.9.1.5: combined effect of drilling parameters:

All optimized parameters was combined in one simulation process , all actual parameters was replaced with the optimum parameters .

4.9.2: Output:

The output results of the effective parameters is shown on Table 4.6 below

Table 4.6 final results of optimized parameters:

Simulation	Drill bit type	Nozzles size (inchs)	Time (hrs)	Cost/ft $	Cost $	**Saved time (hrs)**	**Saved cost $**
Actual datal of heglig 50 well	PDC	15	295	79	630108	**-**	**-**
Bit selection opt	**Milled tooth**	15	279.25	70	554906	**15.75**	**75202**
WOB, RPM opt	PDC	15	210	68	538237	**85**	**91871**
Hydraulic opt	PDC	**13**	275	77	608690	**20**	**21418**
Combined effect	**Milled tooth**	**13**	**223**	**55**	**435163**	**72**	**194945**

4.9.3 discussion & analysis:

From the Table 4.6 we notice that when we change the bit to milled tooth bit (bit selection opt) both cost and time are reduce ,thus we achieved saved time 15.75 hrs and saved cost 75202 $, and when we rise both WOB & RPM (WOB&RPM opt) by using PDC bit ,this can saved time 85 hrs and saved cost 91871 $,on the other side by changing the bit nozzles (hydraulic opt) the saved time was 20 hrs and saved cost was 21418 $.

To achieve less cost and time we combined all optimized effective drilling parameters the combined effect was saved 72 hrs of time and 194945$ of cost ,which is greater saved cost than individual optimized parameters .

When we raised both WOB and RPM thus saved more time than combined effect but the overall cost is higher .

Chapter 5

Conclusion and recommendations

5.1Conclusions:

Review:

by looking at this project , after we study all effective drilling parameters using **"Payzone**" simulator , and based on results above it becoms clear to us how important it is to perform an optimaizaton process before drilling a new well ,and

this helps to save both cost and time . After we ran a drilling simulation on the case study **"heglig 50"** we came with the following conclusions :

- Running the simulator showed that Milled tooth bit to drill the formation can obtain less time and cost , bit selection has great effect on the drilling optimization process .the saved cost was 75202$ and time saved was 15.75 hrs .
- The drilling parameters analysis showed that WOB and ROP are critical in drilling optimization. In soft sections of the lithology, increasing the rotary speed can improve the penetration rate with little effect on bit cutter wear.
- Relatively low WOB is recommended. In medium strength sections increased rotary speed will not have the same result as in soft formations. WOB of 13klb and 120 RPM was founded as optimum parameters .
- Due to mud pump limitations in providing high pressures, mud flow rate and nozzle sizes should be adjusted in a manner that the overall cutting removal is the nearest possible case to perfect cleaning process.
- Using bit nozzles of 13 inches is recommended.
- Combining all effective optimized parameters can give better results and saves more time and cost. It saved 194945$ of cost and 72 hrs of time .

5.2 recommendations:

- The simulator was used is an old version , using an upgrade version is recommended .
- Real-time optimization is more accurate and faster we recommend to work on it .
- Working on complete data including logging data will give more accurate data

RFERENCES:

- Carlos M. C. Jacintoa, Paulo J. Freitas Filho, Sílvia M. Nassar , Mauro Roisenberg, Diego G. Rodrigues ,and Mariana D. C. Lima (2013),” *Optimization Models and Prediction of Drilling Rate (ROP) for the Brazilian Pre-Salt Layer*” Dept. of Informatics and Statistics - PPGCC-Federal University of Santa Catarina -VOL. 33, 2013, Copyright © 2013, AIDIC Servizi S.r.l.

- Bahari .A,and Baradan .A seyed (2007),“*Tryst-Region Approach to find cnstants of Borgoyne and Young penetration rate model in Khangiran Iranian Gas field*” ,represented at 2007 latin American and Cribean petroleum Engineering conference held in Buenos Aires , Argentina 15-18 April 2007.

- Adam t. Bourgoyne Jr.,Keith k.milheim,Martin E.chenevert,f.s.young Jr(*Applied drilling engineering*),1st printing.SPE.Richardson,Tx-1986.

- Bourgoyne, A., Millheim, K., Chenevert, M., Young, F.: Applied Drilling Engineering, society of petroleum engineers, (1986) 209.
- Cooper, G.A., Cooper, A.G. and Bihn, G.: “An Interactive Simulator for Teaching and Research,” paper SPE 30213 presented at the 1995 Petroleum Computer Conference, Houston, 11-14 June.
- Bataee .M, Kamyub .M, Ashena.R,(8-10 June 2010) "inverstigation of various (ROP) Models and optimization of drilling parameters for Ppc and roller - cone bits in shadegoan oil field", presented at the CPS/SPE international oil and gas conference and Exhibition in China-Beijin,1-10.
- Hossain M.E (2015), “Fundamentals of Sustainable Drilling Engineering”.
- Irawan . S, Abd Rahman .A and Tunio.S.Q (15 June 2012),” Optimization of Weight on Bit during Drilling Operation Based on Rate of Penetration Model”, Petroleum Engineering Department, Universiti Teknologi PETRONAS, Malaysia. 1690-1695, 2012.
- Mostofi.M, Shabazi .K, Rahimzadeh .H, Rastegar.M,(8-18 June 2010) " Drilling optimization based on the ROP model in one of the Iranian oil fields ", presented at the CPS/SPE international oil and gas conference and Exhibition in china, Beijin,China .
- Abouzeid, A.A. and Cooper G.A.: “The Use of a Drilling Simulator to Optimize a Well Drilling Plan,” paper presented at the 2001 Geothermal Resources Council Annual Meeting, San Antonio, Texas, 26-29 August.