Journal of ICT, Design, Engineering and Technological Science (JITDETS)
VOL. 5, NO. 2, pp. 1-16, 2021
DOI: https://doi.org/10.33150/JITDETS-5.2.1

ORIGINAL CONTRIBUTION

Systematic Review of Drilling Problems and Their Solutions in Petroleum Engineering

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***Abstract*— The difficulty in drilling arises due to unexpected and surprising behavior of rocks which leads to waste of time, cost, material and sometimes whole borehole. The logging becomes difficult to perform and to investigate due to drilling issues such as borehole instability, lost circulation stuck pipe and under gauge holes. This study sheds light on the state of art of drilling problems, affiliated issues and causes along with their best possible prediction, prevention and solution methodologies. The well schedule, weekly drilling report, construction document, and different well documents were thoroughly inspected. This study incorporates the benefits of statistical analysis of 20 wells, including lateral longitudinal and vertical, as well as how effective constitutive modeling is for classifying well-bore instability triggers and forecasting safe mud-weight windows. The detection models discussed encourages superior comprehension of the fundamental material science standards, and gives improved situational consciousness of drilling problems' occurrences.**

***Index Terms*— Drilling Problems, Petroleum Engineering, Drilling Bit, Well logging, Borehole**

Received: 19 August 2021; **Accepted:** 17 October 2021; **Published:** 21 December 2021

I. INTRODUCTION

A. Borehole Instability

The undesired phenomena of autonomous change in nominal diameter of hole; may include opening or narrowing of hole, hole washing out, and collapsing; is termed as borehole instability. It is a critical issue that not only waste a lot of time but money also. The congregation of factors that may lead to bore hole are drilling through already fractured shale or brittle shale; and unjustified amount of mud used [1].

Borehole instability was reported at the hilltop area of the Western Canada while drilling the weak, fissile shale which caused problems like pipe stuck, poor logging conditions, poor cleaning of the hole, excessive mud and cement volumes [2, 3]. Shell Columbia is one of the historical explorers in this region and a major producer of the natural gas. According to the review of shell Columbia around 56% of all drilling related issues and 12% of the total drilling cost is directly or indirectly related to the borehole instability [4]. Which are alarming numbers hence the counter measure was taken, and the on-duty team developed to address the issue. The team strived but was unable to address the issue appropriately and proper predictive modelling of the well couldn't be done because of the lack of available data. This situation aroused the need for the well geology tracking while drilling. Various scientists strived and many studies were done to improve knowledge regarding the problem.

Forgoing in view McLellan [4] proposed that the density of the mud alone cannot be used as a source to reduce the tendency of the well to collapse. Mud additives such as salts are helpful in decreasing the mud losses and hence, the stability problems as they are effective inhibitors [1]. In addition, the two factors, the surge pressure and the dynamic swab have to be contemplated while examining the pressure of bottom hole. Reduce the angle intercept between the bedding and that of a hole trajectory. Reduce the amount of time the drill remains in contact with the shale and weak fissile area by optimization. Moreover, proper hydraulics maintenance is an important factor in the stability of hole. Borehole instability evaluation should be conducted for all the hilltops wells with the angle of inclination greater than 25o. Finally, it was recommended that studying the well using ultrasonic imaging can provide with a quality data on different modes

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of well stability [4]. Another study [5] of similar type was reported afterwards.

II. METHODOLOGY

The purpose of this study was to classify the reasons that cause the problems of instability. Well schedule, the weekly drilling summary, the construction document and the various records of many wells were reviewed carefully. This report integrates the benefits of statistical analysis of 20 wells, including lateral longitudinal and vertical, and how useful constitutive modelling is to classify triggers of instability of well-bore and forecast safe mud-weight windows. The inclination direction, azimuth, and form of mud are considered as the main reasons for ambiguity. It is more found normal in wells with an azimuth which is close to the location of max lateral stress and the inclination of the field's main axis itself. The usage of Oil-Based Mud (OBM) is said to have reduced the degree of instability, but has not been able to eliminate it completely.

Classification of Borehole Instability and its Causes

The classification of borehole instability and its major causes are described in Table I.

TABLE I
CLASSIFICATION OF MAIN CAUSES OF HOLE INSTABILITY [6, 7, 8, 9]

Hole Instability Causes			
Uncontrollable Causes		Controllable Causes	
Name	Description	Name	Description
Tectonic stresses	Caused by highly stressed formations and difference between drilling fluid density and wellbore stress restraining pressure.	Bottom pressure	Either concentration of mud or relative circulating density lowers the cavity pressure.
High in-situ stress: (Figure 1)	Abnormal stresses near the salt dome or faults in the folds of internal limbs.	Well inclination and azimuth	Either the lower pressure of the cavity, the density of the mud or the relative circulating density (ECD).
Mobile formations	The mobile structure crushes into wellbore as the forces compress it.	Transient pore pressure	Caused by rapid reduce in pressure by swabbing action of drill string.
Unconsolidated formations	Insecurely packed material with particles, pebbles or stones drops into the wellbore.	Rock and fluid interaction	Changes in dispersion, hydration, swelling, rock softening and strength.
Natural shale collapse	Caused by under-compaction, overburden and uplifting.	Vibrations	Holes can be enlarged by drill string vibrations.
Induced shale collapse	Caused by wellbore fluid hydrostatic pressure after being subjected to that pressure for several days	Temperature	Stresses due to thermal concentration or expansion stresses cause wellbore stability

Disregarding long periods of study, issues of borehole instability keeps on being a main consideration in the expense of oil boring, logging, and cementing. The present endeavours to bore extended reach wells are particularly influenced, with borehole instability regularly keeping the goal from being achieved when as of now accessible WBM's are utilized. With the utilization of OBM getting progressively limited by ecological guidelines, there is an incredible requirement for a naturally adequate WBM framework that can give borehole stability, filtration control, and lubricity.

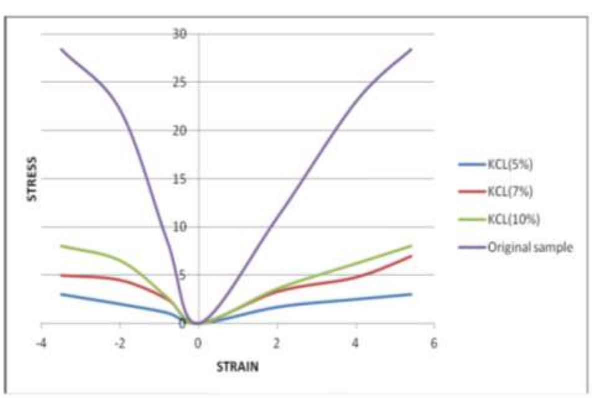

Fig. 1. Contribution of Stresses in Borehole Instability (Adopted from [10])

Intensive studies of borehole instability have been made by knowing the properties of the rock. Such examinations show that failure can be anticipated based on estimations of properties of the rock, observations of in-situ stresses, and estimation of pore-pressure, alongside information on hole inclination and its direction and mud pressure. The forecasts ordinarily demonstrate that there is a maximum mud weight that can be utilized without ductile failure causing lost circulation, just as both a base and most extreme mud weight that will stay away from borehole instability from compressive failure or shear disposition [11]. Figure 2 demonstrates the effect of mud on caused stress in wellbore.

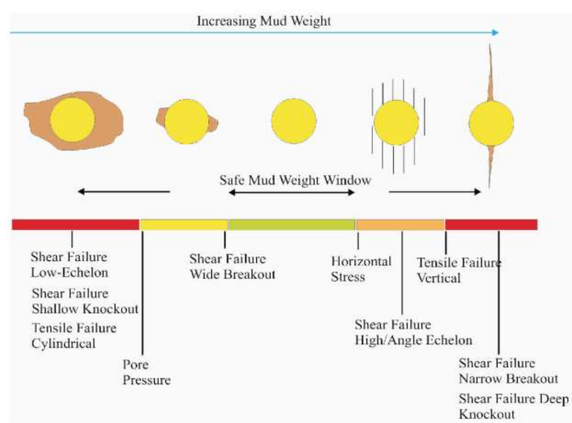

Fig. 2. Stress Caused in Wellbore Due to Mud Weight

WBM create instability conditions in borehole, which further results in shale deformation because,

- Water is free to enter the shale
- The inorganic salts in WBM creates a weak membrane outside of the

shale.

The borehole instability in fractured lithologies having fine grains is also determined as special case. Such lithologies served as reservoir seals in the array of cavernous petroleum well in the Timor sea. The potential causes of such instability are reported; such as intersection of fault set at wellbore, damage induced due to drilling, cyclic natured mud pressure loadings and orientation of wellbore. In this case, mud pressure loadings in cyclic fashion greatly influences the stability of the borehole during petroleum drilling. During normal operating conditions, numerous varieties of fluid pressure are imposed on wellbore. These changing pressures pose a great impact on stability of the borehole and it is helpful in determination of equivalent weight of mud and effect of change of its ratio upon principle stresses. Empirical results show that weight of the mud is directly proportional to displacement around wellbore. Periodic loading over a large period causes borehole to displace and hence causes a net deformation ultimately. Empirical results also show that higher and medium permeability in test models caused higher deformation as compared to lower permeable models. It can be concluded that wellbore stability can be enhanced by the reduction in joint permeability. This can be done by reduction in the ability of wellbore fluid to penetrate joints of the rock mass because of pressure difference [12].

In order to evaluate effect of various parameters like size of particles, far-field stresses and drill hole diameter small scale isotropic and anisotropic models for drill holes were developed in which drilling was done at different drilling angles. It was observed that the properties of shale like stiffness and strength vary widely because of the layered structure that accounts for their fiscality. The drilling process also causes the stresses in the drill zone to redistribute, the affected area is referred as Excavation influenced zones. The angle between shale planes and bore hole axis has high impact on the stresses which is confirmed by experiments with cylindrical holes on lab scale. Figure 3 depicts effect of circumferential angle on wellbore instability.

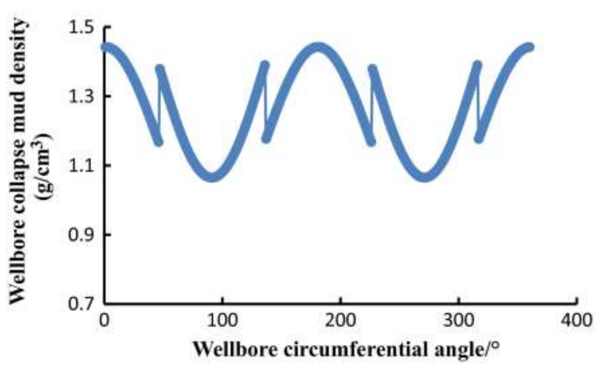

Fig. 3. Effect of Circumferential Angle on Wellbore Instability [12]

The effects of drilling-fluid pressure on the instability of shales in the formation is also discussed [13]. Drilling through the shales is a highly difficult process and is mostly done using water-based mud, the mud pressure causes the borehole to destabilize near the shale section of the formation. Shale systems are induced with two major type of force: the physio-chemical forces and mechanical forces. The physio-chemical forces consist of double-layer-repulsion and the famous van der Waals forces, whereas the mechanical forces include compressive and tensile forces caused by the cementation of borehole, the pressure caused by pores and in-situ stresses. Borehole instability is also caused by the adding a high-density mud fluid, using higher water pressure and pore-pressure, and by adding insufficient mud weight to the borehole. Chemical osmosis also causes borehole instability due to the motion of water into the shale section due to higher pressure different.

In order to achieve borehole stability, the effective stress near borewalls must be controlled. This can be done by controlling the mud composition, mud density and pressure around the walls. In order to find the right values of these parameters new simulation techniques are devised based on the measurements of pore-pressure in shales, pressure due to mud fluid and analysis of fluid motion inside the borehole. New equipment was designed [13] for analyzing the mud fluid properties, its pressure and the pore-pressure of shales. This allows the engineer to calculate the formation permeability to a greater resolution by varying the fluid pressure. Borehole stability can be achieved in the shale section of formation by changing the non-hydraulic difference, decreasing the permeability of shales at the entrance, by using increasing the viscosity of the mud fluid and by inducing a reverse osmotic pressure in the shale region.

Hard brittle shale is more prone to having cracks and micro-cracks which can lead to cause mishaps during drilling like sloughing, collapsing etc. The hard-brittle shale are considered to be more effected by hydration when coming in contact with unstable drilling fluid as the main cement constituents in the shale (quartz and clay minerals) have noticeable micro-cracks in in their structure which leads to a big drop in rock strength and leads to collapse formation. To avoid such an occurrence drilling fluid activity is predetermined and monitored so that it is guaranteed that collapse will not occur during drilling. Based on the physicochemical properties, hard brittle shale is regarded as an elastic body with small deformation. A mechanics/chemistry coupling model of a deviated section borehole stability was established, which takes in-situ stresses, column pressure, percolation of drilling fluid and formation hydration into consideration. This model assumes that the formation is a kind of homogeneous isotropic and linear elastic porous material, and that the borehole is in a plane strain state. The factors affecting the collapse pressure are occurrence of the dip angle and inclination of the weak plane and certain other chemical factors like hydration, cohesive force and friction angle etc.

Under the mud overpressure, cracks connected to the borehole wall can open, and consequently make a small region of the fracture network available for the drilling fluid.

Because the joints open and there is no pressure drop across the blocks in this region, joints can be loosened and then be eroded by the drilling fluid. This mechanism is compatible with various field observations:

• increase in mud density will open more cracks and cause further destabilization.

• No detectable fluid loss occurs from the well toward the formation as only a limited region of the fracture network is affected.

• Any means of increasing the sealing capacity of the mud through filtrate reduction and viscosity increase will have a beneficial effect.

Thermal effects have been considered seldom, but they deserve great attention because of their consequences. The temperature of rock is altered due to excavation of rock, mud circulation and pressure loss at rock bit. In the case of a hole drilled with no change in temperature of rock tangential compressive stresses are generated. If these tangential compressive stresses are greater than the compressive strength of wall, then failure arises instantly. If the wall of bore is colder than the rock, this cooling causes a decrease in axial and tangential stresses for which the wall of the borehole can be stable temporarily. If mud circulation is stopped for too long, wall will become warm and tangential and axial stresses will increase due to which rupture can occur.

Author described the conclusions that were made on drilling wells in Meillon St Faust field in the South-west of France, and one well in Gabon, Baudroie-Nord-Marine. Mostly all wells were completed successfully except one which was stopped after 92 days due to borehole instability. The drillers concluded that the major parameter that causes problem are stresses near the SALT DOME. It appeared that state of stress changed due to pressure induced by salt dome on rock. In both cases it appeared that closer the salt dome to well, the more disturbed stresses are. If the stresses are disturbed, they increase the mud density which causes destabilization rather than stabilization which produce shear failure and poor conditions for borehole stability.

A. Prediction and Assessment

There are certain indicators that indicate when a borehole becomes unstable. These can either be direct or indirect. Direct indicators include under gauge holes, an increase in the cement volume requirement for filling the hole, excessive volume of cuttings removed, etc. Indirect indicators include phenomena such as stuck pipe due to caving, failure of the drill string, excessive doglegs, etc.

Certain models have been developed in order to predict wellbore instabilities. The wellbore stresses model [14, 15, 16] analyses the presence of stresses within a formation. The stresses are divided into different components such as vertical, horizontal, radial and tensile. Before the drilling begins, the formation is in equilibrium. As the rocks are removed during drilling, this equilibrium is disturbed, and the stresses become imbalanced. This imbalance can be prevented by providing enough drilling fluid pressure. Failing to do so can result in failure of the borehole. The wellbore stresses model applies several equations in order to calculate stresses and predict wellbore instability. Other models include The Mohr-Coulomb shear-failure model [17, 18, 19], Von-Mises shear model [20, 21], the tensile model, etc. [22, 23].

Various approaches have been used to resolve or predict the borehole instability. The most widely used model is rock failure criteria which is not very accurate due to oversimplification in the model [24]. [24] focused on resolving borehole instability by focusing on the mathematical prediction models used to predict failure in crust and rock and proposes to improve such models. A novel prediction theory, called the damage theory was also investigated using same approach and was improved. Damage theory is based upon loss of function instead of the commonly used loss of strength criteria. The main improvement was that in damage theory the rock functioning life is not limited to the yielding point, but a state between the failure (UTS point) and yielding point of the stress-strain diagram. The prediction of minimum mud weight which can prevent shear failure in bore holes was also presented. Also, the results from the model show that the mud window can be made much wider, thus reducing on operational costs. The comparison to other models such as Mohr-Coulomb was also made, which shows that the proposed model is more accurate and adaptable, especially in cases of poly-axial stress conditions.

Discrete Element Modeling (DEM) is also adopted to explain the mechanisms behind instabilities. This model depicts that the values for tangential and normal stiffnesses of fractures cannot be measured directly and are estimated from the literature. Yet, calculations performed with another set of stiffnesses showed little difference from the overall results even though the absolute values of joint displacements were obviously different. The use of a 2-D plane strain geometry and of regular blocks is not representative of the fracture pattern which can be expected in these situations and primarily chosen because of its simplicity [25].

The analysis for stability of bore hole is based on the stress distribution calculated around the hole and prediction of failure pattern by applying failure criteria. The failure is difficult to predict due to dynamic nature of stress distribution, so a different approach called DEM was used by researchers for modelling fracture mechanisms for different drilling conditions, initial stresses and borehole diameter. Inherently anisotropic model was analysed by DEM in order to visualize anisotropy, deformation mechanism and failure pattern. The DEM model was validated by performing uniaxial unconfined compression test in 30 mm specimen at different angles with step of 15 degree. The test showed that DEM closely matched with actual condition. It was concluded that there is close agreement between stress measured from DEM and that calculated from analytical model. For failure by hydrostatic stress particle size plays an important role. Spiral shaped breakouts are more evident in homogeneous structures and V shaped breakouts are evident in heterogenous conditions. For smaller boreholes the value of critical stress is greater, and the failure mechanism is dominantly shear failure of parallel bonds rather than tensile failure. Weaker structure causes the stress concentration around bore hole to change significantly. The proposed numerical model is in close agreement with laboratory experiments hence the model can be used to address borehole stability problems [26].

A mathematical model was also developed to determine the collapse pressure distribution more accurately. According to the mathematical model established in the study [27], 25 pieces of core from the collapsing section were tested, 6 of which were used to test the relationship between swelling ratio and water activity, 6 were used to test the relationship between water activity and water absorption, 7 were used to test the mechanical characteristic of rock, and the rest 6 were used to test the strength of weak plane after soaked in water-base drilling fluid.

The trend of collapse pressure obtained from the mechanics/chemistry coupling model proposed was determined as similar to that from weak plane model. Because of chemical factors, soaking in water-based drilling fluid with the activity of drilling fluid of 0.98, formation rock is in a very unstable state, even if mud density can be adjusted to the range between 1.4g/cm3 and 1.71g/cm3, the borehole still could crack at any time because of excessive water absorption.

However, under the same geological conditions, soaking in drilling fluid with the activity of drilling fluid of 0.56 (the upper limit of water activity window), collapse pressure gradient is just between 1.24g/cm3 and 1.55g/cm3. Hence, drilling fluid density decreased by 10%, borehole stability still can be guaranteed, if only the water activity of drilling fluid is controlled in the proper activity range. The relationship of swelling ratio, water activity, water absorption and mechanical properties of weak plane was established to work out the drilling fluid activity window I.e. to figure out proper water absorption and critical swelling ratio that can keep rock stable, as well as the hydration degree that the weak plane can bear, and finally the collapse pressure. For hard brittle shale, the hydration of intrinsic rock can be omitted, but for inner cracks as weak planes, hydration effect must be considered. Compared with cohesive force of weak plane, the borehole stability of hard brittle shale is more sensitive to the weakening of friction angle, that is to say hydration degree of internal friction angle has a stronger effect on the distribution of collapse pressure. The mechanics/chemistry coupling model proposed in can be used to predict collapse pressure distribution more accurately; borehole stability can be ensured and density of drilling fluid can be decreased as long as the activity of drilling fluid is controlled in the activity window [27].

Later on, mathematical prediction models were proposed to predict failure in crust and rock as discussed in [10]. The study investigates the shale instability with drilling fluid. The methodology was considered to account for catering the effects of polymer drilling fluid on the mechanical properties of shale for improving the performance. There were substantial problems being discussed in the study; borehole fluid invasion to shale, pipe sticking potential, swelling or hydration that triggers increase of non-production time (NPT). Wellbore stability is going to be determined by the type of drilling fluid employed for the operation. For this purpose, several fluids were assessed to see their effects on shale strength which is being exposed with fluid for 24 hours. Highly compressive potential of mud is most befitting. This study aims to conclude the shale which experiences the lowest strength. Utilizing the brine solution of KCL for drilling fluids rely mostly over the properties of shale that inhibits. In addition to that, it is assumed that K+ ion adds attraction with clay platelets due to the fact of size and charge. On the contrary, shale leaves its strength when interacted with polymer drilling muds mixed with 5% KCl, 7%, 10% KCl respectively. Shale is having Kaolinite in it became one of the reasons. It is evident from the experiment that density of drilling fluid is affected and became reduced hence, improves of the stability of wellbore and it tends to keep shale stable. Various other measurements can also contribute in prevention of hole instability such as controlled circulation density, reduced time of hole opening, offset well data usage and proper maintenance of mud weight [22].

B. Lost Circulation

Lost circulation is the unusual loss of drilling fluid in the formation. Lost circulation is defined as "the total or partial loss of drilling fluids or cement to high-permeability zones, cavernous formations and natural or induced fractures during the drilling or completion of a well" [28, 29].

C. Drilling fluids

In 1846 Favela used flushed water as drilling fluid, using water alone was partly successful as only limited depth could be achieved. This inability forced companies to shift to other fluids. In 1890, Chapman proposed to use plastic material and water as drilling fluid. In 1901, mixture of clay and water was used and in 1935, Betonies clay was introduced in drilling fluid by Hearth and this serves as a basis of current drilling fluids. [30] Drilling fluids are important part of drilling process. Some of the primary function it serves is:

1. Cutting
2. Lubrication
3. Cooling
4. Hole Stability [30]

D. Types of Fluid

1) Water based mud

Main issue with the Water Based Fluid is their ability to dissolve salts which results in undesirable increase in density. Moreover, Water Based Mud effect the gas and oil flow through medium with high porosity. WBM also promotes dispersion of clays. WBM is not usable if surface is porous or water sensitive shale is present. WBM accelerates the corrosion rate of pipes and drilling equipment.

2) Oil based mud

Places where WBM is not suitable, OBM is used but it has some limitations too. Using OBM is quite expensive due to various reasons i.e. High cost of constituents, High cost of post treatment and disposal as disposing openly may result in water pollution. Secondly, OBM is unsuitable for use in open gas reservoirs.

3) Gas based mud

Like the other two GBM also has limitations, most commonly, using GBM can be dangerous as it may cause explosion due to high pressure, it accelerates drill string corrosion. Drilling Engineers do not use GBM in water containing formations as it is not possible to carry it by air or gas.

In order to deal with the above-mentioned issues, some chemical additives and bentonite clay are added to drilling fluids. These additives decrease corrosion rate, improve density, alter viscosity and stop bacterial growth. But, in deep drilling where operating temperature and pressure is quite high it is impossible to meet heat transfer requirement on the drilling fluid [30].

E. Description of Lost Circulation

Due to the increased demand of petroleum products to meet the energy requirements petroleum, wells are being drilled in various environments. Drilling engineers came across various problems while performing the drilling operations [31].

one of the most common drilling problems is Lost Circulation. It is defined as "Partial or Complete loss of drilling to the formation" [30]. It can result in reduced hydrostatic pressure, allowing gas and fluid under high pressure to flow into the wellbore and dry drilling which damages drill bit along with other drilling equipment [32].

This usually occurs due to cracks, holes, gaps or crevices in well wall. This loss leads to increase in time and cost to achieve desirable depth. As well as it also creates pressure loss leading to safety issues [30].

1) Types of losses

Mud losses are classified on the basic of the amount of mud lost per hour. These losses depend upon a number of factors i.e., drilling fluid properties, formation properties and formation breakdown pressure. Mud losses are classified into 4 categories. If the mud lost rate is in the range of 0.5-1 m3/hrs, the loss is classified as seepage loss. Next one is the partial loss, in it rate of fluid loss is in the range of 1-10 m3/hrs. Partial losses occur in gravel beds and small horizontal fractures. Then we have severe loss which is the loss of fluid at a rate of 15 or more m3/hrs. After that is the complete loss which represents the complete loss of the fluid. These losses are because of the large natural horizontal fractures, caverns, interconnected vugs and too widely open induced fractures [31].

2) Causes of losses

1. Losses through Matrix permeability: This occurs I porous formations where the mud pressure is higher than the formation fluid pressure. The quantity of losses is predicted through Darcy's Law for radial flow.

2. Losses through small natural fractures: Lubrication theory is used to model the flow of fluid inside these fractures. It is combined with the power yield law which expresses fluid velocity in terms of pressure drop.

3. Induced Lost circulation: These are caused by induced fractures in the formation due to high mud pressure exceeding the shear stress limit of the rock [33].

F. Prediction of Lost Circulation

Machine learning technology shows a lot of promise for the correct identification of lost circulation. Machine learning application shows extraordinary ability of examining very complex problem when compared to conventional theories for lost circulation. Ensemble algorithm or majority voting algorithm, a type of Machine learning model is used to find hidden links between the 3D seismic data and lost circulation events from a geological point of view, to make a prediction about loss circulation. Four seismic characteristics that are linked with (variance, attenuation, sweetness, RMS amplitude) loss circulation are used for training the model.

With the help of these data, prediction model is made using ensemble learning/majority voting algorithm. Added benefit of this method is the resolution of the prediction. The machine learning model is even capable of detecting minute change on each signal sample of numerous seismic characteristics. The model performance is judged by testing on six drilled well, and result seems to be promising. Case study of one unidentified Iraqi oil field is also discussed, and application of machine learning proved to be fruitful as it was able to detect loss circulation zones [34].

G. Solutions

CM Treatments: This is done in losses due to matrix permeability. The pore throat diameter is first estimated. The LCM is then chosen based on the pore throat diameter using one of the plugging principles such as Abrams method, Vickers's method etc.

Wellbore strengthing: This is preferable for losses due to induced or natural fracture.

MPD: Managed Pressure Drilling is suitable for tight pressure gradient between pores and fractures.It holds the pressure above the loss zone and thus allows drilling to continue.

UBD: Underbalanced Drilling designs the mud weight to be below the pore pressure

CwD: It can be used for natural and induced fractures

Solid Expendable Systems: For wells where casing is short, SES can run to cover the low pressure zones [33].

Use of Non-Mud System: This system is most efficient combat system because it has high shear strength, low initial viscosity, reproducibility, low density to reduce hydrostatic pressure. In addition to this it should require minimum surface mixing equipment so that it can be designed easily. Normally Portland Cement with thixotropic is used for non-mud system.

Silicates: According to the paper currently Silicate Based System are used for solving the severe issues of loss circulation. These silicates have low initial viscosity, high shear strength, low density and adequate strength. Only drawback of silicate is water development during the permanent zone plugging. This happens due to the reaction of the Silicates with the brine solution which produce water as by product [35].

Corrective treatments: There are various plugging and bridging materials and techniques which could be used for the treatment of the thief zone. All these materials and techniques are classified to help engineers differentiate between them on the basis of performance and appearance. Essential purpose of all this is bridging across the existing fractures and bugs and the prevention of the further penetration of fractures within the well walls.

Preventive treatments: A wide range of pills, squeezes and pre-treatments are there to prevent the lost circulation. All the measures that are taken to reduce the circulation loss before entering the loss circulation zone are classified as preventive treatments. Strengthening of the well bore is the main objective of these treatments. The concept of wellbore strengthening can be defined as, "a set of techniques used to efficiently plug and seal induced fractures while drilling to deliberately enhance the fracture gradient and widen the operational window". Well bore strengthening increases the fracture gradient of the well bore and hence widen the mud weight range to be used for drilling.

Advanced drilling techniques: Numerous advanced technologies i.e. expandable tubular and Casing-While-Drilling (CWD) have been used to mitigate the lost circulation problem. By using the expandable tubular different mud weights could be used for different sections of the bore whereas CWD provides the benefits of lowering the Non-Production Time (NPT) and casing running time [31].

Plastering Effect: It is also proposed that the combination of three forces pipe rotation, high annular velocity and proximity of casing wall will result in crushing of drill cuttings against the formation, ultimately leading to the creation of wall cake with less permeability. Analysis on particle distribution shows that Casing Drilling produces smaller particle sizes compared with conventional drilling. This is due to the fact that casing drill grinds and crumbles the cuttings in their way up the annulus. Then these cuttings are coated to the wellbore by Plastering Effect. In short, the cuttings act as a substitute for lost circulation. The casing rotation plasters the cuttings into well formation interface. In this way no space is left for drilling fluid to escape to the formation. While in conventional drilling filter cake was built up as a result of particles accumulation on the borehole wall that depended on formation permeability and mud overbalance. That filter cake was usually knocked by drill collars, while they moved around the borehole.

Continued Drilling with Losses: In worst case scenarios if losses are impossible to be completely cured because of bug fractures or cavities drilling is usually continued with reduced losses until casing is reached total depth. In this case to continue drilling we adopt better wellbore cleaning and lower flow-rates.

In Casing Drilling, we have smaller annulus than conventional drilling so smaller flow rate for better mud circulation is required. Lower flow rates lessen the mud loss, encase losses are happening around bit. Lower flow rates also control Equivalent Circulating Density preventing additional pressure on the formation, further reducing the losses. Higher annulus helps in cleaning the wellbore more effectively if breakouts are falling into the wellbore [36].

Linked polymer gel: The use of cross-linked polymer gels is widespread when it comes to mitigating lost circulation in areas where there might be a potential risk of lost circulation, such as in areas of induced fractures and cavernous formations.

A cross linked polymer gel with controlled gelation time possessing high gel strength has been fabricated at elevated temperature. It was named as HTCMG. HTCMG was prepared by using the free radical polymerization and the three major components of this gel were: crosslinking agent, initiator, and acrylamide monomer. The gelation time is the most important parameter in the cross-linked polymer gel. The initiator was encapsulated by resin material in order to increase the gelation time. The effects of salt concentration, monomer concentration, temperature, and pH on gelation time were investigated. HAKKE Mars 40 and uniaxial compression apparatus were used to examine the properties of the fabricated gel.

It was found in light of the performed analysis that the gelation time may be adjusted according to the requirement. The temperature range for gel formation was found to be 80-150°C. Furthermore, the fabricated gel was found to successfully plug a 3mm width hole. HTCMG is efficient in terms of time, moreover, it is cost effective compared to other materials used for the same application [37].

High viscosity Patch: use mud with high viscosity for drilling purpose it should have low weight we can increase the viscosity by adding Bentonite, lime, or by adding salt clay, time required is 2 to 3 hours

Reducing the drilling parameters: Decrease mud weight, pump pressure, RPM and bit without nozzle

Super stop Material: Add 5 to 6 bags of super stop material weight of each bag 25kg for each 1m^3 of water this should be done separately after cleaning the tank. Take the drill pipe string from the upper side of loss zone and circulate mud for 10minutes

Cement plug: Pump the slurry of cement with calculated density to meet the treatment of formation rapture

Fibers in cement: This is formed by adding lost circulation mud with cement in particular ratio to restore the lost circulation mud. Time required for this is 18hours

Use of high filtration mud: High penetration mud is used to treat the loss for sealing it well the water is passed through mud in formation and solids will make seal in front of thief zone, time required for this is 4 to 6 hours

Gilsonit cement: It is same like the gilsonit plug but instead of bentonite gilsonite material is used: [38]

H. Summary

Failure initiation and maximum stress concentration arises inside the wall not on the surface according to standard elasticity. The shear failure predicts various shapes of spalling on the bore wall. If the weight of mud increases, it leads to shear failure.

Borehole is relatively stable when we are using Oil Based Mud (OBM) because it avoids shale deformation due to these reasons;

• Because capillary forces stop oil from entering the shale. Therefore, the shale will not get soft.

• Interaction of Shale with OBM creates a membrane outside the Shale the prevent water and other salts from entering the shale.

Lost circulation is an expensive problem for drilling industry. It can result in reduced hydrostatic pressure, allowing gas and fluid under high pressure to flow into the wellbore and dry drilling which damages drill bit along with other drilling equipment. To reduce circulation losses, Lost Control Material (LCM), wellbore strengthen, Managed Pressure Drilling, Underbalanced Drilling, Use of silicates. The silicate base system is very useful for solving the problems occurred during loss circulation. Reduction in Mud Weight is not an effective method to prevent the loss circulation. In order to solve the circulation losses combination of LCM Pills, Cement Plugs and Silicate should be deployed. Use of Preventive treatments is also feasible option.

I. Stuck Pipe

Stuck pipe is a situation in which drilling string got stuck in wellbore such that it cannot move and rotate or partially move or rotate. The literature and computer based simulations are evidence that stuck pipe is one most cost endeavouring factors [39]. A fundamental drilling bore unit is depicted in Figure 4.

Stuck Pipe is by all accounts an unavoidable issue. In view of historic data, each of third well encounter stuck pipe, and different gauges show that related expenses surpass 250 million dollars every year for the business. Stuck pipe is a regular unscheduled occasion during drilling activities, yet it is particularly risky as it represents in any event 25% of the ineffective time, which is equal to a yearly cost of 2 rigs. Since the issue is repetitive, a coherent countermeasure is to store the information depicting stuck pipe circumstances and execute systems that reuse this data to comprehend comparable issues when experienced. At the point when an adequately large information base is made, it tends to be applied to break down any new insight and experience to avoid such issues [40, 41].

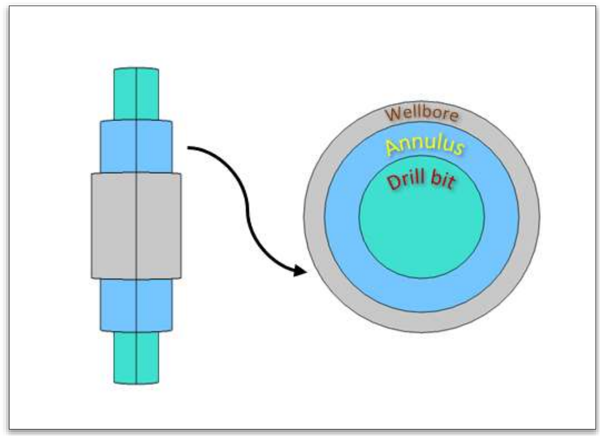

Fig. 4. Drilling Unit Structure

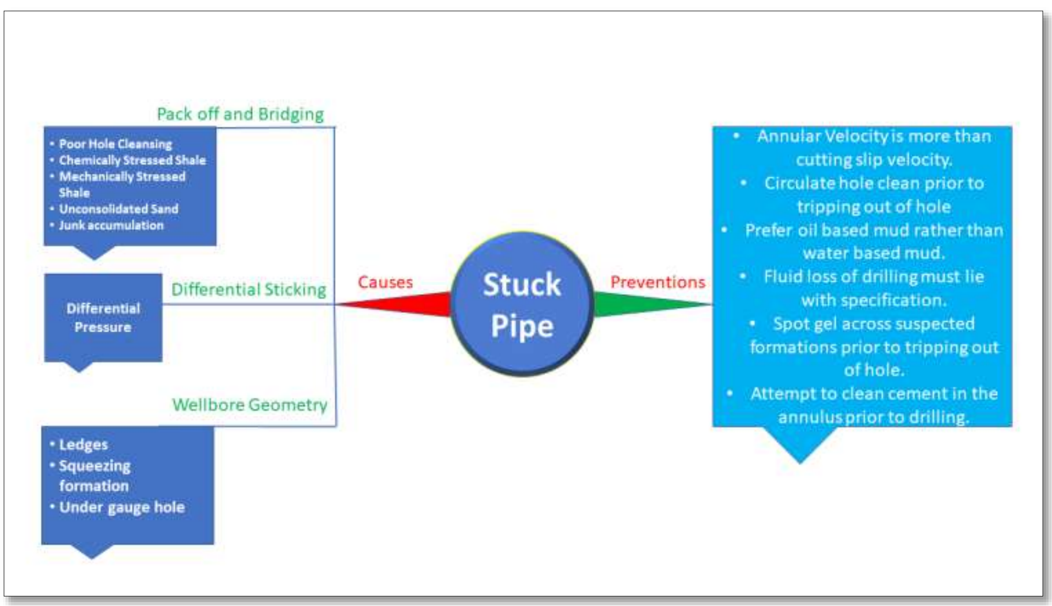

Fig. 5. Summary of Stuck Pipe Causes and Failures

J. Solution for Differential Sticking

1) Polymer implications

Highly deviated or horizontal holes are very difficult to drill in high permeable formations [42, 43]. Drilling problems like differential sticking [44], wellbore instability [45], and mud loss [46] are usually caused by high-pressure differentials. Oil-based fluid muds reduce these problems to a certain extent. These challenges are on the rise due to continuous drilling of the already depleted reservoirs. A redesigning of the fluid system to solve problems in drilling a thorough series of highly permeable sand and shale formations is one option. The fluid system will inhibit shale decomposition through the effective bridging. It will also strengthen wellbore and reduce pore pressure by increasing hoop stress in the wellbore. To evaluate different fluid properties and to evaluate fluid performance under different conditions, software modeling and permeability plugging tests were usually conducted. The normal bridging solution containing calcium and graphite were not found to efficient. It became essential to include micronized sealing deformable polymer along with the normal bridging materials. The deformable polymer component can reshape itself to fit a broad range of pore throat sizes which was not attainable first [47]

The extra cost of the stability problems which is approximately 5-10% of the total cost of exploration & production can be reduced by a significant amount through the use of the micronized sealing polymer. The polymer allows the additive to plug & seal micro-fractures in shale and depleted sand formations hence preventing elevation of pressure in shale and minimizing the risk of stuck pipe events. The laboratory test demonstrated the enhancement infiltration and showed no negative effect on mud properties which were effectively conveyed to the field [47]

2) Nanoparticles

Recent researches indicate that many drilling problems, such as the differential pipe sticking, well bore instability, lost circulation, and low drilling rates, can be solved by the addition of nanoparticles to water-based drilling muds [48, 49, 50]. As compared to macro-materials, nano-particles can provide better strength and thermal stability, high quality mud cake and can reduce the differential pipe sticking and friction, ensuring the stability of the well bore, protecting the reservoir, and increasing the recovery of gas and oil. Previous work in this regard showed significant promise. The use of SiO2 and TiO2 nano-particles enhanced the rheological properties and resulted in a reduction of the filtrate loss of the water-based mud under low pressure, low temperature conditions [49]

Similarly, the utilization of cellulose nano-particles resulted in an improvement of the rheological properties and a reduction of the filtrate loss [49, 51, 52]. Another study suggested that drilling fluids that contained nano-sepiolite performed better than the base-drilling fluids under high pressure, high temperature conditions [53]. The aim of this particular study [49] was to investigate the effects of the addition of Hydrophilic Gilsonite Nano-particles (HGNs) to water-based drilling muds, especially in terms of the differential wall sticking problem, rheological properties, lubricity characteristics, filtration loss reduction, and well-cleaning process.

The methodology included the characterization of hydrophilic Gilsonite nano-particles using Fourier-Transform Infrared Spectroscopy (FTIR), Thermo-gravimetric Analysis (TGA), Differential Thermo-gravimetric Analysis (DTG), and the Dynamic Light-Scattering (DLS) technique. Rheological and filtration loss tests, lubricity evaluation, and tests for the determination of differential sticking coefficient were carried out, the results indicated an improvement in the overall properties of the water based muds after the addition of HGNs.

The addition of Hydrophilic Gilsonite Nano-particles (HGNs) to the drilling mud enhances the chemical and thermal stability of the mud, as shown by a decrease of only 31% in the yield point of the sample mud after the hot roll process, as compared to an original decrease of 70%. Similarly, an increase in the YP/PV value indicates improved rheological properties and maintained efficiency of drilling in the well cleaning process. In addition, a decrease in the filtration loss and thickness of the mud cake, and an increase in the lubricity of the mud was observed. The addition of the HGNs also resulted in a decrease in the torque and lubricity coefficient by 13.63% and 15%. Most importantly, the experiments showed a reduction in the differential sticking of the mud at ambient temperatures. Hence, HGNs are appropriate additives for water-based drilling muds and can solve many drilling problems as depicted in Figure 6 [49].

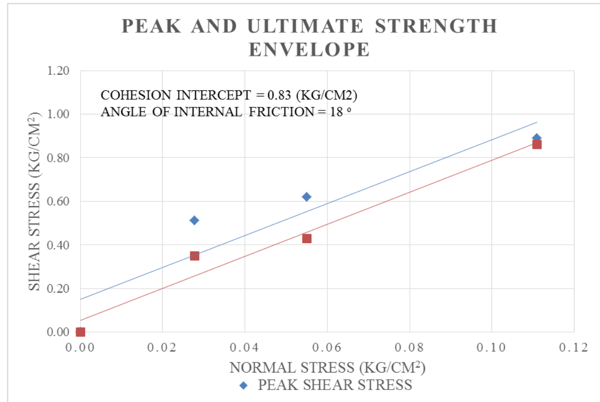

Fig. 6. Reduction in Differential Sticking by Addition of Hydrophilic Gilsonite Nanoparticles [49]

Differential pipe stuck has been one of the major problems for offshore reservoirs. The Managed Pressure Drilling system [54, 55, 56, 57] has been around for a while for mitigating such problems, and for this case, the MPD system was initially proposed with Constant Bottom Hole Pressure method [58] of operation. The new technique for MPD proposed [59] is based on its ability of instantaneously and efficiently optimizing the mud weight while drilling. With this new technique, the mitigation in the differential pipe stuck problem was observed (done by reduction in the differential pressure between the pressure of formation pore and the dynamic equivalent circulation pressure). This was done because of the following key features of the MPD system: capacity to perform Dynamic Pore Pressure Test, Dynamic Formation Integrity Test identifying and quickly governing any influx from the formation. Increase in the rate of penetration was one of another key benefits obtained from this technique. All in all, with all the data procured, it was established that the MPD system: Is the right solution to overcoming pressure uncertainties occurring due to pressure maintenance program and reservoir depletion, and provides different and better ways for the re-entry of the horizontal and vertical water injector wells. For future recommendations, the methodology of MPD can be used with other techniques as well for the exploration of better drilling techniques and coming up with solutions for other drilling problems. One of new techniques could be the installation of advanced control systems overboard for better monitoring, assurance and anticipation of the differential pressure related problems [59].

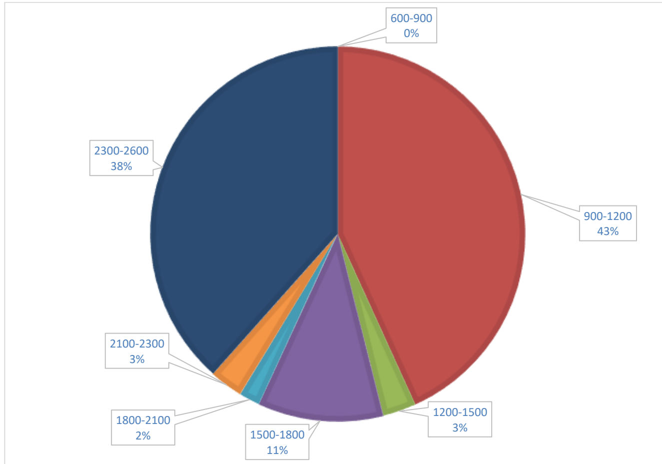

Fig. 7. Probability of Stuck Pipe with Respect to Differential Pressure (psi)

K. Prediction Models

Oil and gas drilling is a field filled with many uncertainties, making the job of drilling to tap fossil fuel reserves quite difficult. This difficulty is enhanced when the area to be drilled has complex underground formation, which may lead to many problems during drilling including the most common problem of stuck pipe. The study [60] presents the physical and chemical analysis of backflow cutting, drilling fluid, well site drilling data and other parameters with respect to their influencing factors. Through these data collection, the occurrence of stuck pipe is predicted successfully. This report suggests a unique approach to predict the occurrence of stuck pipe through the usage of data statistics along with geological lithology, well structure, drilling fluid performance, collapsed rock physical properties and backflow cuttings typically seen in stuck pipe incidents. The influence weightage of various factors is considered the input as depicted in Figure 8 and through least square calculations and computer intelligent data analysis, the probability of stuck pipe is obtained [60].

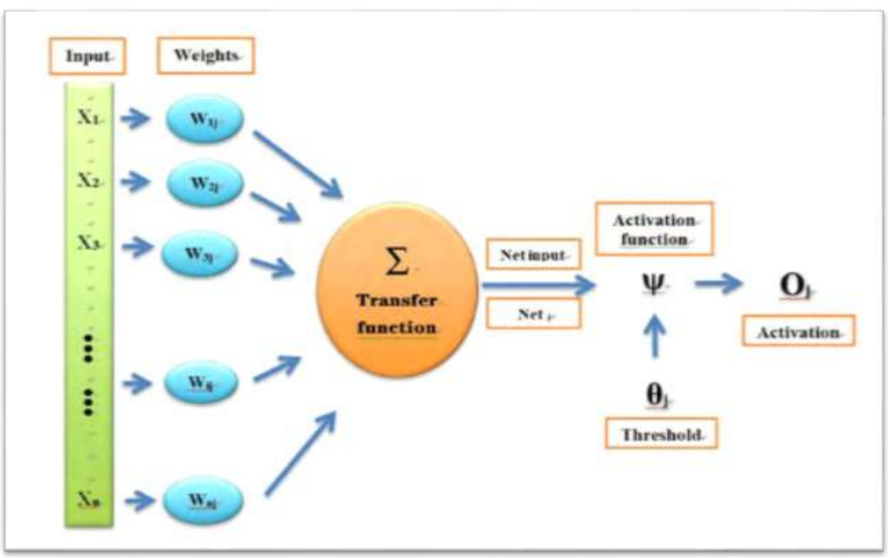

Fig. 8. Algorithm of Artificial Neural Network (ANN) Model to Predict Stuck Pipe Phenomena [60]

Stuck pipe is as yet a significant operational test that forces a lot of downtime and related expenses to oil and gas investigation activities. The probability of liberating stuck pipe relies upon reaction time and ensuing surface move made by the driller during and after the sticking is experienced. A late and improper response not just purposes lost time in attempting to release stuck pipe yet in addition brings about the loss of a significant segment of costly cylindrical, downhole equipment and tools. Therefore, a quick and viable reaction ought to be made to discharge the stuck pipe. Researching past effective reactions that have solved stuck pipe issues makes it conceivable to possible to predict and adopt the proper treatments.

The study [61] shows an investigation on the utilization of machine learning techniques to build up a specialist framework that can be utilized as a source of perspective guide for the drilling engineer to make intelligent decision and decrease the lost time for each stuck pipe event. Field datasets, including the drilling operation parameters, formation type, and fluid mud characteristics, were gathered from 385 wells bored in Southern Iraq from various fields. The new models were created to predict the stuck pipe solutions for vertical and veered off wells utilizing Artificial Neural Networks (ANNs) and a Support Vector Machine (SVM). The results of the analysis show that both ANNs and SVM approaches can be of incredible use, with the SVM results being all the more encouraging. These machine learning techniques offer insights that could improve reaction time and procedures for treating stuck pipe [61]. Prevention of stuck pipe is definitely more efficient than even the best of releasing methodology. In any case, when prevention falls flat, the drilling engineer must move quickly to choose the best treatment. Utilizing experimentation to locate a stuck pipe arrangement isn't constantly a practical strategy, and there are outcomes in costly downtime. There is a requirement for an intelligent alternative that gives the engineer increasingly accurate solutions. This paper examined master frameworks enabled by adaptable machine learning algorithms. The most well-known machine learning strategies for ANNs and SVM have been used to anticipate stuck pipe arrangements [61]. A comparison of various prediction model is depicted in Figure 9.

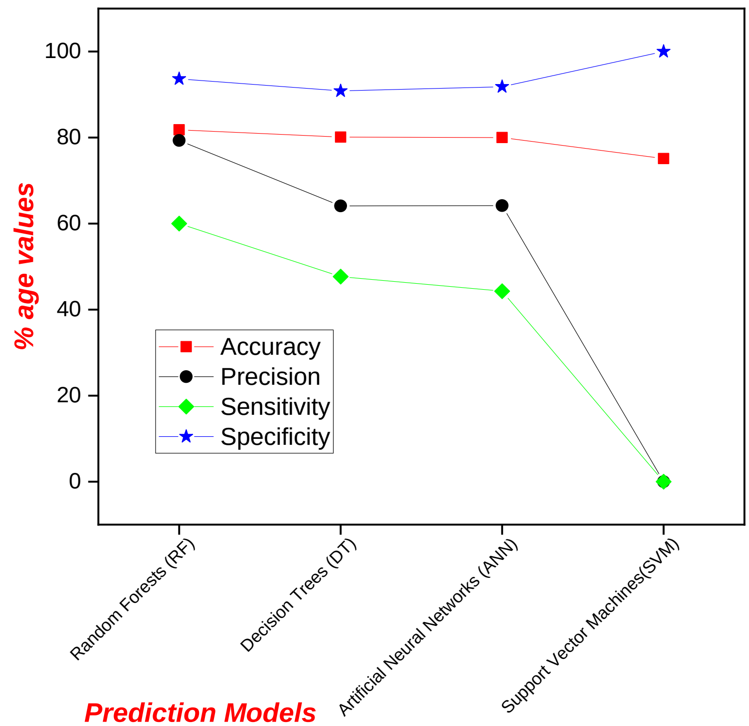

Fig. 9. Comparison of Prediction Models [62]

The sooner a stuck funnel event is anticipated and moderated, the higher the possibility of avoiding in liberating the pipe or dodging extreme sticking of pipe. Time is of foremost importance in such cases as an inappropriate response to a stuck pipe event can aggravate the situation as elaborated in Figure 10. In this study [41], a novel model was created utilizing ongoing information to naturally recognize driving indications of the stuck pipe incidents during drilling activities and to convey the perceptions and cautions with adequate time to counter the issue. All through the most recent couple of decades, following the prescribed procedures for stuck pipe evasion has demonstrated to be extremely powerful in diminishing stuck pipe events [41].

Sadlier et al. [63] and Ferreira et al. [64] have displayed one methodology utilizing the mix of robotization and human information in moderating the drilling issues. The model provides design acknowledgment fused in an automated decision support tool. This apparatus gives constant case-based thinking to evaluate the hazard and alleviate stuck pipe incidents in joint effort with a specialist. The tool utilizes case-based thinking to coordinate the constant examples with recorded closely resembling situations where a similar past event was observed. This permit giving computerized suggestions for restorative activities dependent on the perceived examples and authentic match. The specialists are to team up in a timely manner with the choice help tool to give direction in alleviating the issue. The model proposed uses the key penetrating parameters to distinguish irregular patterns that are recognized as driving signs to the stuck pipe. The parameters and examples utilized in building the framework were recognized from distributed writing and recorded information, and reports of stuck pipe occurrences [41].

The alarm is to be populated in the constant condition and communicated to the labors in an auspicious way to guarantee ideal outcomes, giving them more opportunity to anticipate or remediate a potential stuck pipe incident. Testing the model on a few wells demonstrated promising outcomes as inconsistencies were identified right off the bat in time before the genuine stuck pipe occurrences were accounted. It further encouraged a superior comprehension of the hidden material science standards and gave familiarity with the stuck pipe event. It improved observing and monitoring the drilling data streams. Besides such pipe signs, the model assisted in the detection of similar issues in the downhole conditions of the wellbore, the drilling equipment, and other electronics. The model outstandingly utilizes the strength of information along with the material science-based examination of stuck pipe. This hybrid model has given successful discovery of the indications noticed by specialists and has given improved forecast and hazard evaluation [41].

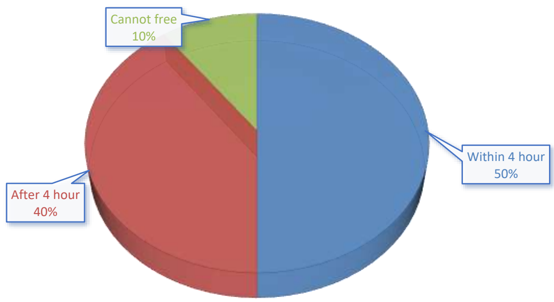

Fig. 10. Importance of Time in Releasing Stuck Pipe [41]

III. UNDER GAUGE HOLE

Under-gauge hole is a drilling defect caused due to wear of drill bits. Using worn bits results in a difference of diameter in the hole which may cause pipe sticking. Under-gauge holes are formed when a drill bit is rotated in a hard and abrasive underground rock. This rock normally wears the drill bit. As a result, the diameter of the hole being drilled starts to decrease. When a new drill bit is later inserted which is of the same diameter as the previous drill bit initially was prior to its wearing it is unable to reach till the bottom of the hole because of its diameter being slightly greater than that of the hole. It would be stuck at some point above the bottom of the initially drilled hole.

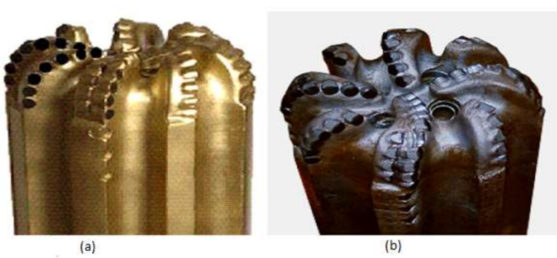

Fig. 11. (a) New Bit IADC M432, (b) Dull Bit [65]

A. Major Causes

The boring procedure in oil industry is legitimately corresponding with financial aspects and if even a little issues experiences on any point during boring will might results a business misfortune. Issues related with the boring of oil/gas wells are because of the lithology of the subsurface arrangement that produce unsettling influence because of worries around the borehole made by the borehole itself

1) Clay Particle Swelling

This is an inherent problem in sandstone that contains water-sensitive clays. When a fresh-water filtrate invades the reservoir rock, it will cause the clay to swell and thus reduce or totally block the throat areas [66].

2) Mud Chemistry

Another reason for instability and under-gauge is mud chemistry. Shales, mostly, are affected by mud chemistry the volume change of the wellbore cannot be attributed to a pressure decrease in the wellbore. It must be interpreted as a general water sensitivity, which is commonly known in sedimentary formation under the phenomenon of "brittle shale failure", where competent and non-reactive shales are completely destroyed by water imbibition along a network of microfractures. Efforts are being made to reduce the free water content and HPHT filtrate of the mud, and to monitor these variables as closely as possible. The monitoring was done using the Capillary Suction Time (CST) method. The CST value is indicative for the free water content of the drilling mud which is not bonded to the drilling mud particles of polymers and available for migration into the rock [67, 68].

B. Effects of Under-gauge Holes

1) Increased Costs

Under-gauge hole can increase the operational costs in drilling. Under gauge holes may require another run for drilling which increase time required to drill the hole and consequently increase the cost.

2) Pipe Sticking

Under gauge holes may cause pipe sticking. Three methods are available to deal with pipe sticking caused by under-gauge holes:

1. The simplest method was to apply the maximum pull force which was obviously limited by the strength of the pipe and the amount of force was determined.

2. The second method focuses on introducing slightly lighter density mud on the either side of the drill bit and the calculations of pull force were made.

3. The third method was to increase the buoyancy on the drill bit. This was achieved by introducing seawater into the hole and the calculations were made.

It was concluded that introducing slightly less dense mud was the most effective method to decrease the pull force required to free the wall sticking. Buoyancy off course was effective but it was not enough to produce a considerable difference. Therefore, the minimum density proved to be more effective than the maximum buoyancy.

C. Strategies to Avoid Under-gauge Holes

Following are the potential strategies to avoid under gauge holes.

1) Using Underreamer

Eduardo [61] presented a new system of placing the underreamer in the middle of the measurement and the rotary drill system, which has been gaining interest in recent times. Current practice is that the underreamer be placed above the measurement system leading to an under-gauge hole of around 200 feet to total depth. The new arrangement allows for a much shorter under-gauge hole. Their system utilizes two underreamers, a primary one placed in a conventional arrangement and a second one placed between the measurement and rotary assembly. The connection between the measurement and rotary assembly now is wired and goes through the secondary underreamer. The underreamer now called the Intelligent Underreamer will record data, the time for the bore to be complete was accurately known [61, 69].

This arrangement eliminates multiple drillings and reduces other operating processes' time. Further design evolutions are promising to use one underreamer near the bit i.e., between the Rotary Steering System and the measurement/logging while drilling systems. The communication between the RSS and the MWD/LWD must be distinct as similar channels can interfere with each other. The new depth of the hole was reduced to about 37 feet, which entails that drilling time of about four days and a sum of four million US dollars were saved. This was tested in the Gulf of Mexico's deep-water basins [61].

2) Bi-Center Bits

Bi-center bit technology is a drilling bit that combines a bit and under-reamer. The author [69] describes a new type of Bi-Centre bit to open holes in interbedded formations. It features an elongated pilot section with a new mid-reamer which makes it more stable and due to balanced cutter forces. The mid reamer also provides an already gauged section to the main reamer and reamers on the drill collars. This improves the quality of the borehole by helping make a more consistent gauge throughout the length of the borehole.

Bi-Centre Bits are not comprised of moving parts and they minimize risk of debris and junk in the borehole. They feature eccentric geometries which enable them to pass through holes which are smaller than the size of the holes that they themselves dig. This is why they can be helpful to mitigate the risk of stuck pipe due to the drill bit being stuck in an under-gauge hole.

Bi-center bits have two important parts which are namely the pilot bit and the reamer. Pilot bit is lot like the conventional drill bits and its job is to centralize the whole bit while drilling. The reamer, which has most of its cutting edge on one side of the bit then follows the pilot bit to enlarge the hole to the required diameter. In addition to these two features a new mid-reamer was added in the new design between the pilot and the reamer. This resulted in less angle drop in tangents and better hole quality in soft formations and better pilot stability and less damage to pilot cutter in hard formations. This also leads to a tapered bit overall so it matches the shape of the hole and has a greater degree of freedom to move in the hole and better control [70].

The article concluded that this new type of Bit was preferred due to its non-moving parts. It also concluded that the new bit displayed outstanding stability. Nonproductive time (NPT) caused by reaming runs was also reduced, saving cost and time [61].

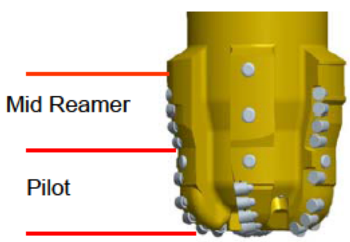

Fig. 12. Bi Center Bit [61]

3) Scanning electron microscopy

A scanning electron microscope is a type of electron microscope that produces images of a sample by scanning the surface with a focused beam of electrons. Scanning Electron Microscopy technology can be used to find different operative wear mechanism of tungsten carbide composites and also to compare them with each other. This comparison can then be used to select the best composite for drilling to optimize wear and drilling costs. This test may also be used for on-site wear testing [71, 72].

4) Mechanical specific energy logs

Identifying when a bit is past its life is complex task. Pulling a bit at the right time can yield significant economic savings [73]. Especially considering costal drilling sites, which are often high cost regions. Identifying when a bit can no longer produce economic savings can be a tricky task. However, the decision-making process on itself can be tremendously inefficient. Certain methodologies that work under specific conditions can enhance the decision-making process to a great extent. Specifically improving the monitoring techniques can optimize this process.

Mechanical Specific Energy is an accepted criterion of bit evaluation during drilling process. In addition to bit wear assessment, it can also be used for cost assessment.

5) Basic principle

Teale was the first person to define the concept of Mechanical Specific Energy (MSE). Teale defined it as the energy required to destroy a unit volume of rock. For the calculation of MSE, he used the following relation:

$$MSE = \frac{W}{A} + 120\pi \frac{N*T}{A*PR}$$

The MSE is graphed against depth while drilling to replace the drill bit in Figure 13

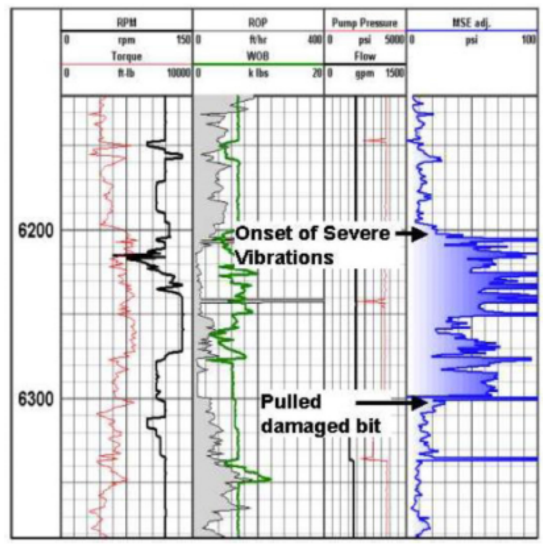

Fig. 13. MSE Against Depth while Drilling to Replace the Drill Bit [73]

6) Calculation of rate of penetration [73]

ROP models are the experimentally and mathematically derived relationships between the drilling operation conditions and the rate of penetration. Borgouyne and Young ROP model (developed in early 1970s) is the most famous one which is the function of some drilling variables and parameters discussed below. This model is mathematically given by:

$$ROP = f_1 \times f_2 \times f_3 \times f_4 \times f_5 \times f_6 \times f_7 \times f_8$$

Where f1 to f8 are the different effects on ROP which are defined as:

$$\text{rock drillability} = f_1 = e^{2.303a_1}$$

$$\text{the depth effect} = f_2 = e^{2.303a_2(10000-D)}$$

$$\text{the effect pore pressure} = f_3 = e^{2.303a_3D^{0.69}(g_p-9)}$$

$$\text{the effect of overbalance} = f_4 = e^{2.303a_4D(g_p-P_c)}$$

$$\text{the effect of weight on bit} = f_5 = \left[\frac{(\frac{w}{d_B}) - (\frac{w}{d_B})_t}{4 - (\frac{w}{d})_t}\right]^{a_5}$$

$$\text{the effect of rotary speed} = f_6 = \left(\frac{N}{60}\right)^{a_6}$$

$$\text{the effect of bit wear} = f_7 = e^{-a_7 \times h}$$

$$\text{the effect of bit hydraulics} = f_8 = \left(\frac{F_j}{1000}\right)^{a_8}$$

The main disadvantage of this technique was that it required measurement of torque which is not always measured.

7) Rabia and Farrelly's method

Rabia and Farrelly based their research on Teale's findings and concluded an empirical formula for calculation of specific energy:

$MSE = 20\frac{W*N}{d*PR}$

However, the problem with this method was that it does not consider the properties of rock being drilled.

8) Solution proposed by Abbas [73]

The previous methods were not suitable (as the measurement of torque was not possible) for use in many producing wells in southern Iraq (Basrah region). Therefore, a new method was described to calculate the torque using available parameter. This enabled the technicians to easily calculate the mechanical specific energy and predict the appropriate time for replacing the worn drilling bits. The following relation was used to calculate torque:

$T = \left(3.79 + 19.17\sqrt{\frac{PR}{N*d}}\right) * d * W * \left(\frac{1}{1+0.00021*L}\right)$

The proposed method was tested on 5 producing wells in Iraq. The results predicted bit wear efficiently.

A defect of this approach was its inability to give accurate results due to vibrations while drilling shale formations. The researchers recommended development of a wear evaluation model which incorporates rock properties such as hardness, Young's modulus and fracture toughness [73].

IV. PROPOSED METHOD

Talking about proposed solution 1st thing is since a bit get stuck in under-gauge hole then the possible solution is reaming the hole. But it cannot be done by running a separate reamer. Various attempts have been made to attach a reamer to bit just above it. But it causes unbalancing because teeth are mounted on one side of reamer for displacing the well cuttings as in case of bi-centre bit. If a new type of bit is designed that contains a reamer with cutting teeth uniformly distributed around periphery of a stabilizer just above bit then the problem of unbalancing can be solved. But the diameter of teeth circle should be decreasing on upward and bottom of stabilizer to cause reaming in both directions while moving it in drilling hole. If such a bit is designed, then under gauge hole can be re drilled by circulating bit in direction opposite to drilling direction when pulling it out of well after getting stuck. But the diameter of this reamer is slightly under gauge ½ to ¼ inch than bit to be used for reaming only when drill bit has worn and it stays stuck in under gauge hole. Our proposed bit design with under-gauge stabilizer for reaming is shown in Figure 14.

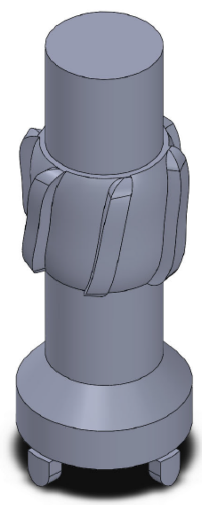

Fig. 14. Proposed Diamond Bit for Reaming Under-gauge Hole

Now if a diamond bit is used then its cutting teeth can be extended slightly backward to ream an under-gauge hole when pulling it out of well by rotating it in direction opposite to that during drilling.

Adding to it the weight of bit designed with reamer attached to it must be as light so that it can be easily pulled off the well by reaming under gauge hole with drill rotating in opposite direction.

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