MAJOR PROJECT REPORT SUBMISSION ON

BHA Design Analysis and Its Failure in Directional Wells.

SUBMITTED BY

Rohit Pal(27) **Tushar Pant(46)** **Pooja Agrawal(21)**

500017144 **500018437** **500016648**

UNDER THE MENTORSHIP OF

Mr. Vamsi Krishna Kudapa

(COES,UPES)

B. Tech Applied Petroleum Engineering with specialization in Upstream

Batch 2011-15

Department of Petroleum Engineering and Earth Sciences

University of Petroleum & Energy Studies, Dehradun

Course Coordinator **Head of the Department**

Dr. Pushpa Sharma **Dr. D. K. Gupta**

Email id: pal.rohit5834@yahoo.in(1),tusharpant8@gmail.com(2)pooja.agrawal1120@gmail.com(3)

PREFACE

The drilling industry is one of the most multi faceted industries and involves multi disciplinary team of not just engineers but also academicians and researchers. In our project also we have incorporated principles of mechanics which are applied to the drilling process and sound practices of engineering which makes the entire process feasible and economical.

Failure in drilling operations is one of the prime concerns. It leads to a loss of time and as it is widely true that money is time. Any kind of failure which leads to the rig downtime and NPT adds the burden to the operator as well as the service side in coping with the time limit to achieve the target depth within the stipulated time and attain the P10 estimate or rather P50 estimate. The early the well is drilled, the more economic it is.

Any cause of failure must be the prime concern and be eliminated as soon as possible. Failure of drillstring is one of the major reasons of downtime. Additional fishing operations carried out to recover the strings not only consumes more time and money but the chance of success also brims. .

A CFD based approach helps us to analyze the effect of the drilling fluid and the internal pressure generated on the face of the shoulder connections as they are the weakest and tend to fail at the earliest. We can analyze the flow of fluid and the dynamic pressure distribution on each and every part of the drillstring with this approach. For the first time, with the CFD approach the engineers are able to visualize the flow behavior of the drilling fluid and count the drilling fluid and pipe body interactions. Right from the turbulent flow regime to laminar, each flow pattern is solved by Navier Stokes equation and the mesh elements are dominated by the control volumes which are spread on the structure body.

Finally the need for SRF has been explained and the importance of these structures in mitigating the stress distribution has been studied. A rather more convenient design and the optimized stress relief features have been proposed for the drillstring which would reduce the chances of failure. The new design has been justified by the recalculated value of Bending Strength ratio.

CERTIFICATE

This is to certify that the project titled **BHA Design Analysis and its Failure in Directional Wells** submitted by **Pooja Agrawal (R870211021)** to the **UNIVERSITY OF PETROLEUM AND ENERGY STUDIES,** for the partial fulfillment of the requirements for the award of the degree of **BACHELOR OF TECHNOLOGY** in APPLIED PETROLEUM ENGINNERING with specialization in UPSTREAM has been successfully completed under my supervision from “September 2014 to May 2015”.

Mr.Vamsi Krishna Kudapa
Professor

Dr. Pushpa Sharma
Course- Coordinator

Dr. D. K. Gupta
HOD
Department of Petroleum and Earth Sciences

Place: DEHRADUN
Date:

CERTIFICATE

This is to certify that the project titled **BHA Design Analysis and its Failure in Directional Wells** submitted by **Rohit Pal (R870211027)** to the **UNIVERSITY OF PETROLEUM AND ENERGY STUDIES,** for the partial fulfillment of the requirements for the award of the degree of **BACHELOR OF TECHNOLOGY** in APPLIED PETROLEUM ENGINNERING with specialization in UPSTREAM has been successfully completed under my supervision from "September 2014 to May 2015".

Mr.Vamsi Krishna Kudapa
Professor

Dr. Pushpa Sharma
Course- Coordinator

Dr. D. K. Gupta
HOD
Department of Petroleum and Earth Sciences

Place: DEHRADUN
Date:

CERTIFICATE

This is to certify that the project titled BHA Design Analysis and its Failure in Directional Wells submitted by Tushar Pant(R870211046) to the UNIVERSITY OF PETROLEUM AND ENERGY STUDIES, for the partial fulfillment of the requirements for the award of the degree of BACHELOR OF TECHNOLOGY in APPLIED PETROLEUM ENGINNERING with specialization in UPSTREAM has been successfully completed under my supervision from “September 2014 to May 2015”.

Mr.Vamsi Krishna Kudapa
Professor

Dr. Pushpa Sharma
Course- Coordinator

Dr. D. K. Gupta
HOD
Department of Petroleum and Earth Sciences

Place: DEHRADUN
Date:

DECLARATION BY AUTHORS

WE, hereby declare that the project entitled **BHA DESIGN ANALYSIS AND ITS FAILURE IN DIRECTIONAL WELLS** is a genuine work carried out by us under the supervision of **MR. VAMSI KRISHNA KUDAPA** for the partial fulfillment of the requirements for the award of the degree of **BACHELOR OF TECHNOLOGY** in **APPLIED PETROLEUM ENGINNERING with specialization in UPSTREAM**. All the interpretations have been made on the basis of the literature survey being conducted and the information taken from the sources have been acknowledged.

We declare that if any part of the report is found to plagiarized, we shall take the full responsibility.

ROHIT PAL
(R870211027)

TUSHAR PANT
(R870211046)

POOJA AGRAWAL
(R870211021)

Place: DEHRADUN
Date:

ABSTRACT

The Bottom hole assembly (BHA) is an integral element of the drilling system. The BHA refers to the Drillcollars, Stabilizers, Heavy weight drill pipes and other accessories which are used to drill a well in a certain location. The vertical as well as the horizontal wells require a specific design criterion in order to achieve the target objectives.

The directional control of the wells depends upon effective positioning of the BHA components in the drill string. The drillcollars add weight to the bit and conditions under which they fail when cyclic stresses are generated within them will be analysed in our project. The failure analysis of the drill string and points where bending stresses are mostly concentrated in the limber parts of the drill string such as the pin joint will be analyzed. The designing of the tool joint and the points where failure occurs majorly either due to fatigue. Finally the criterion used for the drill string designing will be:

COLLAPSE:

Worst case criterion will be used for designing the collapse designing of the Drillpipe. The maximum pressure from the external fluid will be experienced by an evacuated drill string (Complete evacuation). This criterion will also be accounting for the plugged bit or the failure to fill the string when a float is used during the trips into the hole. A design factor of 1.125 will be used.

TENSION:

The maximum tension load will be evaluated by using the maximum load concept. Buoyancy factor arising from the drilling fluid will be included along with the maximum load carried in the topmost section, shock loading, bending forces and slip crushing design will be considered. The margin of overpull will be decided considering the inclination of the well. The ninety percent of min. yield strength will be taken as the margin before deciding for the MOP and tension design factors. The drillpipe maximum stretch due to submergence and torsional design strength will also be considered.

DOGLEG SEVERITY:

Alternating bending stresses because the grains to slide over each other and at higher stress levels cracks may be generated which will lead to the connection of smaller cracks and finally failure due to fatigue in the Drillpipes. The maximum dogleg severity for fatigue damage considerations will also be calculated. The maximum permissible bending stress which is grade dependant is also calculated from the buoyed tensile stress. The above listed criterion are enlisted and studied for the failure considerations of the Drillpipe. The failure criterions as mentioned will be evaluated for the directional wells and the results are generated on an Excel Sheet. The drilling fluid plays an important role in imparting a normal force on the internal profile of the drillstring. This force cannot be calculated by analytical approach. CFD studies have been performed to understand the impact and mechanism of energy transfer between the fluid body surface and the pressure contours and velocity streamlines have been plotted to understand the stress distribution and identify the weaker sections.

Finally the stress relief features have been studied and the changes in its geometry have been proposed with a comprehensive cost estimation studies and field implementation program. Use of rubber as a stress absorbing material in the cylindrical bore has been proposed.

ACKNOWLEDGEMENT

When we look at how long we have travelled from where we started to where we are today, we realize that this journey would not have been possible if it were not for the profound presence and guidance of our mentor, **Mr. Vamsi Krishna Kudapa.** Sir gave us the avenues and opportunities to explore beyond the conventional areas and helped us develop newer insights and closely understand the workings, which made us go beyond the confines of books.

We are also deeply indebted to our Course Coordinator, **Prof Pushpa Sharma** for her constant motivation throughout the course duration of the major project. Ma'am made us keep a check over our project timeline for timely completion and gave us useful inputs for better improvisation. Her help and guidance have enlightened us during the entire project.

We are at a loss of words to express all our thankfulness to **Dr. DK Gupta** for helping us gain the platform and resources that have helped us develop the project. His kind words and compassion have always been an inspiration for us. We would also like to thank **Dr. Kamal Bansal, Dean COES, UPES** for providing us with his opportunity to present our thesis as a partial fulfillment to our graduation degree. Special thanks and sincere acknowledgements to **Dr. Srihari Honwath**, **Vice Chancellor, and UPES Dehradun** for providing us with the much needed industrial collaboration that helped us gain an understanding of the subject.

And this project would never have seen the completion, if our friend **Condra Krishkant**, B. Tech ASE (2011-2015) would not have helped us understand computational modeling and debug it for successful running and simulation of CFD simulation.

And lastly to all those who we are failing to mention here, we are grateful to everybody out there who directly or in any other way possible helped us get here.

AUTHORS

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LIST OF ACRONYMS

- API – American Petroleum Institute
- BHA – Bottom Hole Assembly
- BSR – Bending Strength Ratio
- CFD – Computational Fluid Dynamics
- DLS – Dog Leg Severity
- DST – Drill Stem Test
- HWDP – Heavy Wall Drill Pipe
- MOP – Margin of Overpull
- MWD – Measurement While Drilling
- OIIP – Original Oil In Place
- PDM – Positive Displacement Motor
- ROP – Rate of Penetration
- UTM – Universal Testing Machine
- SRF – Stress Relief Features
- WOB – Weight On Bit

LIST OF FIGURES

1. INTRODUCTION

1.1 Review of literature

The analysis of Drillstring design and BHA components have been thoroughly studies by various authors. Stress analysis with calculations based on HOOPS STRESS formula extended with certain assumption has been carried out by H. Raba in his textbook "Well Engineering and Construction". The failure of Drillstring is encountered in several modes such as vibrations cyclic stresses, corrosion wear, tool joint disengagement, washouts, etc. As the Drillstring is subjected to longer life cycle it is also prone to fail under different conditions of temperature, pressure, depth and inclinations. All these factors are aggravated with unsuitable ROP, Bit rate, flow rate, rake angle, WOB and various other factors.

Simultaneous analysis of all the factors is not an easy task since the parameters increasing the chances of Drillstring failure may keep varying from time to time and with every single depth. The strata drilled also dictate the stress concentration along the Drillstring by providing an equivalent back torque and drag. A drillstring designed particularly for a certain well may fail at some other well due to a phenomenon just as simple as 'Stick and Slip'.

To analyze the stress concentration in the entire drillstring, laboratory testing has been carried out by different companies prior to designing or producing any new BHA component. Fatigue tests on simple instruments such as UTM machine have been carried out for years. However such tests have been only limited to nearly straight wells or wells with minimum dogleg severity. Drillstring fatigue resistance-analysis-for directional wells is carried out by Drillpipe combined loading curves or certain equations. These curves take into account the stress as a function of combined dogleg and tension and shows regions of "No fatigue damage" or "Fatigue damage". These curves also take into account the cyclic stress history which is generally difficult to quantify appropriately.

Current methods which are employed on a large scale to analyze the drillstring fatigue failure risk are based on full scale fatigue test of entire drill string. The general elements of failures can be broadly classified into two separate categories as; Construction factor and Drilling technology factor. Once the tubular goods are manufactured, the fatigue failures are liable to occur at a certain predetermined value dictated by the type of material used. The size of the drillstring component, thickness, etc. can no longer be altered at the rigsite. On the other hand factors such as, Make up Torque, corrosion, trip technique, critical flow rates and abrasive wear can be certainly kept under control during the drilling process. This may vary from location to location and type of equipment used. (Barashnikov, Anatoly, et al. "A New Approach to analysis of drillstring fatigue behavior", SPE Drilling and Completion, June 1997.)

The absence of cyclic loading history eliminates the possibility of using guidelines in prediction of it. The non stationary loading process which is generally subjected on drillstring is assumed to have a continuous and almost equal impact on every component of drillstring working together. Although the laboratory analysis doesn't takes into account but the service life of one component affecting the other component must be taken into consideration as quoted by Anatoly Barashnikov in his paper.

American Petroleum Institute (API) 7 RG "Recommended Practice for Drill Stem Design and Operating Limits" suggests equations for carrying out the tension load calculation, collapse load calculation and torsional yield strength of Drillpipe.

Use of connection SRF has been discussed in the API Spec 7 as being optional. It is described as "The surfaces of stress relief features shall be free of stress risers such as tool marks and steel stencil impressions. Laboratory fatigue tests and tests under actual service conditions have demonstrated the beneficial effects of stress relief contours at the pin shoulder and at the base of the box thread. It is recommended that, where fatigue failures at points of high stress are a problem, stress relief features be provided. The boreback design is the recommended relief feature for box connections. However, the box relief groove design has been shown to also provide beneficial effects. It may be used as an alternate to the boreback design." (API Spec 7, 1994).

The stress relief features have been researched upon and boreback structure has been suggested by various authors. Boreback structures are described as being more necessary for the thicker sections such as Heavy weight drillpipe (HWDP) and Drillcollars which do not bend easily and hence the stresses tend to remain concentrated at the connections. In boreback box, generally metal is removed only from those threads which are unengaged by machining a cylindrical bore back in the box. Some portions of engaged threads may also be removed to accomplish a larger suface area for reducing stress concentration. This makes the area next to connection more limber and the stress is not concentrated at the connections since less bending is transferred to the jonts. As a result of it, the connections of Drillcollars and Heavy weight drillpipe have a longer fatigue life.

1.2 Background

Drillstring designing has been concerned with four main design criterions;

1) Tension design
2) Collapse design
3) Cyclic Stresses
4) Dogleg severity

Of these generally, cyclic stress history of the well is not present while designing the drill string as a part of well planning. Stress relief features in drillstrings have been proposed quite some time ago, but their wide scale application is yet to be seen. More efficient stress relief features with the use of composite materials are yet to be designed and made commercially viable. The stresses acting on the drillstring due to the internal flow of fluids which causes a normal pressure on the walls of the Drillpipe and drill collars have not been studies in detail yet. By the unified approach of Computational Fluid Dynamic (CFD) analysis, however these behaviors and their effects on drillstring have been studied in this project. The model in which the pressure acting on the walls and affecting the tool joints have also been studied. Washouts, twist offs, etc. are the modes of failures commonly exhibited and flow factors contributing to them are a major factor contributing to the downtime of the rigs.

As more wells are being drilled deviated and much away from vertical, the chances of failures occurring in the drillstring has also been increased. In the past few decades however improvement in the field of material science and the ability to incorporate the intricacies of residual stresses has lead to a decrease in the no. of failure occurring due to in-situ stress generation. There has been a shift also from the use of drill collars to more no. of HWDPs being used these days as the no. of directional wells have been increasing. By this project we aim to study the stress behavior of the drillstring by the conventional method and also analyze the fluid behavior on the internal structure and the type of failures it causes. An analysis has been carried out ton the success of SRFs and how much of the problems can be addressed by them. Certain new features have been also suggested in the SRFs and the calculations of the BSRs have been found to be in line with the expected results thus indicating a higher efficiency in the new design proposed.

1.3 Statement of Purpose

We want to analyze the stress distribution in the drillstring and identify the weaker sections which are more prone to fatigue failure. Further CFD analysis have been carried out to define the pressure contours and streamline maps within the drillstring and analyze the effect of fluid flow through it. Stress Relief Features and their efficiency in mitigating stress concentration at the failure points have also been studied and some improvements in it will also be suggested.

1.4 Objectives

The objectives of our project are:

- Calculation of adjusted length and combined weight of Drillpipe and tool joint for BHA used in MANGALA EAST 2B well.
- Calculation of bending strength ratio for HWDP and DC.
- Calculation of collapse strength and design factor of Drillpipe.
- Determination of maximum tensile stress, margin of overpull, shock loading and bending forces acting on the drillstring.
- Calculation of bending stresses and moment of inertia for the Drillpipe.
- Determination of maximum permissible dogleg severity within the elastic limits.
- Modelling of pipe design in the CATIA software.
- Differential meshing of the drillstring model and discretization of individual meshes.
- Simulation of drilling fluid flow through the entire pipe structure.
- Determination of pressure contours on the internal wall structure of the drillstring.
- Determination of streamline velocities entering and exiting the pipe.
- Identification of parts where SRFs be incorporated.
- Design and integration of rubber element in SRFs and its ability in enhancing BSR.
- Cost analysis of proposed design for integration in drillstring.

2. DRILLSTRING DESIGN

2.1. Basic design features

The design of any tool/component takes into considerations a number of factors like operating depth, stress conditions, temperature, pressure, its compatibility with the parent machine of which it will form a part of , economics of that particular design etc. Taking the case of oil field where drilling is being carried out, the hole being dug is continuously progressed further towards its target zone by applying stress greater than that of the sub-surface formation but as we go deep into the formation the amount of stress to be applied also increases and thus, the properties of the hardware providing has to be such that they don't get break down under high stress conditions.

The stability as what one defines is the state of complete equilibrium and this is what one requires to achieve. First, of all it is necessary to attain wellbore stability; most wellbore are designed in circular form/ shape the reason being that it minimizes the amount of stress and reduces the chances of collapse. Now, talking about the design of the hardware such as drillstring, its components are circular designed to reduce the stress. Such designs also aims to reduce the effect of induced and hoop stresses plus additional design (stress relief) features are included in their body which helps to enhance their efficiency and to increase their fatigue life.

2.2. Components of BHA

BHA (Bottom Hole Assembly) is a part of the drillstring that comprises of standard and non- standard equipments. The standard BHA configuration comprises of Drill collars and stabilizers which are the main direction control equipments:-

- DRILL COLLARS: These are heavy, thick-walled steel tubes which provide weight on the bit to achieve penetration and works under compression. They also help to keep the Drillpipe in tension. A number of drill collars may be used between the bit and the Drillpipe.

  Different profiles of drill collars are as follows:-

  1. Slick Drill Collars: They have the same nominal outside diameter over the entire/ total length of the joint. They usually have the following profiles:-

1.) A slip recess for safety, and

2.) An elevator recess for lifting

2. Spiral Drill Collars: These are used to reduce the problem of differential sticking by reducing the contact area by as much as 50% and reduce the weight of the collar by only 4-5%.

3. Square Drill Collars: These are rigid and are primarily used in special drilling situations to reduce deviation in crooked hole formations.

Figure 1

- STABILISERS: These are the tools which are use to control hole deviation, differential sticking and dogleg severity by centralising and providing extra stiffness to the BHA. They also help to provide improved bit performance and are placed just above the bit and along the Bottom Hole Assembly (BHA).

These are of two types:-

2. Rotating: These include integral blade stabilizer, sleeve stabilizer and welded blade stabilizer. Integral blade stabilizers are machined from a solid piece of high strength steel alloy having blades either straight or spiral. The blade faces are dressed with sintered tungsten carbide inserts.

1. Non-rotating stabilizers: It comprises of a rubber sleeve and a mandrel. With sleeve designed to remain stationary while the mandrel and the drillstring are rotating. This type is used to prevent reaming of the whole walls during drilling operation and to protect the drill collars from wall contact wear.

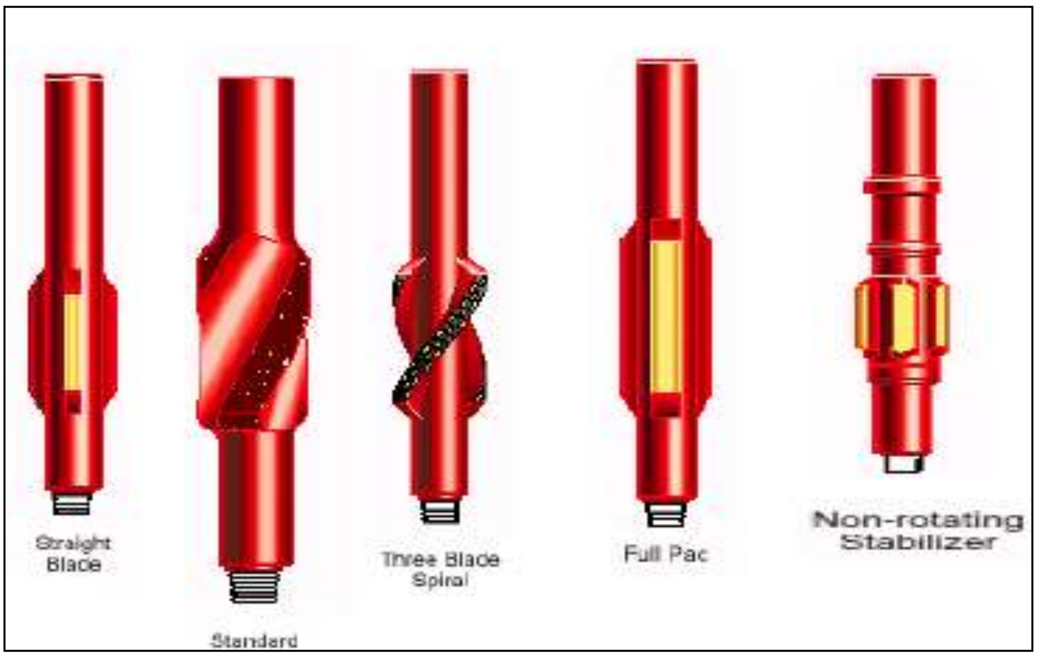


Figure2

- HEAVY WALL DRILL PIPE (HWDP): It has the same outside diameter (OD) as that of a Drillpipe with much reduced inner diameter (ID) which is usually around 3 inches and is used between drill pipe and drill collar to provide a smooth transition between the section moduli of drillstring components and has an extra tool joint. The HWDP is used to provide part or all the weight on the bit while drilling.

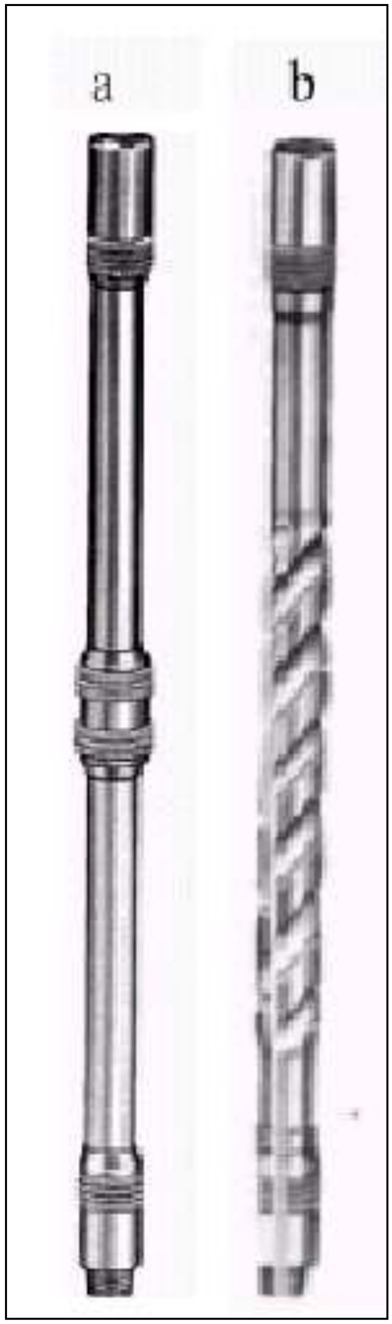


Figure 3

Non-standard BHA equipments:-

- ROLLER REAMERS: These are used to replace near bit and string stabilisers where high torque and swelling or abrasive formations are encountered. They either have 3 or 6 cutter sets. Sealed bearing roller reamers should always be used in preference to non-sealed bearing reamers as it ensures the risk of dropping a cutter block set from the reamer is minimized.

Figure 4

- DRILLING JARS: A jar is basically a mandrel which slides within the sleeve and is used for providing upward or downward blows to the stuck pipe. Depending upon the tripping mechanism there are two types of jars – Mechanical and Hydraulic jars. Different types of jars are as follows:-

  1. Mechanical jars have a preset load being set at the surface that causes the jar to trip; hammer striking the anvil. They are thus sensitive to load being used and not to time.

  2. Hydraulic jars use a hydraulic fluid to control the firing action until the driller can apply the appropriate load to the string to give a high impact. This controlled action (delay) is provided by

Hydraulic fluid which is forced through a small port or series of jets. Hydraulic jar firing delay is dependent upon the combination of load and time.

3. Oil Jars are used for proving upward blows to release a stuck pipe.

4. Accelerators are used to increase impact efficiency of oil jars by storing energy above the drill collars.

5. Bumper jars allow downward blows to be transmitted to the fish. And for releasing overshots downhole and at surface. They also help in providing free travel to assist in engaging the fish.

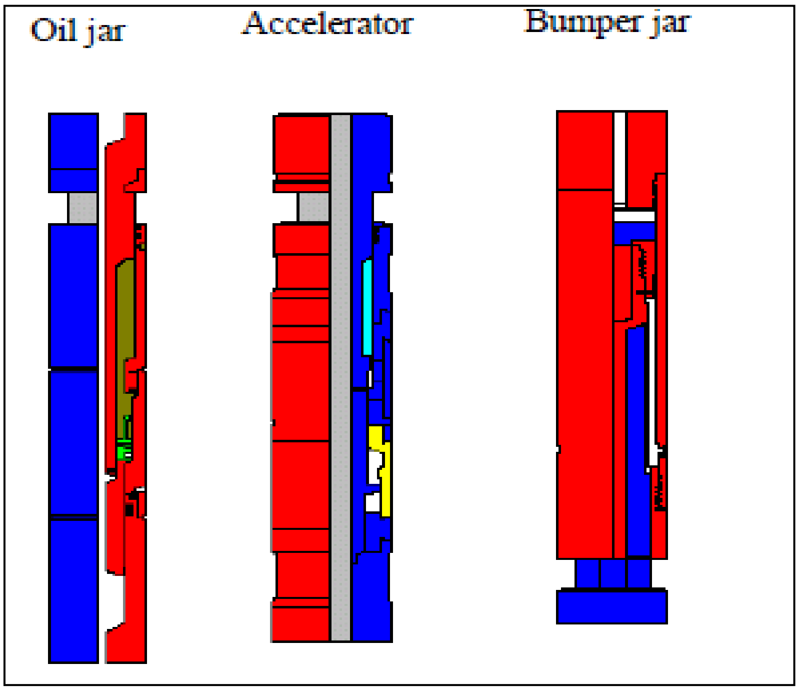


Figure 5

- SHOCK SUBS: It consists of three parts: a grooved female housing, a matching splined male housing and a set of entrapped spring elements. The spring and spline mechanisms are lubricated in hydraulic oil which is retained by seals between the housing and the mandrel. Shock subs helps to reduce fluctuations in WOB and vibrations in the downhole assembly by rapidly stroking up and down around the median point and thus, enhance bit performance and bit life with reductions in fatigue wear of the string.

- MWD (Measurement While Drilling) TOOL – It is a tool equipped with sensors, power tools and transmitters installed as a part of BHA used for measuring the azimuth and inclination in real time, drilling parameters (WOB, torque etc.). it is an highly equipped tool used to determine the closure and

  Vertical section of the trajectory to give an efficient and smooth direction to the well staying within the target location.
- CROSSOVER – A sub which is used to connect drill string components of different types or sizes of threads.
- POSITIVE DISPLACEMENT MOTOR (PDM) – A near bit tool which is used to rotate the bit without having to turn the entire drillstring. A spiral rotor is forced to rotate within a rubber sleeved stator by pumping mud through the tool.

2.3. Drillstring design criterion

The design of drillstring takes into consideration the variety of stresses acting on its different components which further gets aggravated due to well inclination, its crookedness, subsurface environment, formation characteristics etc. The design considerations include collapse, tension and DLS (Dog Leg Severity). Brief discussions of these parameters are as follows:-

- COLLAPSE DESIGN: DST serves as the worst case for the collapse design of the Drillpipe. The maximum collapse pressure should be determined for an evacuated string, with mud hydrostatic pressure acting on the outside of the drill pipe. This criterion helps in the selection of the drill pipes and their grades and also accounts for the incidence of plugged bit or failure to fill the string the sting when a float is used during the trips into the hole. A design factor of 1.125 is generally used.

- TENSION DESIGN: it is calculated using the maximum load concept with buoyancy included to represent realistic drilling conditions. The tension design includes the following:-
  1. Tensile forces which include weight carried, shock loading and bending forces.
  2. Design Factor (1.6, if shock loading is not include and 1.3if shock loading is included)
  3. Slip crushing design: the maximum allowable tension load should be designed to prevent slip crushing of the pipe.

Once all the tensile loads have been calculated decision for selecting the grade of the pipe and couplings are done. Torque and drag modeling has to be done to evaluate the tension strength requirements of the pipe and couplings in case of highly deviated extended reach wells or horizontal wells.

- DOG LEG SEVERITY (DLS): It is defined as a measure of the amount of change in the inclination and /or the direction of a borehole. It is expressed in degrees per 100 ft of course length. Fatigue as we define is the tendency of the material to fracture under repeated cyclic (reversal) and chemical attack. The bending of a pipe in a dog leg induces compression in the inner wall of the pipe and tension on the outer side of the pipe as a result of theses stresses the total stress (weight carried + induced stress) on the outer wall to be significantly greater than the stress on the inner wall of the pipe.

2.4. Mode of failure in Drillpipes

The stress generation in Drillpipe causes failure during its running action. This generally happens when the yield point of pipe of a particular grade is exceeded. The different types of failure in Drillpipe are as follows:-

- TRUE TWISTOFFS – this type of failure in Drillpipe is a result of pure torsion and in early days of rotary drilling, when fishtail type bits were being used and pipes were made of softer steel got twisted and broken as a result of bit being caught up in the formation while rotary table was still moving.
- SPIRAL TEARS – a type of torsional failure that occurs when the bit gets hung up and rotary table continues to turn. The possibility of such type of failure arises when the pipes were rather closely confined inside of casing and if there had already been a transverse crack that could have possibly aggravated the stress affect resulting in crack or scar tears into a very uniform spiral which is always right handed.

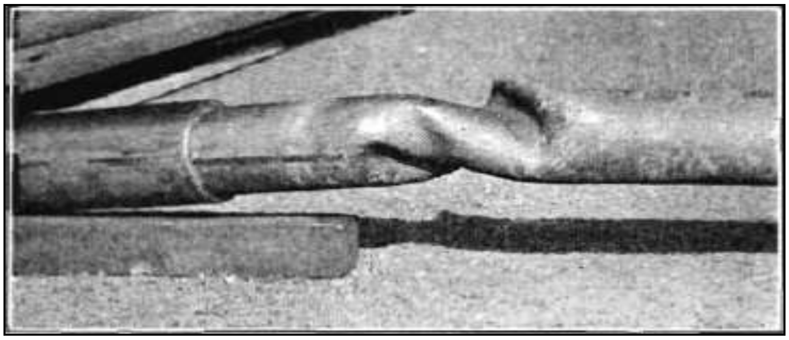


Figure 6

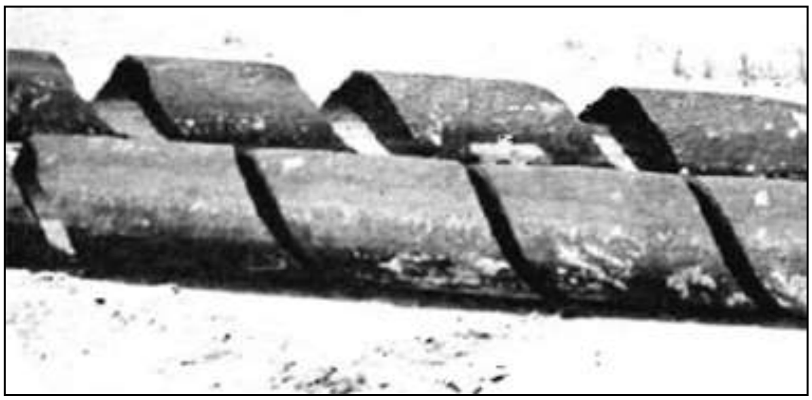


Figure 7

- TENSION FAILURES – The failure that arises when steps taken to pull out a stuck pipe results in pipe thinning/ neckening at the weakest point resulting in tensile failure. The contributing factors are low pipe tensile strengths, absence or malfunctioning of the weight indicators such that one may ignore or possible cannot figure out the Margin of Overpull (MOP).

Figure 8

- LAST- ENGAGED THREAD FAILURES – connections being made in the Drillpipe by applying sufficient torque to prevent against any leakage or, unscrewing gets subjected to bending or vibration stresses that results in fractures through the upsets. These fractures develop as a result of transverse cracks at the bottom of last engaged threads of a pipe that occur as result of stress concentration due partly to compressive effect and partly to the resistance to bending imposed by relatively heavy mass of tool joint holding the pipe. The rapidity or the rate at which the last engaged threads develop cracks is determined by the frequency of stress reversals which in turn is partly a function of speed of rotation. This type of failure is affected mostly by the vibration.

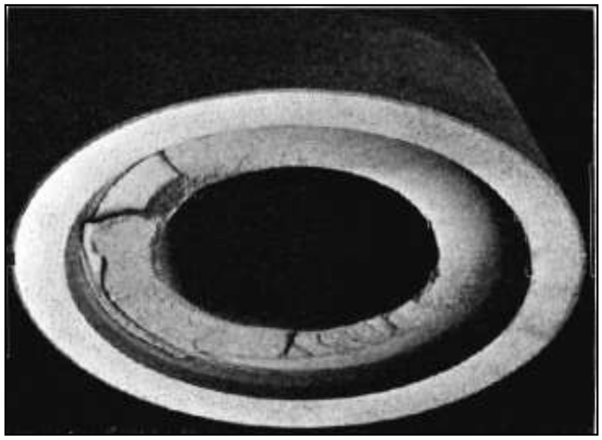


Figure 9

- LEAKAGE THOUGH THREADS – This type of failure occurs in tool joint when an improper make up torque is applied to the Drillpipe while making connections thus not ensuring proper seal plus damage to the pipe threads due to improper handling is also a contributing factor.
- FATIGUE BREAKS – it is one of the most common types of Drillpipe failure and its filed classification is difficult. When the failure is incomplete i.e. when fatigue crack does not travel on around to complete the failure, it is called 'washout' and when it's complete failure, a square break then it is called a "twist off". Fatigue breaks can be subdivided into three classes:-

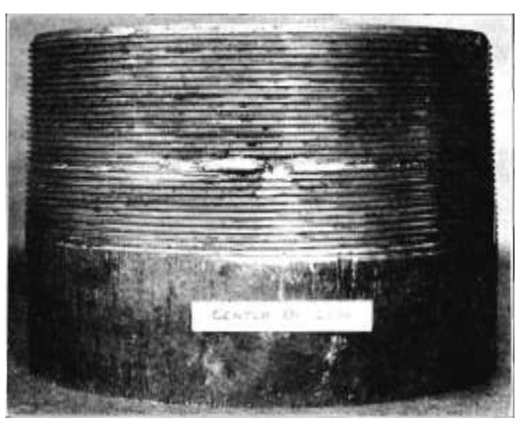


Figure 10

- Pure Fatigue: a case of failure by fatigue fracture whenever the steel is subjected to cyclic stress of sufficient magnitude- whether in tension, compression, torsion or bending.

- Notch Fatigue: Failures accelerated by corrosion, specifically, when the notches are deep enough to allow corrosion to progress, undisturbed by wear.

- Corrosion Fatigue: It may be considered as a notch fatigue in which formation of stress concentration point has been brought on by a corrosion pit and the fatigue progress is accelerated by corrosion.

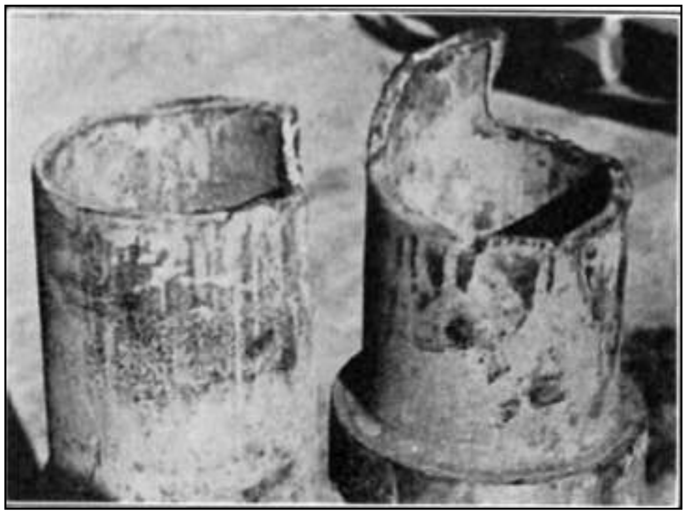


Figure 11

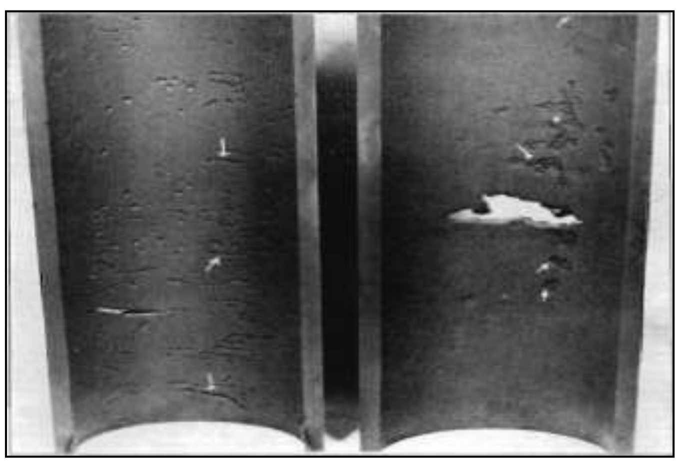


Figure 12

- WORN PIPE – a typical obvious concept that worn out things are a potential source for failure. Similarly, for drillpipes having worn out tool joints with thin shoulders, damaged threads; excessive wear on the outer surface, impact of corrosion etc. are removed from the service and separated out.

- CROOKED PIPES – this condition arises due to improper placing and handling of drillpipes during transportation in railroad cars, in unloading, in trucking, and even while pulling into the derrick or laying down for racking. There are many other instances of drillpipe crookedness instances like in by being made up with grief stems, drill collars, subs or tool joints in which the taper joints are out of alignment; in service at the bottom of the string when insufficient drill collars have been used and where drillcollar is run compression etc.
- COLLAPSED DRILL PIPE – this failure arises during conditions like in Drillstem tests where drill pipe is run empty and setting at the formation to be tested before the valve at the bottom is opened subjecting it to the full hydrostatic pressure of the drilling fluid; from accidentally running the pipe empty; case of tong or slip-crushed pipe.
- INTERNAL EROSION – this idea though stated merely happens as drilling properties are so optimized to cause minimum damage and plus the velocity of drilling fluid is less to do any cutting, even in the restricted area under the tool joints, or upsets (in case of internal – upset drill pipe). This idea could however be related to 'wash-outs' but only to a certain extent.

3. BHA DESIGN FOR DIRECTIONAL WELLS

3.1 MANGALA Overview

The Mangala field is located in the Barmer basin on the western part of the Indian Subcontinent in the state of Rajasthan. The field RJ-ON-09-1 which covers an area of 3111km^2 was auctioned by Govt. of India in the year 1992 under a Production Sharing Contract. The bid was won by Royal Dutch Shell. However failing to get commercial quantities of oil, they sold the first 27% contract to Cairn Energy in the year 2002 to recover the drilling cost. By the year 2002 Cairn Energy acquired the lease from Shell for a cost of 7.25 million USD.

In the year 2004 Mangala field was discovered with 3.7 billion barrels of oil equivalent making it the largest onshore discovery of India in a decade.

A gross oil column was encountered of around 150m in the Fatehgarh group of sandstones of late Paleocene age. The fatehgarh group consists of interbedded sands and shales and is divided into:

1. Lower fatehgarh- dominated by well-connected sheetfloods and braided channel sands.
2. Upper Fatehgarh- dominated by sinuous, meandering, fluvial channel sands.

Mature sands of quartz grains with no diagenitic alteration and high porosities with excellent permeabilities. Average porosity ranges from 33% to 17% whereas average permeabilities of 200mD to almost 5 Darcies.

The barmer hill formation which is of higher gravity anomaly is located in the upper succession which acts as a cap rock in most of the segments. At places where it is fractured, commercial quantities of gas have also been recovered from Barmer Hill formation. The shallow aquifers are present which a source of water used for injection purposes is. Thumbli aquifer is one such formation which was discovered by conventional logging techniques and its water had been used for injection purposes.

Out of the 3.6 billion barrels (570,000,000 m^3) of OIIP, the recovery factor is around 30% only, hence making the recoverable reserves of approximately 1 billion barrels (160,000,000 m^3). The recovery factor is owed to the properties of the oil rather than with the geological settings of the reservoir which generally tends to lower or offset the recovery factors. The API gravity of oil has been tested to be in between 25˚ and 30˚, which makes it somewhat heavier than Brent Crude which has an API gravity of 38˚API. The more dominant than this is the bottom-line factor i.e. the oil is very waxy. This waxy nature can cause it to be completely solidify at room temperature (20 °C, although the daytime temperature of the Mangala field is found to be much higher than that). Brent crude generally has a pour point of around 3 °C while the oil produced by the Mangala Field has a pour point of 42 °C.

The Mangala east 2-B was an exploratory well which was drilled to the target of Fatehgarh top formation.

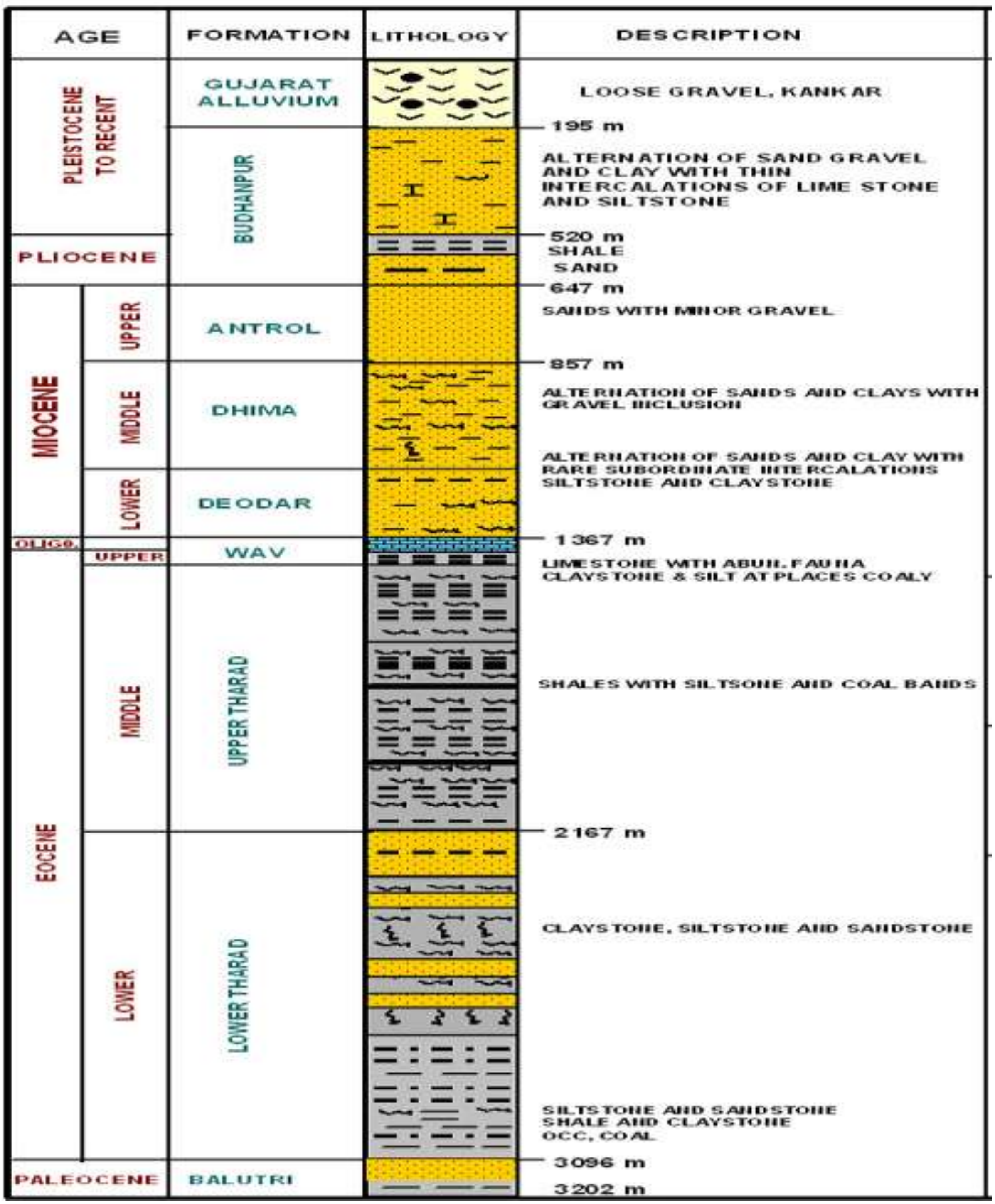


Figure 14

3.2 Directional wells in MANGALA FIELD

Most of the wells drilled in the Mangala field are directional with a high inclination. Average depth of the wells targeting the top Fatehgarh formation is around 2000m and those targeting the bottom Fatehgarh are another 500m to 1000m deep. The 12.25 section is generally drilled with a mud motor due to poor consolidation of the upper sands which doesn't provide an effective stratum for the use of Rotary Steerable System (RSS). The economic feasibility is another factor which restricts the use of RSS system. Some issues have been observed in the past with the directional control and precision of the RSS tools hence mud motors have been preferred in this section.

The 8.5" section is drilled by RSS tool due to stability of formation and higher degree of consolidation.

Anti-collision issues are averted by the use of MWD tools and trajectory control. The vertical section and closures are pre calculated and projected trajectory is controlled by inclination control provided by mud motors.

Pendulum assembly with a near bit stabilizer is used for directional control of the drillstring.

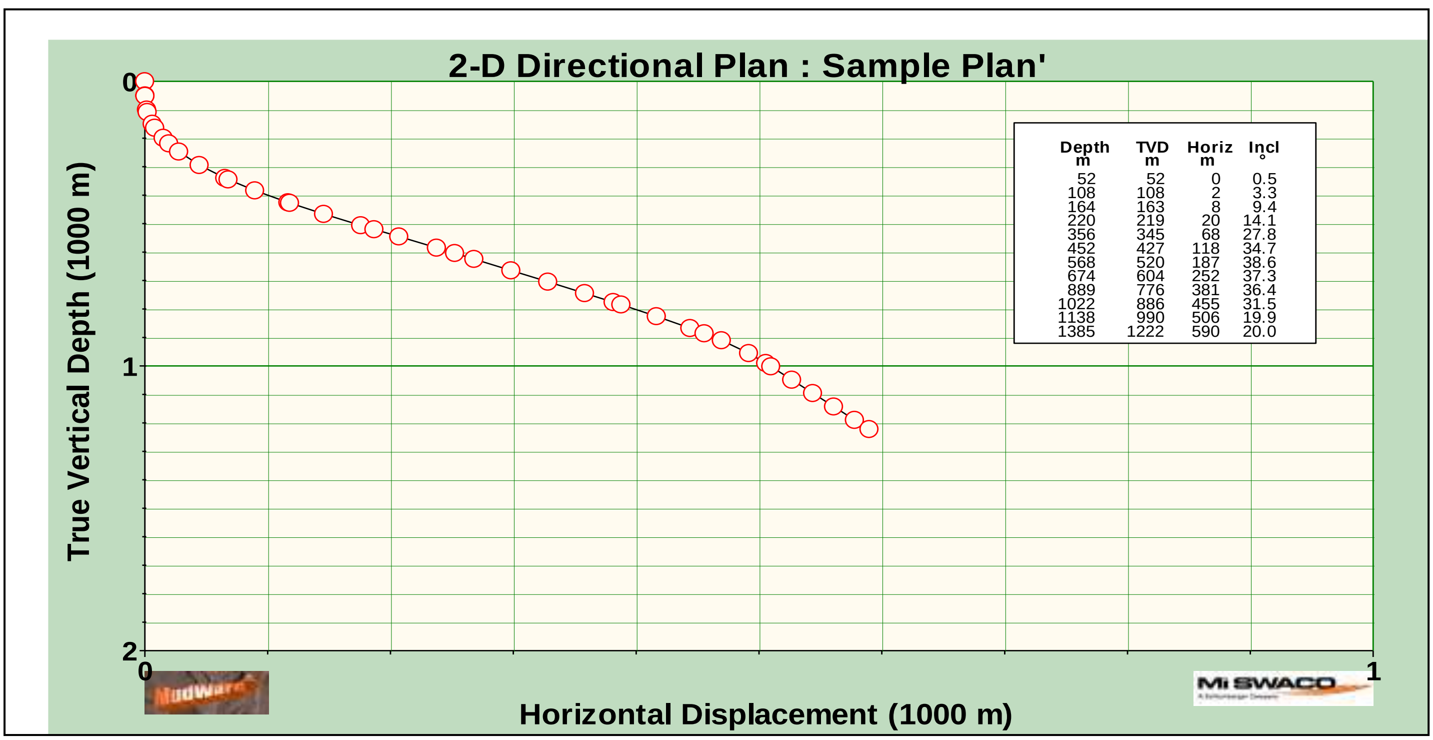


Figure 15

The survey data for the well is as follows:

Directional Survey Data				
MD (m)	TVD (m)	Deviation (deg)	Azimuth (deg)	Dogleg Sev. (deg/30m)
0.0	0.00	0.00	291.00	0.000
6.0	6.00	0.00	291.00	0.000
38.8	38.76	0.33	302.72	0.302
52.5	52.50	0.45	301.96	0.262
70.8	70.78	1.21	288.12	1.281
89.8	89.74	2.09	282.31	1.415
108.4	108.37	3.27	285.46	1.912
126.5	126.41	4.69	286.63	2.359
145.0	144.81	6.86	288.43	3.532
163.6	163.29	9.42	287.32	4.121
181.6	180.99	11.63	290.54	3.810
201.1	200.00	13.29	292.04	2.606
220.5	218.81	14.06	292.48	1.204
239.6	237.32	15.55	293.15	2.349
259.3	256.21	17.32	292.84	2.700
278.7	274.60	19.88	291.97	3.980
298.0	292.64	21.79	291.54	2.978
317.2	310.33	23.55	291.06	2.769
336.5	327.90	25.53	290.36	3.107
355.9	345.25	27.76	289.59	3.488
376.0	362.77	30.16	290.11	3.614
394.7	378.87	31.57	290.38	2.266
413.9	395.14	32.23	290.31	1.035
433.0	411.21	33.63	290.01	2.209
452.5	427.33	34.68	290.58	1.690
471.7	442.96	36.41	292.01	2.996
491.1	458.45	37.86	292.95	2.404
510.3	473.64	37.32	292.90	-0.846
529.6	489.07	36.11	292.63	-1.902
549.2	504.78	37.63	291.62	2.501
567.8	519.40	38.60	290.85	1.744
586.2	533.77	38.60	290.49	0.366
605.9	549.26	38.11	290.30	-0.766
624.9	564.12	38.50	290.14	0.637
637.8	574.27	37.86	290.06	-1.492
674.8	603.57	37.34	289.36	-0.546
695.1	619.77	37.38	288.90	0.415
714.3	634.98	37.38	289.23	0.314
733.6	650.36	37.40	290.39	1.092
752.9	665.66	37.38	291.45	-1.003
772.0	680.86	37.48	291.46	0.157
791.6	696.36	37.44	291.16	-0.287
810.8	711.59	37.51	291.11	0.119
830.3	727.12	37.13	292.05	-1.052
849.3	742.40	36.38	292.96	-1.458
868.8	758.04	36.38	293.94	0.897
888.1	773.60	36.43	294.59	0.604
907.4	789.13	36.12	293.16	-1.403
926.6	804.68	35.94	291.38	-1.656
945.5	820.05	35.63	289.82	-1.526
965.1	836.01	35.29	288.64	-1.170
984.1	851.57	34.23	288.81	-1.686

Directional Survey Data				
MD (m)	TVD (m)	Deviation (deg)	Azimuth (deg)	Dogleg Sev. (deg/30m)
1003.2	867.51	33.07	289.62	-1.948
1022.4	883.74	31.52	290.63	-2.563
1042.0	900.56	29.91	291.23	-2.514
1060.9	917.12	27.98	291.86	-3.098
1081.3	935.34	25.64	292.27	-3.448
1100.5	952.79	23.09	291.73	-4.008
1119.7	970.59	21.41	291.51	-2.624
1138.9	988.51	19.86	291.31	-2.431
1158.3	1006.74	19.97	290.26	0.579
1177.6	1024.89	19.78	289.85	-0.366
1196.6	1042.80	19.95	289.69	0.281
1216.3	1061.27	19.82	289.49	-0.224
1235.4	1079.25	19.93	290.66	0.648
1254.8	1097.50	20.23	292.43	1.046
1274.1	1115.57	20.33	292.02	0.271
1293.2	1133.55	20.29	290.93	-0.595
1312.2	1151.34	20.32	289.77	0.638
1331.6	1169.56	20.39	289.66	0.123
1350.9	1187.60	20.35	289.94	-0.164
1362.1	1198.15	20.29	290.29	-0.361
1382.0	1216.80	20.00	292.00	-0.991

Formation Data		
MD (m)	Frac. (lb/gal)	Pore (lbm/gal)
658.5	14.77	9.33
1382.0	15.09	8.97

Geothermal Temperature Profile			
MD (m)	TVD (m)	Temperature (degC)	Gradient (degC/km)
0.0	0.0	27	0.0
658.5	590.7	50	3.9
808.0	709.4	58	4.4

3. 3 BHA description of MANGALA EAST 2B

The BHA description of the drillstring used for the 8.5" section is described below:

ELEMENT	LENGTH m	ID in	OD in	CUMULATIVE LENGTH m	PRESS.DROP Psi
8 1/2 " Bit (nozzles)	0.00	2.25	5.75	0.00	709.8
8 1/2 " Bit (shank)	0.30	2.25	5.75	0.30	1.4
PD 675 X5 AB 8 1/2" Stabilized CC (Flow Restrictor)	0.00	4.20	6.75	0.30	0.6
PD 675 X5 AB 8 1/2" Stabilized CC (Tool Body)	4.11	4.20	6.75	4.41	54.0
PD Receiver	1.74	2.88	6.75	6.15	2.5
PD675 Flex Joint	3.20	4.00	5.82	9.35	0.9
Lower Saver Sub	0.37	3.88	6.88	9.72	0.1
ARC-6	5.49	2.81	6.75	15.21	25.0
Saver Sub	0.37	3.88	6.93	15.58	0.1
Telescope MWD	7.53	5.11	6.75	23.10	189.1
Saver Sub	0.56	3.88	6.88	23.66	0.2
ADN-6 w/ 8 1/4" Stabilizer	5.70	2.25	6.75	29.36	30.1
Saver Sub/X-over	0.56	3.88	6.88	29.92	0.2
X-over	0.56	3.88	6.88	30.48	0.2
4 X 6.5" Collar	37.00	2.81	6.50	67.48	59.8
X-Over	0.56	3.88	6.88	68.04	0.2
7 x 5" HWDP	66.50	3.00	5.00	134.54	78.3
Jar	9.81	2.81	6.50	144.35	15.9
8 x 5" HWDP	76.00	3.00	5.00	220.35	89.5
5" 19.50 DPG, 10% Wear	1250.65	4.28	4.93	1471.00	321.2

3. 4 Borehole description and Casing Plan

12 ¼" section

The conductor casing is grouted at 30m form the surface. It is a K 55 grade, 54.5ppf, 13 3/8" casing. The 12.25" section is drilled by a PDC fixed cutter type drillbit of the same size. The 9 5/8" casing shoe is placed at a depth of 658.5m. It is an L-80 grade, 40ppf casing. The top of the cement is located at 358.5m.

8 ½" section

This section is drilled by a PDC bit of 8 ½" size. The production casing is of 7" and the shoe is located at a depth of 1376.6m. It is a 32ppf, P110 grade casing. There after an openhole section of 8.7" follows with an excess of 75%. The open hole section follows to a depth of 1471m.

The schematic of wellbore is generated by 'E-Redbook™' by Halliburton.

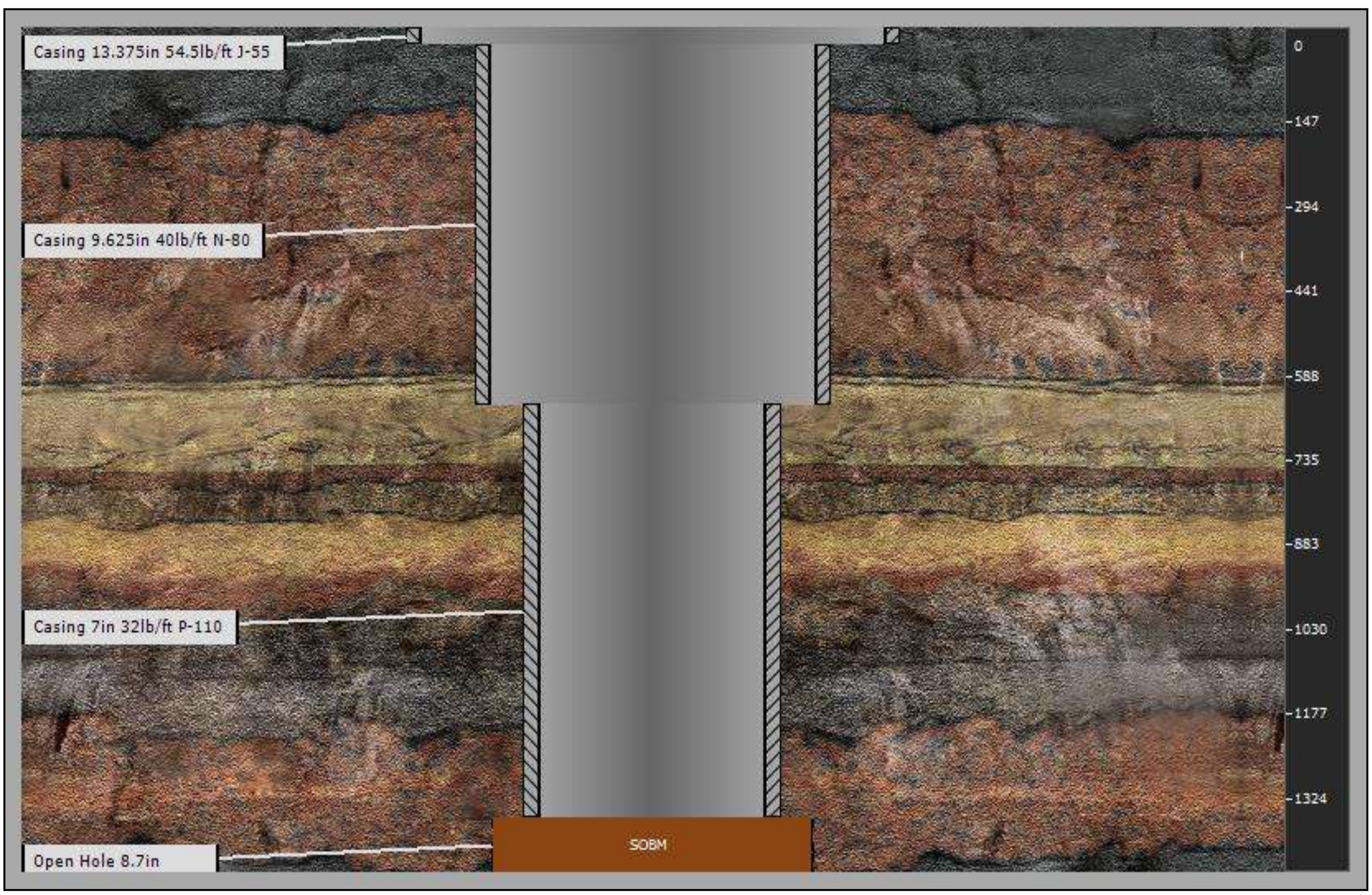


Figure 16

3. 5 Mud Report & Hydraulics

The properties of mud used for drilling the 8 ½" section is as follows:

MUD PROPERTIES	
Type:	Synthetic oil based mud(SOBM)
Mud Wt:	10.00ppg
API PV:	19.0 cP
API YP:	16.0 lbf/100ft2
Model:	Yield Power Law
H-B K:	93.4 eq. cP
H-B n:	0.794
H-B YS:	9.7 lbf/100ft2
P-T:	Off
Fann 3:	9.8 lbf/100ft2
Fann 6:	10.3 lbf/100ft2
Fann 100:	19.9 lbf/100ft2
Fann 200:	27.9 lbf/100ft2
Fann 300:	35.0 lbf/100ft2
Fann 600:	54.0 lbf/100ft2

The cuttings generated at the borehole exhibited properties in the table below.

CUTTINGS	
Cuttings Diameter:	**0.07 in**
Cuttings Density:	**2.60 g/cm3**
Cuttings Concentration:	**1.48 % by vol**
Cuttings Weight:	**37 psi**
Bit ECD Increase:	**0.17 lbm/gal**

Hole cleaning factors are as follows:

HOLE CLEANING	
Critical Rate:	**450.7 gal/min**
Annular Flow:	**550.0 gal/min**
Critical MD:	**665.0 m**
Hole Inclination:	**36.7 deg**
Riser Boost Flow:	**0.00 gal/min**

The hydraulics program for the well is given below.

BHA ELEMENTS	ANNULUS OD in	STRING OD in	LENGTH m	CUM. LENGTH m	FLOW REGIME	REYNOLDS NUMBER	PRESS. DROP Psi
8 1/2 " Bit	8.50	5.75	0.30	0.30	Laminar	1808.0	0
PD 675 X5 AB 8 1/2" Stabilized CC	8.50	6.75	4.11	4.41	Laminar	2586.2	1
PD Receiver	8.50	6.75	1.74	6.15	Laminar	2586.2	1
PD675 Flex Joint	8.50	5.82	3.20	9.35	Laminar	1913.8	0
Lower Saver Sub	8.50	6.88	0.37	9.72	Transition	2714.3	0
ARC-6	8.50	6.75	5.49	15.21	Laminar	2586.2	2
Saver Sub	8.50	6.93	0.37	15.58	Transition	2774.7	0
Telescope MWD	8.50	6.75	7.53	23.10	Laminar	2586.2	2
Saver Sub	8.50	6.88	0.56	23.66	Transition	2714.3	0
ADN-6 w/ 8 1/4" Stabilizer	8.50	6.75	5.70	29.36	Laminar	2586.2	2
Saver Sub/X-over	8.50	6.88	0.56	29.92	Transition	2714.3	0

X-over	**8.50**	**6.88**	**0.56**	**30.48**	**Transitio n**	**2714.3**	**0**
4 X 6.5" Collar	**8.50**	**6.50**	**37.00**	**67.48**	**Laminar**	**2363.0**	**8**
X-Over	**8.50**	**6.88**	**0.56**	**68.04**	**Transitio n**	**2714.3**	**0**
7 x 5" HWDP	**8.50**	**5.00**	**66.50**	**134.54**	**Laminar**	**1569.7**	**6**
Jar	**8.50**	**6.50**	**9.81**	**144.35**	**Laminar**	**2363.0**	**2**
8 x 5" HWDP	**8.50**	**5.00**	**76.00**	**220.35**	**Laminar**	**1569.7**	**7**
5" 19.50 DPG, 10% Wear	**8.50**	**4.93**	**585.65**	**806.00**	**Laminar**	**1546.2**	**56**
5" 19.50 DPG, 10% Wear	**8.84**	**4.93**	**665.00**	**1471.00**	**Laminar**	**1335.8**	**50**

The plot of standpipe pressure and it's variation with depth at different flow rates is plotted.

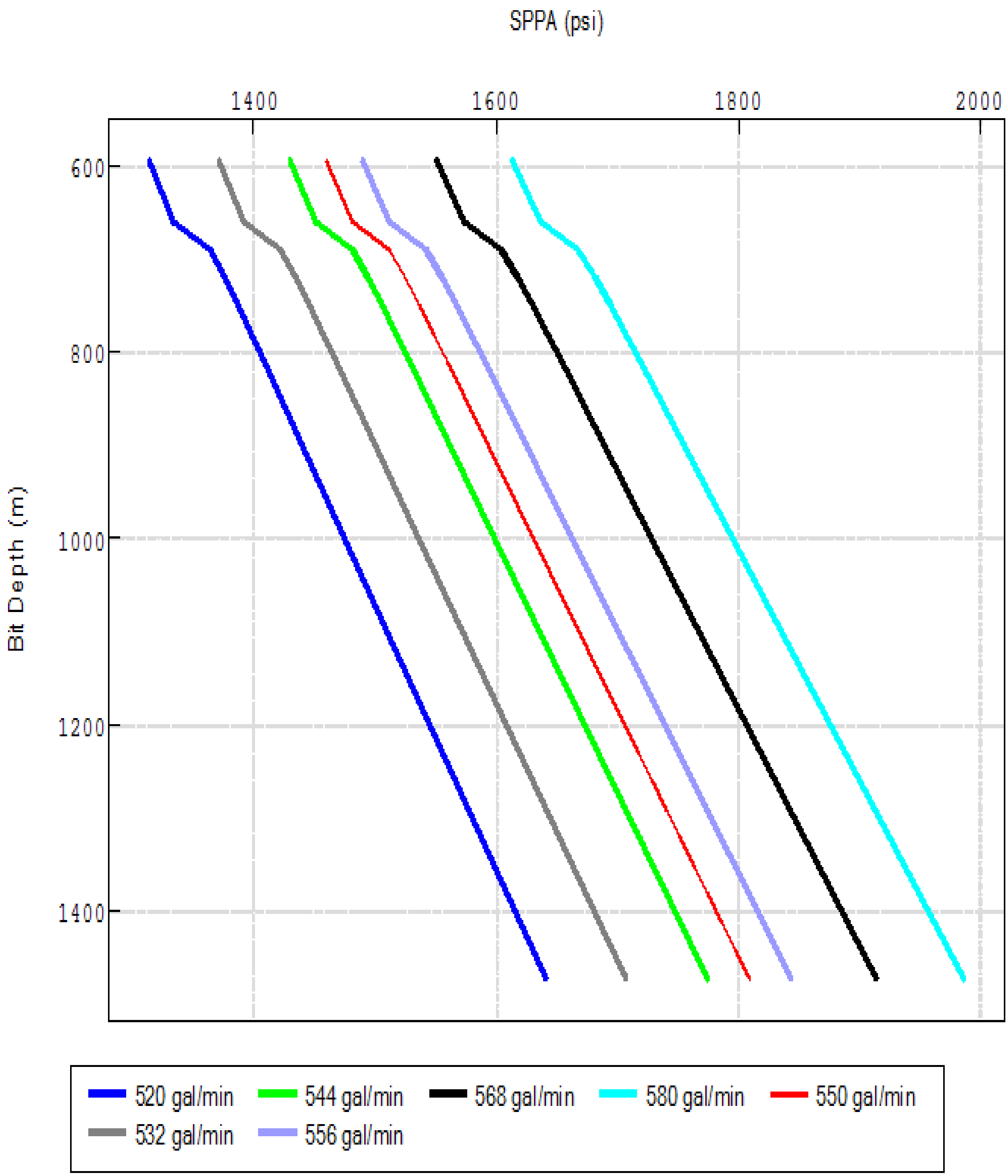


Figure 17

The plot of pressure drop vs. Flow rate is shown below. The bit depth is 1471m at a flow rate of 550gpm.

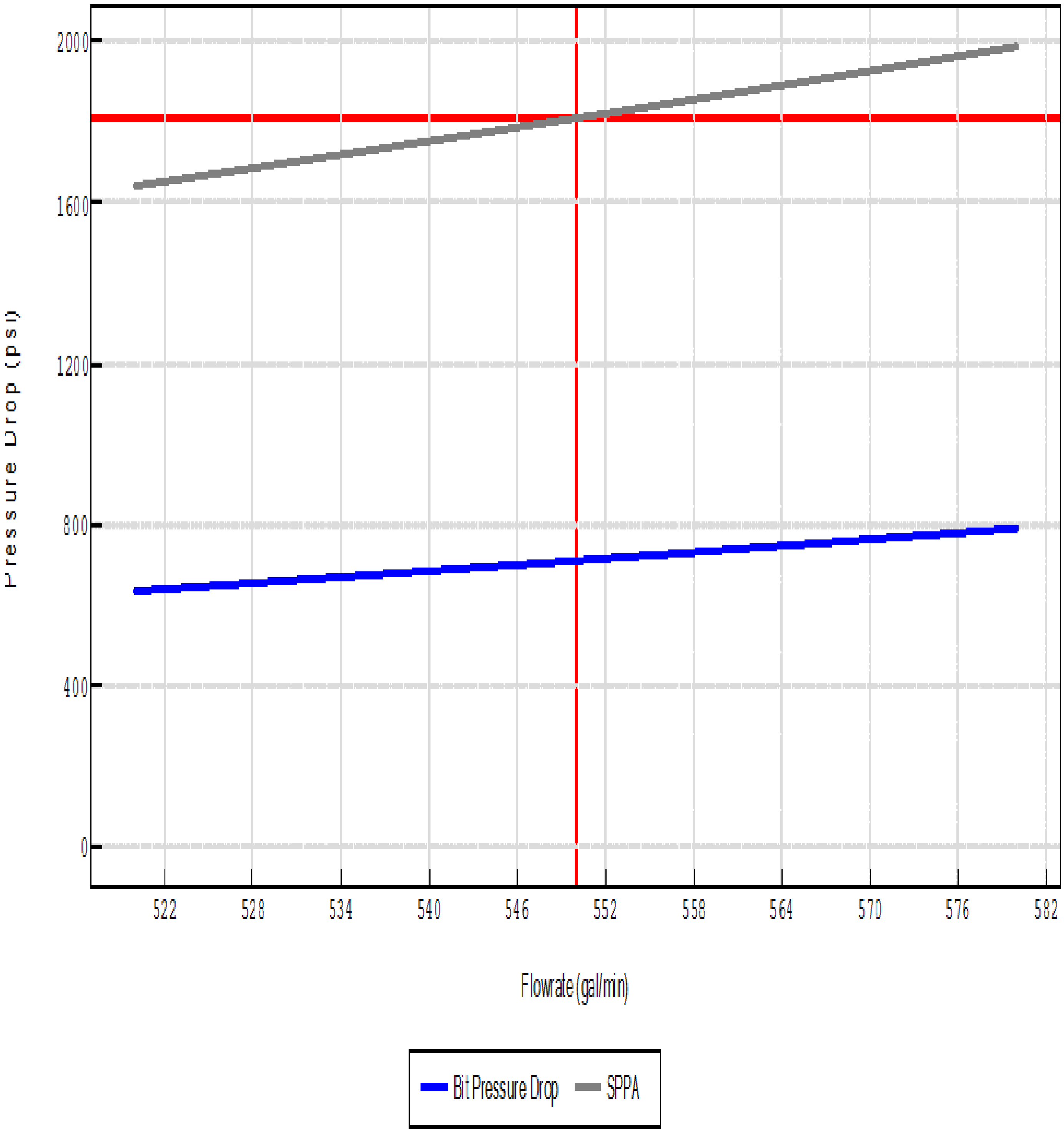


Figure 18

The nozzle optimization for total flow area is done at different flow rates. The bit hydraulic horsepower and jet impact force is considered as a parameter for the nozzle flow optimization.

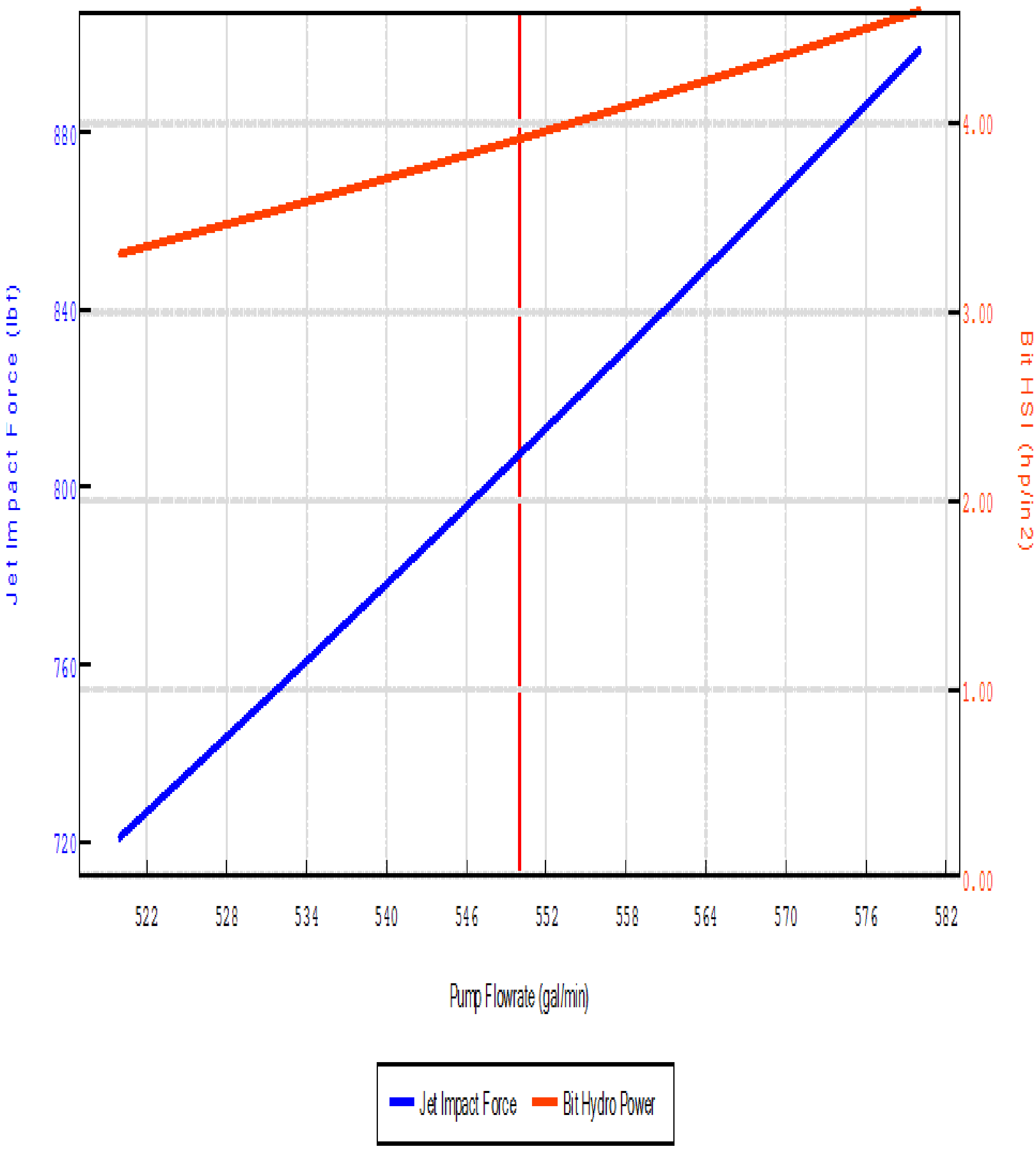


Figure 19

4. STRESS ANALYSIS OF DRILLSTRING

4.1 Design of Excel Sheet

An MS Excel sheet was prepared for the purpose of stress analysis of drillstring. Three different tabs were prepared and automatic computation was carried out based on analytical formulas.

TAB 1 Drillpipe and Drillcollars

INPUT:

- Grade
- Size
- Thread
- Weight (manufactured)
- Combined length (Pin & Box)
- ID of Pin & Box
- OD of Pin & Box
- Upset weight
- Box dia. at upset
- Mud weight
- Maximum weight on bit
- Safety factor
- Maximum well inclination
- Length of a drill collar
- Weight per foot

OUTPUT:

- Approximate adjusted weight of tool joint
- Approximate adjusted weight of Drillpipe
- Adjusted length of tool joint
- Combined weight of Drillpipe and tool joint
- Buoyancy factor
- No. of required Drill collar
- Bending strength ratio
- Drillpipe and Heavy weight Drillpipe

TAB 2 Collapse design

INPUT:

- Fluid depth in Drillpipe
- Total depth
- Fluid density in Drillpipe
- Fluid density outside Drillpipe
- Collapse resistance

OUTPUT:

- Collapse pressure
- Maximum collapse pressure
- Design factor

TAB 3 Tension design

IINPUT:

- Length of Drillpipe
- weight of Drillpipe
- Length of drillcollars
- Weight of drillcollars
- Buoyancy factor
- Yield strength
- Dogleg severity
- Drillpipe OD
- Coefficient of friction
- Length of slips

OUTPUT

- Maximum tension
- Maximum allowable load
- Margin of overpull
- Design factor
- Maximum length of Drillpipe
- Shock loading
- Bending
- Later load factors on slip
- Friction factor
- Slip crushing

TAB 3 Dogleg Calculations

INPUT

- OD of Drillpipe
- ID of Drillpipe
- Maximum tension load
- Maximum permissible bending stress
- Young's modulus of elasticity
- Half distance between tool joint

OUTPUT

- Moment of Inertia
- K factor
- Maximum dogleg severity

4.2 Collapse calculation

The analytical solution for collapse calculation was based on mechanical formulas.

The input parameters are:

Fluid depth in Drillpipe: 3426ft

Total depth: 3592ft

Fluid density in Drillpipe: 10ppg

Fluid density outside Drillpipe: 10ppg

Collapse resistance: 8765psi

All the input data has been obtained by the data handbook and field data recorded during the drilling operation.

The results obtained are as follows:

Collapse pressure: 1779.64psi

Maximum collapse pressure: 1865.87psi

Design factor: 1.04

4.3 Tension calculation

The input parameters are:

Weight of Drillpipe: 19.5ppf

Length of drillcollars: 25 1/3ft

Weight of drillcollars: 95ppf

Buoyancy factor: 6/7

Yield strength: 83650psi

Dogleg severity: 9.98°/100ft

Drillpipe outside diameter: 5inches

Coefficient of friction: 0.25

Length of slips: 13.5inches

The outputs generated are as follows:

Maximum allowable load: 7524 psi

Margin of overpull: 6978.11 psi

Design factor: 13.78

Maximum length of Drillpipe used:

Shock loading: 29250 psi

Bending: 61302.15 psi

Later load on slip factors: 3.44

Friction factors: 0.24

Slip crushing: 63699.28 psi

4.4 Dog leg calculation

The dogleg calculations were based on maximum inclination theory. The maximum permissible limit for dogleg severity was calculated on the basis of drillstring design factor.

Various input parameters entered are:

Outside diameter of Drillpipe: 5 inches

Inside diameter of Drillpipe: 4 2/7 inches

Maximum tension load: 545 8/9 psi

Maximum permissible bending stress: 11000 psi

Young's Modulus of elasticity: 30000000 psi

Half distance between tool joint: 5 ¾ inches

Results generated are:

Moment of Inertia: 14 ¼ $inches^4$

K factor: 0.016 lbm/ft

Maximum dogleg severity: 10˚/100ft

As per the values obtained keeping in mind the bending and deflection moment, the maximum dogleg was obtained as 10˚/100ft

Any increase in the dogleg may lead to a failure. However a safety factor has been added in the calculations to provide a room for change in the dogleg severity based on the kind of formations encountered downhole.

5. CFD ANALYSIS OF DRILLSTRING

5.1 Introduction to computational fluid dynamics

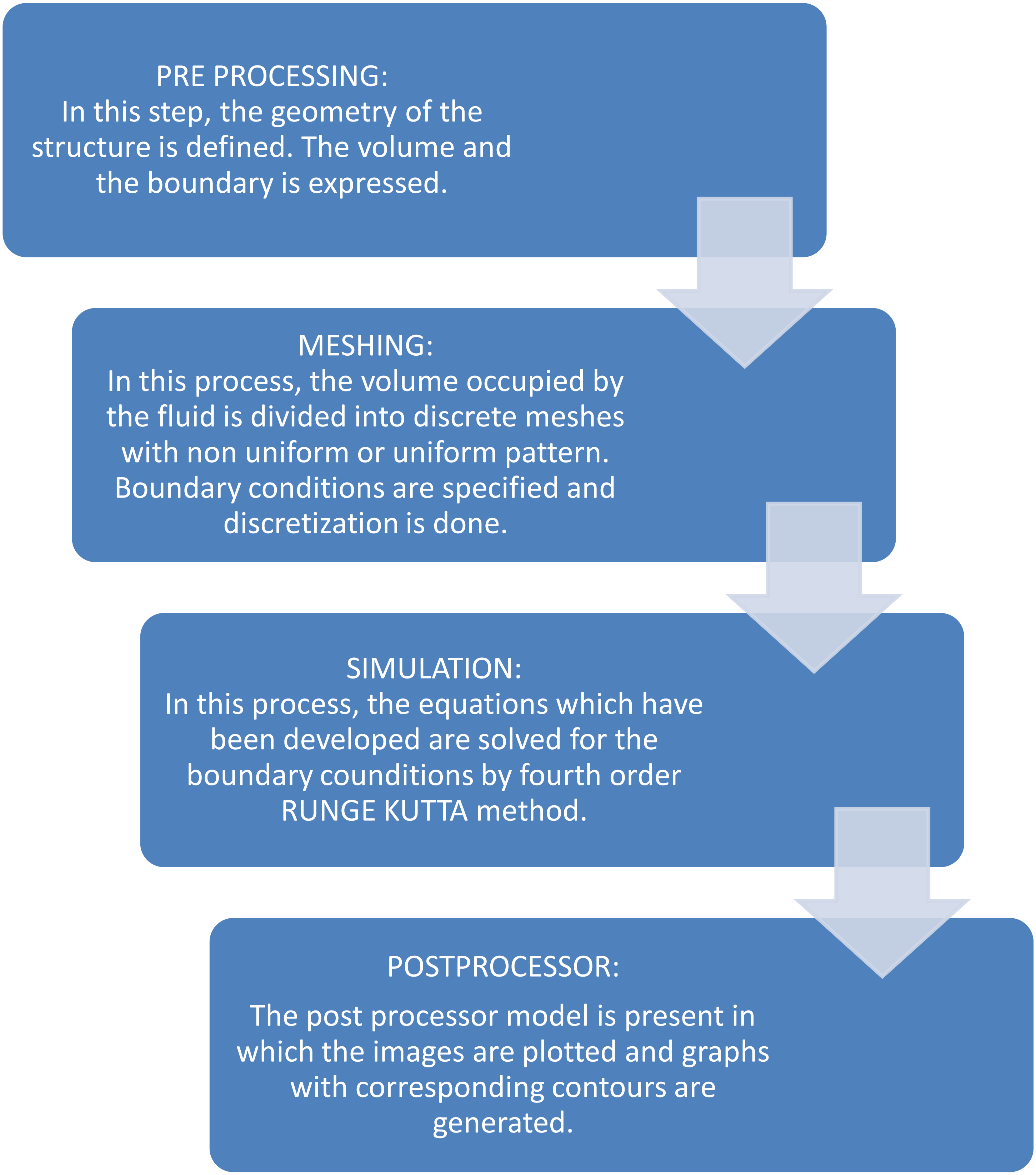
Fluid dynamics is one of the most critical engineering tools which are widely used in our everyday operations. The design of many structures which involves fluid flow modelling, gas flow modelling, heat and mass transfer operations requires an extensive use of fluid mechanics principles for solving the day to day problems with a higher degree of efficiency.

The wellbore structure and the flow of drilling fluids is one of the most complex systems which require the basic application of fluid mechanics principles. The fluid and structure interaction is one of the complex and difficult problems which needs to be solved by applying the properties of discretization. The fundamental equations of fluid-solid interaction within a single phase boundary is defined by the molecular structure of the fluid and the intensity of interaction depends upon the energy of the fluid. As the energy levels change, the layer structure and the orientation of layers in the fluid phase changes. This change generates and equivalent energy which causes deformation in the structure of the solid plane body. The heating and cooling effect, vibrations and sound loses produced by a moving fluid is a result of this energy-particle interaction.

Computational fluid mechanics is one of the widely used engineering application based branch of fluid mechanics which employs numerical solution and simulation to solve the complex solid-fluid interaction of any body or structure.

The body and the structure is generally designed and modeled in the designing software. In our case for instance, we selected CATIA as it provided comprehensive solution for the simulation of pipe flow model. It is also most suited for modelling the shaft structures and is widely used to model varying diameter type structure.

Other modelling software include auto desk, CAD, Gambit, etc. The method of solving the flow equations for velocity, streamlines, pressure, fluid behavior includes the following flow process.


PRE PROCESSING:
In this step, the geometry of the structure is defined. The volume and the boundary is expressed.
MESHING:
In this process, the volume occupied by the fluid is divided into discrete meshes with non uniform or uniform pattern. Boundary conditions are specified and discretization is done.
SIMULATION:
In this process, the equations which have been developed are solved for the boundary counditions by fourth order RUNGE KUTTA method.
POSTPROCESSOR:
The post processor model is present in which the images are plotted and graphs with corresponding contours are generated.

5.2 Fluid flow equations

NAVIER- STOKES EQUATIONS

The Navier Stokes equation is based on the material balance equation and Newton's second Law of motion combined with fluid motion. The equation describes the flow of viscous fluid. The basic assumption is that the stress that acts on a fluid element is the sum of diffusing forces and the pressure that acts on the body. The Navier Stokes is the conservative equation and is within the Froude limit. The solution is a flow field equation generated on the basis of boundary condition. The general form of Navier Stokes equation is written as:

$$\rho\frac{D\mathbf{u}}{Dt} = -\nabla\pi + \nabla\cdot\boldsymbol{\tau} + \mathbf{f}$$

The density is expressed as ϱ. The velocity field is expressed as U while Π represents pressure energy. τ represents the shear stress on the body while f is the body force.

EULER'S EQUATION

It's a set of flow equations for quasilinear hyperbolic equations, for adiabatic and inviscid flow. It can be applied foe the compressible fluid while it is also equally applicable for incompressible flow. The Euler's equation for incompressible flow and with constant density is expressed as:

$$\begin{cases} \dfrac{\partial\mathbf{u}}{\partial t} + \mathbf{u}\cdot\nabla\mathbf{u} + \nabla w = \dfrac{1}{\mathrm{Fr}}\hat{\mathbf{g}} \\ \nabla\cdot\mathbf{u} = 0 \end{cases}$$

The solution to Navier-Stokes equation and Euler's Equation require discretization principle to be applied on closed boundary condition to solve the flow model. The various discretization methods adopted are:

- FINITE VOLUME:
  Most common approach in CFD, the discretization conserves the flux in a particular mesh or control volume.

$$\frac{\partial}{\partial t}\iiint Q\,dV + \iint F\,d\mathbf{A} = 0,$$

Where:

Q is the conserved variable

F is the vector of flux

V is the control volume

A is the area of control volume

- FINITE ELEMENT METHOD

  It is used to solve the system of meshes in solid bodies and structures. It gives a conservative solution. The disadvantage is that it may require more memory space at times. The degree of conservation is much higher.

$$R_i = \iiint W_i Q \, dV^e$$

  R_i is the residual element.

  Q is the conservation equation.

  W_i is the weight factor.

  V^e is the residual volume.

- FIINITE DIFFERENCE

  The coding requires a perpetual update. The codes give a better accuracy and higher efficiency.

$$\frac{\partial Q}{\partial t} + \frac{\partial F}{\partial x} + \frac{\partial G}{\partial y} + \frac{\partial H}{\partial z} = 0$$

5.3 Fluid Flow Impact in drillstring

The fluid flow takes place through the Drillpipe, drillcollars, heavy weight Drillpipe, drilling jars, stabilizers, LWD & MWD tool.

As the fluid flows through these components, the fluid passes through an internal circular profile. This profile generates turbulence, as the flow takes place over the joints and couplings. At points where the mesh structure bends, the flux is random and flow pattern changes periodically.

5.4 Results of CFD Design

The CFD simulation which was run on the CFX software yielded the following results:

VELOCITY STREAMLINE:

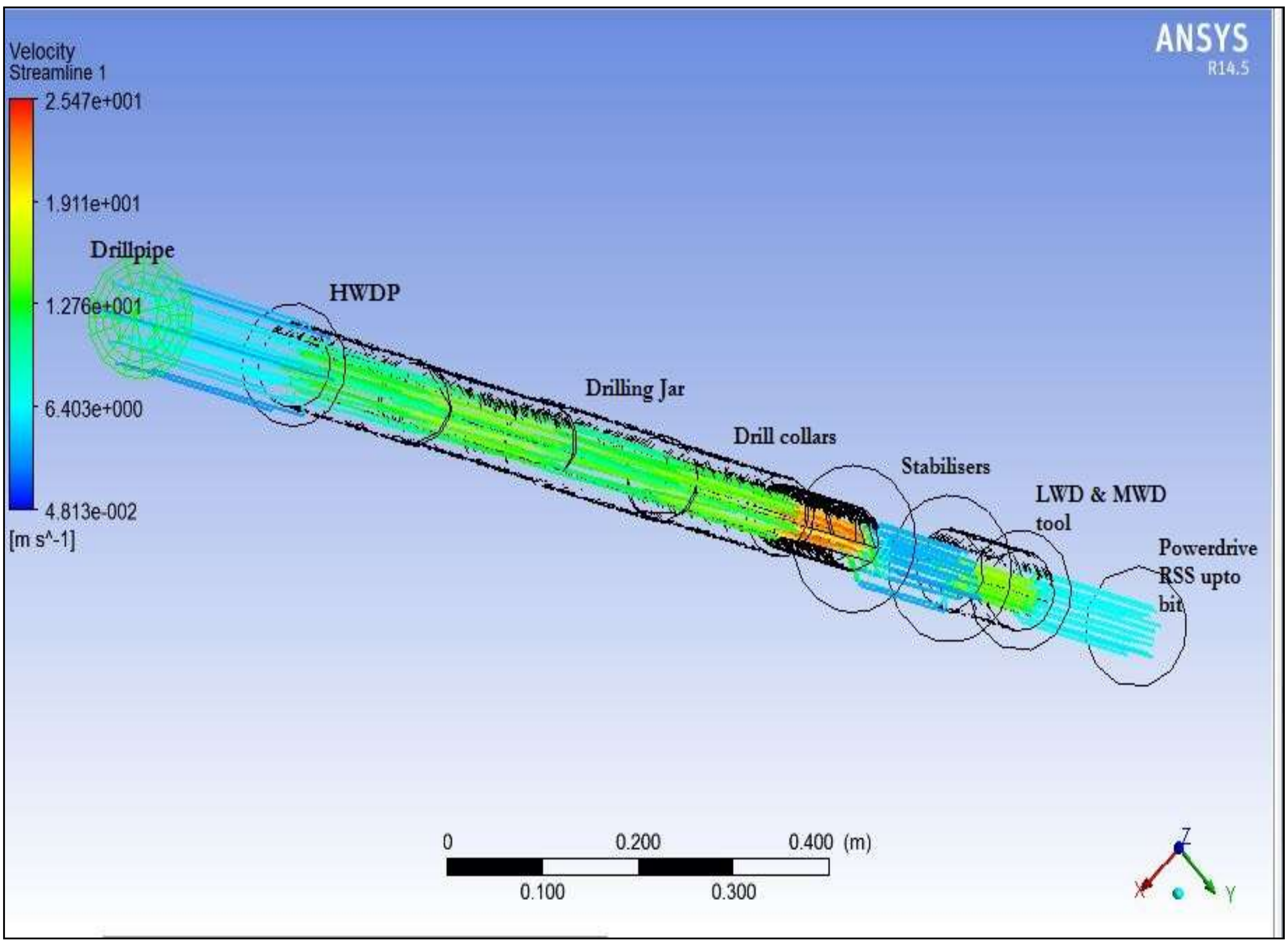


Figure 20

The velocity of the drilling fluid within the drillstring varies at several points. The point velocity can be seen with the color coding.

PRESSURE CONTOUR:

The pressure profile of the drillstring was also plotted.

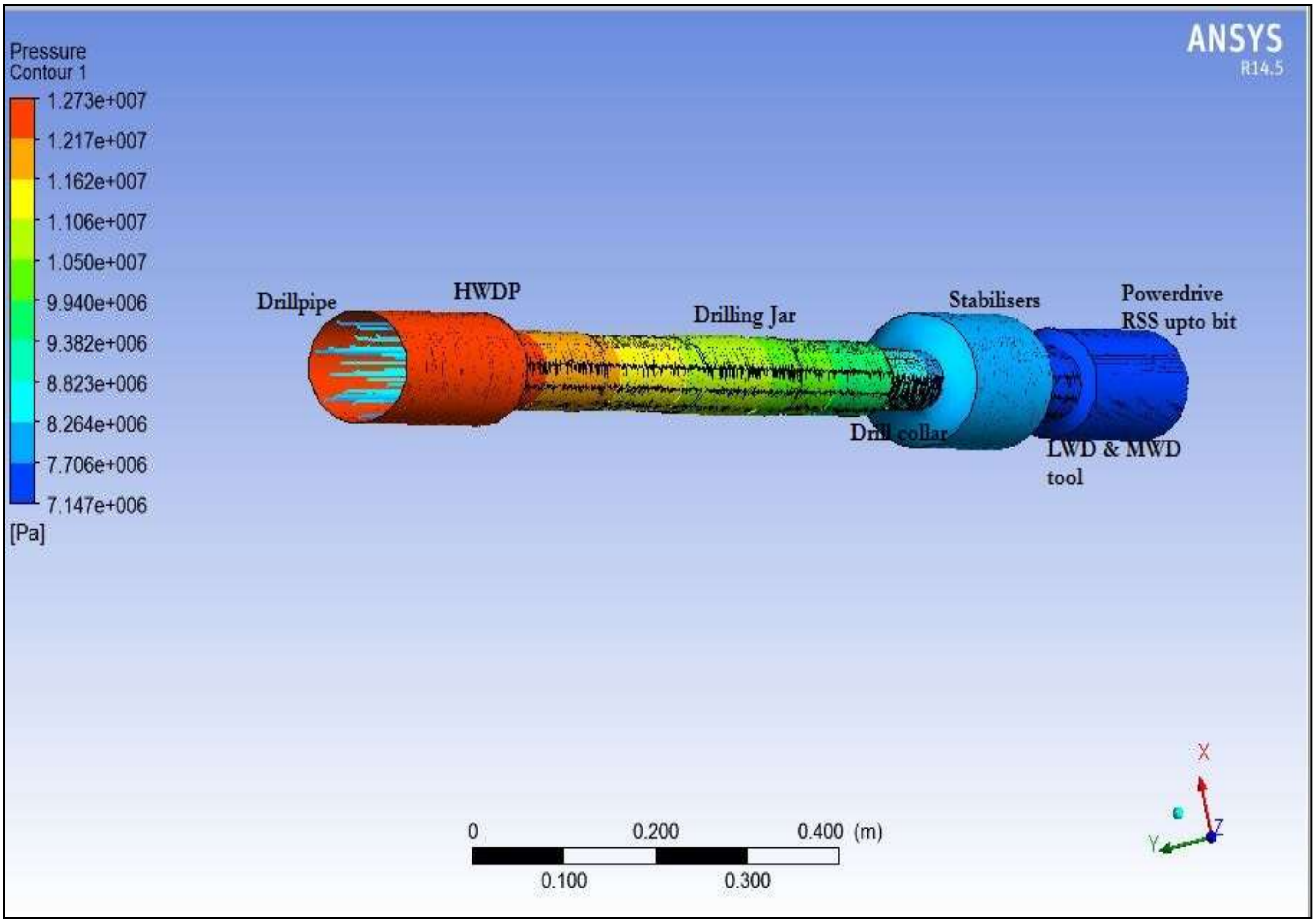


Figure 21

The inlet section is at the Drillpipe and as fluid progresses; it takes the course of different pressure regimes through the Drillstring. The inlet parameters are displayed as follows:

Flow rate: 550 gpm/ 0.034ms^{-1}

Inlet pressure: 1850 psi/ 127.46E5 Pa

Inlet velocity: 257.26 ft min^{-1}/ 1.31ms^{-1}

The outlet parameter at the Power drive face is;

Outlet velocity: 350ft min^{-1}/ 1.78ms^{-1}

Outlet pressure: 1036.7 psi/ 71.47E5 Pa

Density: 1174.298 Kg/m^3

The flow through the tool joints can be visualized.

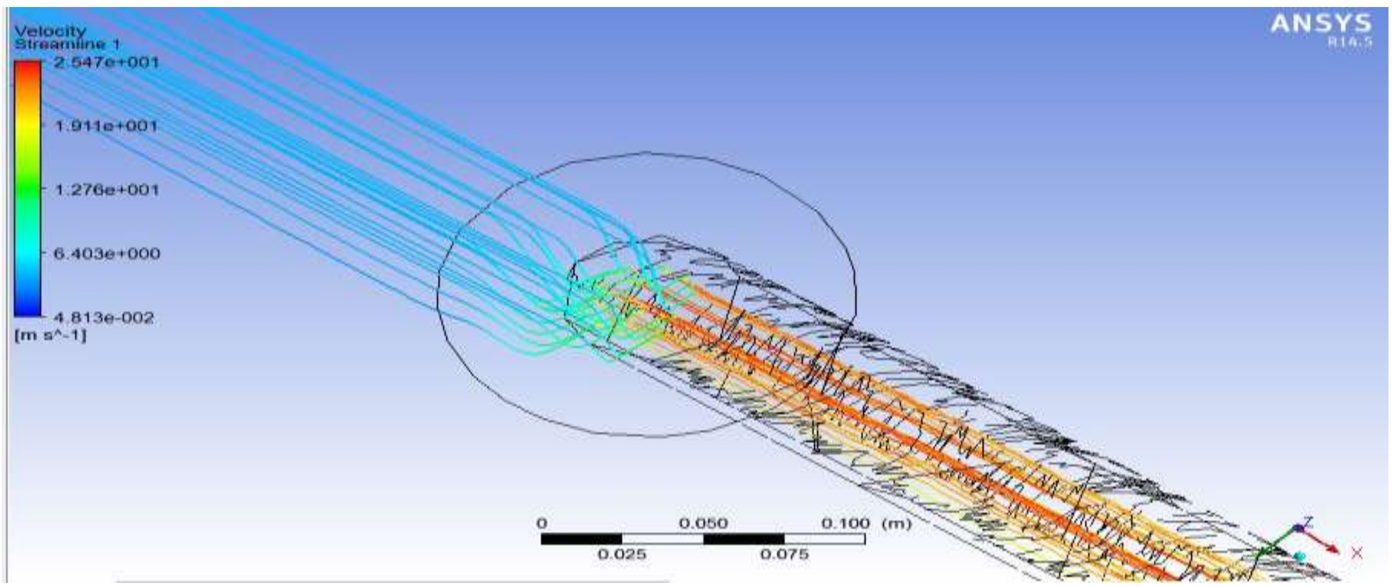


Figure 22

The bending of flow lines and the increased turbulence can be well visualized at the boundary.

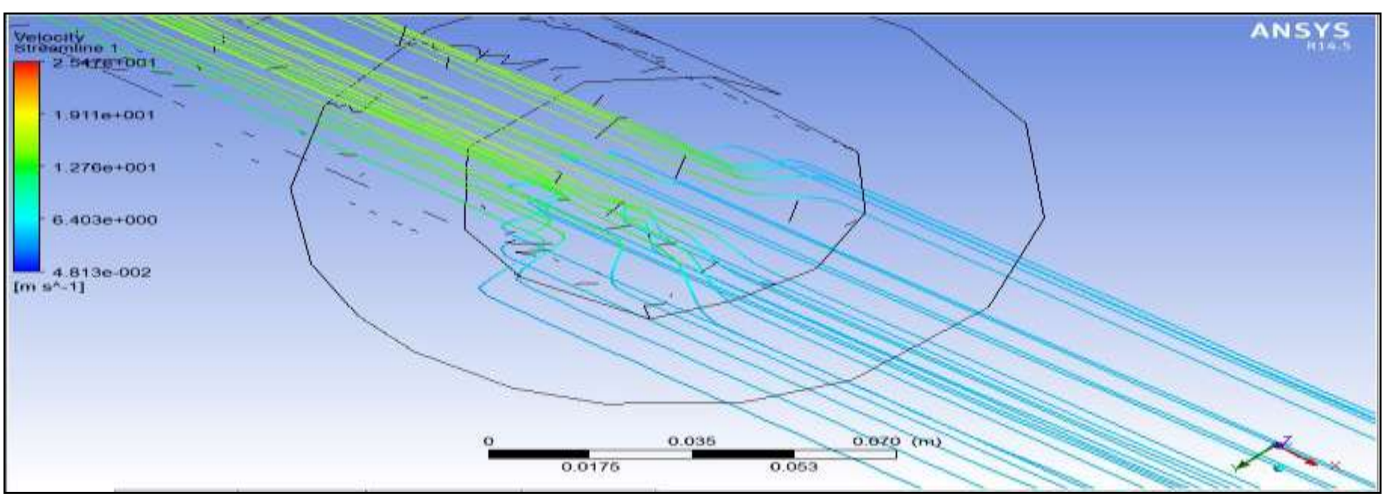


Figure 23

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Need for SRF in Drillstring

From the CFD simulations and the analytical studies following two discussions have come up.

Firstly the Drillpipe is most susceptible to failure as the highest amount of pressure force acts normal to its surface. Hence there is a need to prevent this. Latest advancements in material testing and manufacturing have made the Drillpipes much compatible with the hostile environment of the wellbore. Hence the chances of failure in Drillpipe are decreased. The stress relief features are not required at the Drillpipes since they are limber structure which bends when the tensile forces are acts on them. The next structure which faces the higher tensile stress is the heavy weight Drillpipe. This structure is not so stiff and hence the stresses don't concentrate on the rotary shoulder connection face. (RSC). This is also one of the biggest advantages of using the HWDP as a replacement structure for drill collars in the horizontal drilling BHA assemblies.

The next structure is the drill collar which is heavily prone to failure at the tool joints owing to its failure. The thickness of the drill collar is such that it makes the structure most preferred for incorporating the stress relief feature (SRF).

6.2 Recommended Rubber induced boreback structure

The rubber induced structure in the boreback will increase the BSR in the most profitable and economical range. The Bending strength ratio is an indication of the failure response displayed by a particular drillstring body part. The compressibility of rubber will improve the BSR by a factor of 0.4 - 0.5.

Hence incorporated in the tool joint of HWDP and Drill Collar, the new rubber induced boreback structure will be less prone to failure.

6.3 Thermo Elastic consideration

Neoprene is one of the widely available polymers which can be incorporated in the stress relief feature. The various properties of Neoprene that makes it suitable for application in the stress relief feature.

- **Common Name:** Neoprene
- **Chemical Name:** Polychloroprene
- **Generally Resistant To:** Moderate Chemicals and Acids, Ozone, Oils, Fats, Greases, and Solvents

- **Generally Attacked By:** Esters, Ketones, Chloronated, Aromatic and Nitro Hydrocarbons
- **ASTM D 2000 / SAE J200 Classification:** BC, BE
- **MIL-R-3065 / SAE J-14 / MIL-STD-417 Classification:** SC
- **ASTM D-1418 Designation:** CR

Physical Properties

- **Elongation:** 100% to 800%
- **Hardness Range (Durometer Shore A):** 15 to 95

Mechanical Properties

- **Compression Set:** Good
- **Rebound Rating:** Fair to Very Good
- **Flex Cracking Resistance:** Good to Very Good
- **Abrasion Resistance:** Very Good to Excellent
- **Tear Resistance:** Good
- **Impact Resistance:** Good to Excellent
- **Flame Resistance:** Very Good to Excellent

Thermal Properties

- **Minimum Service Temperature:** -30°F to -70°F
- **Maximum Service Temperature:** +220°F to +280°F

Environmental Resistance

- **Recommended Shelf Life:** 5 to 10 years
- **Weather Resistance:** Poor to Good
- **Sunlight Resistance:** Good to Very Good
- **Ozone Resistance:** Good
- **Oxidization Resistance:** Good
- **Water Resistance:** Excellent
- **Steam Resistance:** Poor to Good

- **Gas Permeability:** Fair to Good
- **Radiation Resistance:** Good, 1 x 10^5 Ga Gy

  Poor, 9 x 10^5 Ga Gy

Chemical Resistance

- **Acetone:** Minor to Moderate Effect
- **Ammonium Hydroxide:** Recommended: Little to Minor Effect
- **Animal Fats:** Minor to Moderate Effect
- **Carbon Dioxide:** Minor to Moderate Effect
- **Chlorine:**
  - **DRY:** Moderate to Severe Effect
  - **WET:** NOT RECOMMENDED
- **Fluorine (Liquid): NA**
- **Fuel Oil:** Minor to Moderate Effect
- **Gasoline:** Minor to Moderate Effect
- **Hydrochloric Acid 37%:**
  - **HOT:** NOT RECOMMENDED
  - **COLD:** Minor to Moderate Effect
- **Hydrochloric Acid Concentrate 37%:**
  - **HOT:** NOT RECOMMENDED
  - **COLD:** Minor to Moderate Effect
- **Kerosene:** Moderate to Severe Effect
- **Methyl Ethyl Ketone:** NOT RECOMMENDED
- **Mineral Oil:** Minor to Moderate Effect
- **Naphtha:** Moderate to Severe Effect
- **Natural Gas:** RECOMMENDED: Little or Minor Effect

The temperature and thermo elastic property of NEOPRENE makes it suitable for application in the boreback structure. It will reduce the severity of washouts in the tool joint and also distribute the stress concentration evenly. It is compatible with the different acids and their rate of degradation on the rubber is also minimal. Hence in adverse wellbore environment also the wear and tear of rubber is quite good. The permeability for gas in the rubber structure is also low, hence reducing the chances of blistering and rendering long service life for the HWDP and the Drill collar.

It is evenly compatible with the synthetic oil based drilling fluids and also one of the most suited material for the drilling operation in absorbing shock loading and jerks minimizing the stress damaged to the fibres at the Rotary shouldered connection (RSC).

6.4 Cost estimation:

A 3mm, grade 1, black, 1 sheet of Neoprene costs around $41. One sheet of neoprene can be used to fill up approximately two joints. The machining and injection process may cost around $2-$3 additional per side.

6.5 Field Implementation strategy:

The rubber induced design cannot be singularly added as gaskets or rings. During the manufacturing process it is advisable to fill up the boreback structure with rubber.

Once the drill collars are bored the rubber material can be injected to set at higher temperatures and fill up some portions of the cylindrical bore structure.

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ANNEXURE

1.

Designation [a]		Pipe-body dimensions				Upset dimensions [b]						
		D_{dp} mm	t mm	d_{dp} mm	w_{pe} kg/m	D_{Ou} mm	d_{Ou} mm	L_{iu} mm	m_{iu} mm	L_{eu} mm	$L_{eu} + m_{eu}$ mm	e_w kg
Label 1	Label 2	See Table A.2	−12,5 %			+3,18 -0,79 [c]	± 1,59 [d]	+38,10 -12,70 [e]	min.	min.	max.	
1	2	3	4	5	6	7	8	9	10	11	12	13
Internal-upset (IU)												
3-$^{1}/_{2}$	13.30	88,90	9,35	70,20	18,34	88,90	49,21	88,90	—	—	—	3,36
4	14.00	101,60	8,38	84,84	19,27	107,95	68,66	88,90	—	—	—	4,00
External-upset (EU)												
2-$^{3}/_{8}$	6.65	60,32	7,11	46,10	9,33	67,46	39,67	107,95	—	76,20	139,70	2,09
2-$^{7}/_{8}$	10.40	73,02	9,19	54,64	14,47	82,55	49,23	107,95	—	76,20	139,70	2,80
3-$^{1}/_{2}$	13.30	88,90	9,35	70,20	18,34	101,60	63,50	107,95	—	76,20	139,70	4,63
3-$^{1}/_{2}$	15.50	88,90	11,40	66,10	21,79	101,60	63,50	107,95	—	76,20	139,70	3,72
4	14.00	101,60	8,38	84,84	19,27	117,48	77,77	107,95	—	76,20	139,70	6,54
4-$^{1}/_{2}$	16.60	114,30	8,56	97,18	22,32	131,78	90,47	107,95	—	76,20	139,70	7,81
4-$^{1}/_{2}$	20.00	114,30	10,92	92,46	27,84	131,78	87,33	107,95	—	76,20	139,70	7,26
Internal-external upset (IEU)												
4-$^{1}/_{2}$	16.60	114,30	8,56	97,18	22,32	120,65	73,02	63,50	76,20	38,10	76,20	3,95
4-$^{1}/_{2}$	20.00	114,30	10,92	92,46	27,84	121,44	71,42	107,95	76,20	76,20	139,70	7,99
5	19.50	127,00	9,19	108,62	26,70	131,78	90,47	107,95	76,20	76,20	139,70	7,63
5	25.60	127,00	12,70	101,60	35,80	131,78	84,12	107,95	76,20	76,20	139,70	6,99
5-$^{1}/_{2}$	21.90	139,70	9,17	121,36	29,52	146,05	96,82	107,95	76,20	76,20	139,70	9,53
5-$^{1}/_{2}$	24.70	139,70	10,54	118,62	33,57	146,05	96,82	107,95	76,20	76,20	139,70	8,35
6-$^{5}/_{8}$	25.20	168,28	8,38	151,52	33,04	177,80	135,00	114,30	76,20	76,20	139,70	—
6-$^{5}/_{8}$	27.70	168,28	9,19	149,90	36,05	177,80	135,00	114,30	76,20	76,20	139,70	—

Fig. Grade X, G and S drill pipe body dimensions, tolerances and masses

2.

Load Case	Make-up Torque too High	Make-up Torque too Low
Torque		Down-hole make-up
Tensile	Reduced tensile capacity	Shoulder separation
Pressure	Reduced tensile capacity	Shoulder leak
Compression	Possible finning of box make-up shoulder	Down-hole make-up
Bending	Fatigue Shoulder yield	Fatigue Shoulder separation

Fig. Problems with Incorrect Make up Torque

3.

Grade	Min Yield (lbs/in^2)	Symbol
D-55	55,000	D
E-75 (*)	75,000	E
X-95 (*)	95,000	X
G-105 (*)	105,000	G
S-135 (*)	135,000	S
V-150	150,000	V
Used	-	U
Note: (*) denotes commonly used grades of drill pipe		

Fig. Drill pipe "GRADES"

4.

Size	Tube OD (+1/16, -1/32)	Tube ID [1]	Tool Joint OD (+1/16, -1/32)[2]	Tool Joint ID (+1/8, -0)	Connection	Max Elevator Upset Dia	Center Upset Dia. (+1/16, -1/32)	Min. Drift Dia.[3]
						D_{eu}	D_{cu}	
3 1/2	3 1/2	2 1/4	4 3/4 (4 7/8, 5)	2 1/4	NC 38	3 7/8	4	2
		2 1/16		2 1/16				1 13/16
4	4	2 1/2	5 1/4	2 1/2	NC 40	4 3/16	4 1/2	2 1/4
		2 9/16		2 9/16				2 5/16
4 1/2	4 1/2	2 11/16	6 1/4	2 11/16	NC 46	4 11/16	5	2 7/16
		2 3/4		2 3/4				2 1/2
		2 13/16		2 13/16				2 9/16
5	5	3	6 5/8	3	NC 50	5 1/8	5 1/2	2 3/4
5 1/2	5 1/2	3 1/4	7 (7 1/4, 7 1/2)	3 1/4	5 1/2 FH	5 11/16	6	3
		3 3/8		3 3/8				3 1/8
		3 7/8		3 7/8				3 5/83/4
		4		4				3 3/4
6 5/8	6 5/8	4	8 (8 1/4, 8 1/2)	4	6 5/8 FH	6 15/16	7 1/8	3 3/4
		4 1/2		4 1/2				4 1/4
		5		5				4 3/4

1 Maximum tube ID is 1/8 larger than nominal. Minimum tube ID is controlled by the drift requirement.
2 Optional Tool Joint ODs shown in parenthesis, to be agreed between purchaser and manufacturer.
3 Drift Diameter is based on ID tolerances of heavy wall pierced tube used for the center section.

Fig. Dimensions Of Heavy Weight Drill Pipe (HWDP)

5.

(1) Connection Type	(2) Pitch Diameter *C*	(3) Taper	(4) Pin Length	(5) Thread Height Not Truncated	(6) Root Truncation	(7) Nominal Counterbore	(8) Thread Pitch	(9) Thread Angle θ	(10) Stress Relief Groove Diameter
NC10	1.063000	1.500000	1500000	0144100	0040600	1204000	.166667	30	—
NC12	1.265000	1.500000	1750000	0144100	0040600	1406000	.166667	30	—
NC13	1.391000	1.500000	1750000	0144100	0040600	1532000	.166667	30	—
NC16	1.609000	1.500000	1750000	0144100	0040600	1751000	.166667	30	—
NC23	2.355000	2.000000	3000000	0216005	0038000	2625000	250000	30	2.140625
NC26	2.668000	2.000000	3000000	0216005	0038000	2937500	250000	30	2.375000
NC31	3.183000	2.000000	3500000	0216005	0038000	3453125	250000	30	2.890625
NC35	3.531000	2.000000	3750000	0216005	0038000	3812500	250000	30	3.231000
NC38	3.808000	2.000000	4000000	0216005	0038000	4078125	250000	30	3.508000
NC40	4.072000	2.000000	4500000	0216005	0038000	4343750	250000	30	3.772000
NC44	4.417000	2.000000	4500000	0216005	0038000	4687500	250000	30	4.117000
NC46	4.626000	2.000000	4500000	0216005	0038000	4906250	250000	30	4.326000
NC50	5.041700	2.000000	4500000	0216005	0038000	5312500	250000	30	4.742000
NC56	5.616000	3.000000	5000000	0215379	0038000	5937500	250000	30	5.277000
NC61	6.178000	3.000000	5500000	0215379	0038000	6500000	250000	30	5.839000
NC70	7.053000	3.000000	6000000	0215379	0038000	7375000	250000	30	6.714000
NC77	7.741000	3.000000	6500000	0215379	0038000	8062500	250000	30	7.402000
$5^1/_2$ IF	6.189000	2.000000	5000000	0216005	0038000	6453125	250000	30	5.890625
$6^5/_8$ IF	7.251000	2.000000	5000000	0216005	0038000	7515625	250000	30	6.953125
1 REG	1.154000	1.500000	1500000	1441000	0040600	1301000	166667	30	—
$1^1/2$ REG	1.541000	1.500000	2000000	1441000	0040600	1688000	166667	30	—
$2^3/_8$ REG	2.365370	3.000000	3000000	0172303	0020000	2687500	200000	30	2.015625
$2^7/_8$ REG	2.740370	3.000000	3500000	0172303	0020000	3062500	200000	30	2.390625

Fig. Rotary Shouldered Connection Thread element information

GLOSSARY

B

- **BHA (Bottom Hole Assembly) -** The bottom hole assembly refers to the drill collars, stabilizers and other accessories such as jars, reamers, shock subs etc.. It is required to carefully design the BHA for both vertical and deviated wells in order to control the well direction so as to reach the target formation.
- **Boreback Box –** It is a stress relief feature in which metal is removed from unengaged threads and portions of some engaged threads by machining a cylindrical bore in the back of the box.
- The boreback box also makes the area next to the connection more limber as a result of which less bending is transferred to the connection. This feature results in longer fatigue life for the drillcollar connections.
- **BSR (Bending Strength Ratio) –** It is defined as the ratio of relative stiffness of the box to the pin for a given connection. From field experience, a BSR value of 2.5 gives a balanced connection while a BSR above 2.5, there is a risk of premature failure in the pin and a BSR of below 2.5 gives a risk of premature failure in the box.
- **Buoyancy Factor (BF) –** A value or a factor used for calculating the buoyed weight of the drillpipe. It is given as:-
    - BF = 1- (MW/65.5)
    - Where, MW is the mud weight being used in ppg
        - 65.5=Weight of a gallon of steel, ppg

C

- **Cross-over -** A sub which is used to connect drill string components which have different types or sizes of threads.
- **Composite materials –** the materials which are made from two or more constituent materials having different physical and chemical properties that when combined produces a material with entirely new property different from those of the constituent materials. They are also known as composition materials or composites.

D

- **Design Factor –** It is defined as coupling or pipe body yield strength divided by total tensile loads..
- **Dog Leg Severity –** A measure of the amount of change in the inclination and /or the direction of a borehole. It is expressed in degrees per 100 ft of course length.
- **Drag –** It is the force required to move the drillstring being in contact with the wall of the borehole.
- **Drill collar** - A heavy, thick-walled steel tube which provides weight on the bit to achieve penetration. It also helps to keep the drillpipe in tension. A number of drill collars may be used between the bit and the drillpipe.

N

- **NC (Numbered Connections) –** It is the most common thread style which has a V-shaped form and can be identified by the pitch diameter ,measured at a point 5/8 inches from the shoulder; the gauge point being multiplied by 10. E.g. NC 50 has a gauge point pitch diameter of 5.0417 inches. The first two digits of this last number identify this thread as NC50.
- **Nominal Weight -** As stated in API5C3, Nominal weight is defined as approximately equal to the calculated theoretical weight per foot of a20 foot length of threaded and coupled pipe based on the dimensions of the joint in use for the class of product when the particular diameter and wall thickness was introduced.

R

- **Rake Angle –** It describes the angle of the cutting face relative to the work and is a parameter used in various cutting and machining processes.

S

- **Stiffness ratio** – It is defined as the ratio of section Modulus of lower section tube to that of section modulus of upper section tube
  From field experience, a balanced BHA should have:
  SR = 5.5 for routine drilling

  SR = 3.5 for severe drilling or significant failure rate experience

T

- **Tool joint –** It is a part of drillpipe joint in which one end of the joint acts as a pin and the other end as a box and helps to make Drillpipe connections when a certain amount of torque is applied depending on the size of Drillpipe and its grade. Tool joints have coarse tapered threads to withstand the strain of making and breaking connections and to provide a seal. All API tool joints have minimum yield strength of 120,000 psi regardless of the grade of the Drillpipe they are used on (E, X, G, S).
- **Torque – T**he turning force applied to the drillstring which causes it to rotate and it is measured in ft-lbs.
  - **Torsional Yield Strength –** It is defined as the resistance of the tube to failure by twisting torque or force. The torsional yield strength is based on the shear strength equivalent to 57.7% minimum yield.

W

- **Washouts –** A condition in which leak path gets developed around the tool joints due to broken seal or improper torque being applied at the time of connection as result of which erosion occurs around the tool joint by the drilling mud which in severe cases lead to breaking of the pipe surface.