A Project Report on

CHALLENGES IN THE EXTENDED REACH DRILLING

A DISSERTATION SUBMITTED TO UNIVERSITY OF PETROLEUM AND ENERGY STUDIES FOR THE PARTIAL FULFILLMENT OF

MASTER OF TECHNOLOGY

IN

GAS ENGINEERING

Submitted by:

HARSH NIGAM
Roll no. R030205021

Under the Guidance of

Mr. C.K. JAIN
(PROFESSORE, COE, UPES)

COLLEGE OF ENGINEERING
UNIVERSITY OF PETROLEUM AND ENERGY STUDIES
MAY-2007

UNIVERSITY OF PETROLEUM & ENERGY STUDIES

CERTIFICATE

This is to certify that, this is the bonafide record of the major project work entitled **"CHALLENGES IN THE EXTENDED REACH DRILLING"** carried out by the student **Mr. Harsh Nigam** of Final year M.Tech (Gas Engineering) college of engineering, during the academic year 2007 in partial fulfillment of the requirement for the award of the degree of Master of Technology to the university of Petroleum and energy studies.

To the best of my knowledge, the content of this project work did not form as basis of the award of any pervious diploma/degree by any one else.

06.06.07

DR. B.P. PANDEY
DEAN, C.O.E.
U.P.E.S.

Mr. C.K. JAIN
PROFESSOR, C.O.E.
U.P.E.S.

Corporate Office :
Hydrocarbons Education & Research Society
... Floor, PHD House, 4/2, Siri Institutional Area
August Kranti Marg, New Delhi-11001 India
+ 91-11-41730151-53 Fax : +91-11 1730154

Main Campus :
Energy Acres, PO Bidholi, Via Prem Nagar,
Dehradun-248 007 (Uttaranchal) India
Ph. : +91-135-2261090-91, 2694201/203/208
Fax : +91-135-2694204

Regional Centre (NCR) :
SCO 9-12, Sector-14, Gurgaon 122 007
(Haryana), India
Ph. : + 91-124-4540300
Fax : +91 124 4540 330

ACKNOWLEDGEMENT

I have immense pleasure in expressing my sincerest and deepest sense to gratitude towards **Mr. P.D. ARORA** (Consultant Petroleum, Visiting Faculty, college of engineering). Permitting and providing the facilities to complete my Major Project in between to their busy schedule.

I also express my deepest sense of gratitude towards my Major Project guide **Mr. C.K. JAIN** (Professor College of Engineering) for his invaluable guidance, encouragement, criticism and helpful suggestion each and every step of this project work.

My deepest regards & thanks also go to **Dr.B.P. Pandey** (Dean, College of Engineering) and **Dr.R.P.Badoni** (Course coordinator of Gas Engineering) for providing me valuable guidance and encouragement during project work.

I also extended thanks to faculty members of COE, Librarian and my friends for their continual enthusiasm and willingness to help.

Last but no least, I am very thankful to my parents because of them sacrifices devotion & Love this work is complete.

HARSH NIGAM

TABLE OF CONTENT

ABSTRACT

ABBREVATIONS

LIST OF FIGURES

1. Introduction ...1

2. Planning for ERD wells ...3

3. Drilling Technologies for ERD

3.1 Consideration of Drill Pipe ...5

3.2 Rotary Steerable System ...5

3.3 Top drive ...14

3.4 Near Bit Reamers ...15

3.5 Thrusters ...15

3.6 Torque and Drag ...16

4. Drilling Fluid Design and Management for ERD

4.1 Introduction ...18

4.2 Fluid Selection ...19

4.3 Down-Hole-Modeling ...20

4.4 Hole Cleaning 22

4.5 Bore-Hole stability 24

4.6 ECD Management 25

5. Logging & Completion and Work-over

5.1 Measurement-While –Drilling ...26

5.2 Through Bit Logging ...27

5.3 Solid Expandable Tubular technology ...28

5.4 Casing Floatation ...32

5.5 Coiled tubing casing patches ...32

5.6. Well Control ...33

Benefits ...34

Suggestion ...35

Future Development ...37

Conclusion ...38

Appendix:

1. **Design of ERD Well Trajectory** ...39
2. **Case Study :** Chayvo Field ,Russia 48

References 57

ABSTRACT

Challenges in the Extended Reach Drilling

Challenges to successful ERD include problematic movement of down hole drill string and well casing. Applying sufficient weight to the drill bit, possible bucking of well casing or drill string and running casing successfully to the bottom of the well. Drill string tension may be a primary concern in vertical well, but in ERD drill string torsion may be the limiting factor. Running normal weight drill pipe to apply weight to the bit in ERD can lead to buckling of the drill pipe and rapid fatigue failure. Conventional drilling tools are prone to twist off because of unanticipated failure under high torsion and tensile load of and extended reach well. Torque can be significantly reduced with the use of non rotating drill pipe, additional mud pumps enhanced solids control, higher capacity, top drive motors, more generated power and oil- based drilling fluids. ERD requires longer hole sections, which requires longer drilling times; the result is increased exposure of destabilizing fluids. Oil based muds in extended reach drilling. Water based muds may not provide the inhibition, lubrication or conforming support of oil based muds. The introduction of a new second generation rotary Steerable drilling system helps to addressee the challenges imposed by critical well paths .This systems uses "point the bit" technology to steer the well bore in any desired direction while rotating the drill string. To accurately assess well bore position, it provides real time continuous steering information with at bit measurements. The system is also fully integrated with LWD sensors and rig information systems, creating a complete drilling and formation evaluations package. State of the art rotary Steerable systems like this are the clear choice for extended reach and designer well applications in which excessive torque and drag can

inhibit drilling operations. Because this systems has the ability to place the well bore through multiple targets, it can greatly improve recovery from a single well. It also eliminates spiraling caused by aggressive side cutting bits, which allows it to be used for applications in which excessive torque and drag could inhibit operations. It is now understood that spiraling is the main contributing factor to excess well bore friction and also degrades the efficiency of cuttings removal due to the troughs created on the low side of the spiraled hole. By eliminating the mechanism that creates spiraling (unstabilized short gauge bits) this new systems improves overall drilling efficiency by improving directional control and directional drilling efficiency , hole cleaning , bit life , and down hole tool reliability (due to reduced vibration levels with a stabilized bit) while yielding more efficient casing and logging tool running operations[1]

Many surfaces use conflicts can be avoided through directional drilling and ERD. However some reservoir are located or sized such that directional drilling can't eliminate all possible conflicts.

ABBREVIATIONS

AC:	Alternating Current
API:	American Petroleum Institute
BHA:	Bottom Hole Assembly
DLS:	Dog Leg Service
DC:	Direct Current
DSTJ:	Double Shouldered Density
ERD:	Extended Reach Drilling
ECD:	Equivalent Circulating Density
FH:	Full Hole
GPM:	Gallons per minute
HSE:	Health, Safety & Environment
HP:	Horse Power
IF:	Internal Flush
ID:	Inside Diameter
LWD:	Log While Drilling
MD:	Measured Depth
MWD:	Measurement While Drilling
N:	Normal force
NOx:	Nitrogen Oxides
ROP:	Rate of Penetration
SCR:	Silicon Controlled Rectifier
TVD:	Total Vertical Depth
μ:	Co-efficient of Friction
˥ :	Torque
Ft.bs:	Foot pounds
Lb/ft:	Pound per foot
M:	Meter
Psi:	Pounds per square
Rpm:	Revolution per minute

LIST OF FIGURES

Fig #	Description	Page #
Fig 1	An Extended Reach Well	2
Fig 2	Configuration of Rotary Steerable Systems	12
Fig 3	Point the bit rotary Steerable system	12
Fig 4	Point the bit system in bent mode	13
Fig 5	Point the bit In straight mode	13
Fig 6	A push the bit rotary Steerable system	13
Fig 7	Top Drive System	15
Fig 8	Expansion process for Solid Expandable Tubular	29
Fig 9	Location of Chirag Field	45
Fig 10	Chirag- Litho logy	45
Fig 11	A-19 Vs Industry Step out	46
Fig 12	A-19: Strategy for Success	46
Fig 13	Wytch Farm location	54
Fig 14	Chayvo True Vertical Depth Verification	63
Fig 15	Schematic Chayvo ERD wells	63
Fig 16	Completion Diagram	64

CHAPTER 1

Introduction to Extended Reach Drilling

ERD has evolved from simple directional drilling to horizontal, lateral, and multi lateral step-outs. ERD employs both directional and horizontal techniques and has the ability to achieve horizontal well departures and vertical total vertical depth to deviation ratios beyond the conventional experience in particular field.

Extended reach (ERD) wells are defined as wells that have a horizontal departure (HD) at least twice the true vertical depth (TVD) of the well. ERD wells are kicked off from vertical near the surface and built to an inclination angle that allows sufficient horizontal displacement from the surface to the desired target. This inclination is held constant until the well bore reaches the zone of interest and is then kicked off near horizontal and extended into reservoir. This technology enables optimization of field development through the reduction of drilling sites and structure , and allows the operator to reach portion of the reservoir at a much greater distance than possible with a conventionally drilled directional well. These efficiencies increase profit margins on viable projects and can make the difference whether or not the project is financially viable. It is well known that ERD introduce factors that can compromise well delivery and the first challenges prior to drilling and ERD well is to identifying and minimize the risk. Technologies that have been found to be critical to the success of ERD are torque and drag , drill string design ,well bore stability , hole cleaning , casing design , directional drilling optimization ,drilling dynamics and rig sizing . Other technologies of vital importance are the use of rotary steerable systems (RSS) together with measurement while drilling (MWD) and logging while drilling (LWD) to geo steer the well into the geological target . Many of the wells drilled at Wytch farm would not have been possible to drill without RSS, because steering beyond 8,500 m was not possible as axial drags were too high to allow the oriented Steerable motor and bit to slide[1][2]

Drilling ERD wells in deep waters is the next step, even though there are some experiences offshore they are related to wells drilled on shallow waters from fixed platforms.

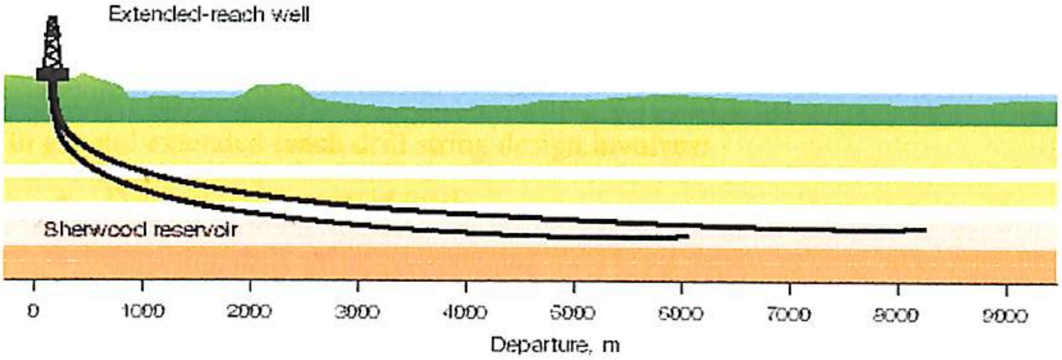

Figure 1: An Extended Reach Wells

The limits of directional drilling continue to be pushed as horizontal reservoir sections are being drilled to tap reserves miles from surfaces well sites. However, this accomplishment would be next to impossible without rotary Steerable drilling systems that can occur guide a well bore through the pay zone at extreme distances. These systems provide at or near the bit measurement to exact geological and geometric bore hole positioning and relay the information in real time to the drilling team. The team can then adjust bit directional to optimally direct the well bore through the formation.

Extended reach wells have numerous advantages. They allow smaller targets at greater distances to be successfully drilled, make it possible to replace sub-sea wells, and allow offshore reservoirs to be tapped from fewer platforms. Extended reach wells also permit the development of near shore fields from onshore and reduce environment impact by allowing development to take place from pads. Finally, they minimize surface disturbance because fewer wells are required and surface sites can smaller foot print. [3]

CHAPTER 2

PLANNING OF ERD WELLS

2.Planning of ERD wells:

Planning for ERD wells is driven by economical, environmental and technical objectives. In general extended reach drill string design involves:

- Determining expected loads
- Selecting drill string components
- Verifying each components condition
- Monitoring conditions during drilling

Economic issues in drill string planning include availability, logistics and cost. Rig and logistics issues include storage space, accuracy of load indicators, pump pressure/volume capacity, and top drive output torque. Hole issues include hole cleaning, hole stability, hydraulics, casing wear, and directional objectives.

Environmental conditions should also be taken into consideration while planning for ERD wells. We can take the example of Wytch Farm extended reach drilling by British Petroleum which has created a new milestone by drilling and completion of an ERD well with an horizontal displacement of 35,196 ft. the Wytch Farm oil field had three main oil fields out of which the Sherwood reservoir was the most productive one. The development plan had to be carefully carried out because not only the area was a tourist spot but also the plan had to adhere to the stringent environmental regulations. Initially, it was planned to have an artificial island and simple directional wells. Instead, ERD wells were chosen because it would better protect the environment and would also cut the costs by half. There is a need to create a multi functional team so as to identify the risks associated with the well and the tools and practices to manage them. Extensive training of all the personnel is a must along with close cooperation for smooth working relationship. A study of successfully drilled ERD wells in the past is also necessary. We can take the example of the Hibernia ERD well for getting a view of their planning process[3]

In 2002, the Hibernia Management and Development Company (HMDC), led by ExxonMobil Canada drilled and completed a 31,000ft MD well with a horizontal departure and vertical depth that has exceeded the present day industry ERD envelope. HMDC created multi functional teams so as to look after different aspects of drilling the ERD wells. Different workshops were held so as to effectively train the personnel's in drilling the ERD well. These workshops were divided into eight focus areas: casing and cementing operations, directional, formation evaluation, down hole tools, open/cased hole wire line logging, drilling fluids and solids control, completions and rig operations. The team of HMDC also initiated specialized research projects in areas of hole cleaning and shale stability.

Similarly, BP conducted more than 300 meetings to plan their ERD well at the Wytch Farm. ADCO drilled their ERD well with a MD of 18,478ft and a HD of 13,780ft.With the help of excellent planning, ADCO was able to beat the learning curve in extended reach wells.

CHAPTER 3

DRILLING TECHNOLOGIES FOR ERD

3.1. CONSIDERATION OF DRILL PIPES

Till now, ERD wells were drilled with either 5-½ in. or 6-5/8 in. or a combination of both. But sue to the problems, which arises due to the above drill pipes, the industry is now turning to 5-7/8 in. drill pipes. The hydraulic performance of 5-1/2in.drill pipe becomes a major limitation in ERD wells resulting in poor cuttings removal, slow penetration rates and diminished control over well trajectory. The 6-5/8in.drill pipe is difficult to handle and requires more physical space on the rig. The 5-7/8in. pipe also provides 16% more ID flow area than 5-1/2 in. pipe. Moreover, it is found that pressure losses are reduced up to 28% with the 5-7/8in. pipes. [3] [6]

3.2 ROTARY STEERABLE SYSTEM

The conventional approach to drilling a directional well has been to employ a down hole motor that uses the mud flow to produce down hole rotation, independent of string rotation, and an angled bend for orientation of the tool face. Historically, this process has been extremely inefficient. With the motor in sliding mode and the drill string stationary the torque generated by the bit and the drag generated by the drill string result in tool face fluctuations and reduced directional control. Irregular transfer of weight to the bit produces varying torque because of changes in the depth of cut and results in a reduced rate of penetration. The lack of tool face control can result in erratic, and sometimes severe, doglegs and high tortuosity of the well. These conditions may cause problems later when setting casing and completing the well. As directional complexity and the length of horizontal sections increase, the problems become even more significant conversely, rotary Steerable systems are able to make changes in inclination and azimuth while the drill string rotates continuously. They produce a cleaner, smoother well bore while reducing drag, improving the transfer of weight to the bit and increasing the rate of penetration.

3.2.1 Point-the-Bit Rotary Steerable System

Introduction

Rotary Steerable systems are gaining acceptance in the petroleum industry. As more and more systems become available, the range of potential applications continues to expand. Initially rotary steerable systems were utilized primarily in extended reach drilling (ERD) wells, where the ability to slide steerable motors was limited by hole drag. Today drilling engineers are considering such systems for additional reasons. These include performance drilling, improved hole cleaning and geologic steering. As Rotary Steerable systems become more widely used, performance demands will increase. The point-the-bit system described here has been designed in anticipation of these Expectations.

The market needs may be grouped into the following areas:

Longer Runs. The ability to replace traditional steerable mud motor systems will be determined by the cost versus benefit for each project. A critical component of this will be improved tool life and reliability. Today, success is often gauged by the completion of 75 hours of operation; this is clearly insufficient. Future systems must be able to compete with, and surpass runs currently completed with traditional steerable systems.

Better Control. Predictable and consistent turns and build rates are important in maximizing performance. When system control parameters are heavily dependent on formation characteristics or individual knowledge of system behavior, dependable performance is compromised. Commercial rotary steerable systems have the potential to remove the perceived art associated with directional drilling. Providing a new level of control and steerability to the industry is a second critical objective.

Bit Selection Independence. Bit characteristics for a given application are often selected to optimize performance in specific formations or zones. Some rotary steerable systems on the market require bits specifically designed for the system to ensure proper operation. Ideally, bit selection should not be limited by the rotary steerable system. The flexibility of rotary steerable systems to operate with a wide range of bit types is desirable. Furthermore, rotary steerable operations will require the ability to operate with bi-centered bits and near-bit reaming devices which create over gauge holes. This introduces new challenges for controlling the system and potentially exposes the tool to additional shock and vibration.

Low Risk. The risks associated with running rotary steerable systems fall into two main categories: the likelihood of tool failure in less time than a traditional steerable assembly and the potential for lost-in-hole situations. Both of these risks will need to be demonstrably reduced for the wider adoption of Rotary Steerable systems.

Performance drilling. Achieving the highest rates of penetration (ROP) without compromising well placement is a key goal in drilling operations. Rotary Steerable systems provide improved drilling performance. [4][6]

3.2.2 CONCEPT OF A POINT THE BIT SYSTEM

Design of the Counter Rotating System

The point-the-bit system can be divided into 3 sub-assemblies. the steering section, electronics and sensor section, and a power generation section. The nucleus of the system, the steering section, contains the point-the-bit mechanism, Fig.1. The steering section contains a universal joint, which transmits torque and weight on bit, but permits the axis of the bit to be at an angular offset from the axis of the tool. The offset allows for the directional drilling tendency of the system . to be controlled through traditional 3-point contact with the well bore. The axis of the bit shaft is kept offset by a mandrel, which is maintained geo- stationary during collar rotation. This is accomplished through the use of a counter rotating electric motor. The feedback/control of the motor is accomplished via the electronics and sensor section. The sensors monitor the rotation of both the collar and motor. This information is utilized to insure feedback for proper control of the system. These same sensors provide full direction and inclination (D&I) measurement capabilities .Power generation is achieved through a high power turbine and alternator assembly.

Major Technical Objectives

The engineering design of the system focused on meeting future application needs by concentrating on several major technical objectives. These included steerability, reliability, flexibility, and operational simplicity.

Steerability: The system achieves directional control by providing 3-touch points in contact with the well-bore. All components of the system, including the contact points are continuously rotating. This provides numerous benefits, including better hole cleaning and less exposure to differential sticking due to static elements in contact with the formation. The point the bit concept allows for excellent steerability. The system has closed loop feed back capabilities. Existing control modes insure tool face and build rates are maintained at specific values. The bit shaft has a fixed offset to the axis of the tool. The system achieves directional control by maintaining the offset geo-stationary, Fig. 2. The system utilizes active feedback to maintain toolface at the desired value. To drill straight, the bit-shaft offset rotates at a rate that differs from that of the tool. This is analogous to rotary drilling with a mud motor and a fixed bend. The result is a slightly over gauged hole, e.g., less than .25 inches, Fig. 3. Variable build rate is achieved by controlling the amount of time spent in the bent and straight modes. The percentage of time is programmable by down linking from the surface. This allows the steering tendency of the tool to be changed according to formation and drilling characteristics. Additional closed loop modes are currently under development. These modes will allow the tool to maintain a specific inclination or build rate upon command from the surface.

Reliability: The system has been tested to insure the specifications in Table 1 will be met. As major sub-systems are based on proven technology, reliability targets can be achieved. New components leverage MWD technology to provide high reliability. To confirm this reliability, these components have been qualified beyond the maximum system specification. This qualification included operational life cycle testing of all components. The risk of tools becoming stuck and leading to lost-in- hole expenses has been minimized as there are no non-rotating parts in contact with the formation, and the tool introduces no limitations to common drilling practices such as back-reaming. To permit the use of a very simple mechanical system, it was necessary to increase the complexity of the control electronics. This approach was proven in the experimental prototype built in 1998.

Flexibility: The system was designed to function with a wide variety of MWD and LWD tool configurations to permit flexibility in BHA design. The system will operate over a range of bit sizes from 83/8-inches to 9-7/8-inches. This system is currently the only commercial system having the potential to operate with bi centered bits. Demonstrating this functionality will be a goal of commercial testing in late 2000.Drilling operations can be improved by the use of drilling motors to complement the power provided by a top-drive or rotary table. A mud motor can be placed above the steerable system described here, allowing the system to operate at bit speeds up to 400 rpm.

Ease of operation: The system communicates to the surface by transferring data through the MWD tool. Near-bit sensors in the system ensure the best overall placement of the well to the planned trajectory by providing the directional driller with improved real time data. A computer interface to the surface system allows the Directional Driller to track the tool path versus the well plan. The driller utilizes the same interface to control the rotary steerable system. The commands are sent to the system using an automatic downlink technique currently under development. Communication withthe tool is achieved by varying the flow rate. Commands can be transmitted to the tool without interruption to the drilling process, thus optimizing the penetration rate.

System Comparisons:

Rotary Steerable systems can be grouped into two categories, push-the-bit and point-the-bit. This characterization is useful for distinguishing the steady state behavior of the systems. During non steady state behavior, i.e., the conditions introduced during steering changes, point-the-bit tools exhibit push-the-bit characteristics and vice versa. Nonetheless, it remains a useful classification. Described below are some of the important differences in each of the methods. [5]

3.2.3 Point-the-bit vs. non-rotating stabilizer systems

Various tools are currently in existence which incorporate a non-rotating stabilizer as part of the rotary steerable system. The presence of a non-rotating member need not necessarily indicate that the drilling system is either of the point-the-bit or push-the-bit variety. The non-rotating component simply acts as a stationary reference point against which a steering mechanism may act. In one manifestation of such tools, the non-rotating stabilizer contains pads that are forced radically outwards against the formation. This imparts a side force upon the bit generating a net directional response. In the second manifestation, a shaft rotating within the non-rotating section is radically deflected away from the axis of the well bore. This results in a predominantly "point-the-bit" system, except during transitional periods when changes in direction are being made. During these times, the tool acts primarily as a push-the-bit system. The disadvantage of both of these methods lies not in the fundamental nature of push versus point the bit, but in the presence of the non-rotating stabilizer. This may act to reduce hole-cleaning efficiency, but more importantly, it can prevent the tool from performing important drilling functions such as back-reaming.

3.2.4 Point-the-bit versus synchronous pad systems

Rotary steerable tools of the push-the-bit type (Fig. 4) that do not contain a non-rotating stabilizer are now well established in the industry and provide the advantage of being able to back-ream when compared to the tools described in the previous section. The synchronous pad type tools operate by activating pads that slide against the well-bore wall at the same rotation rate as the drill-string. As each pad reaches a certain position along the well-bore circumference, it applies a force that drives the bit in the opposite direction. Thus, the effectiveness of such a steering technique depends on the ability of the pads to impart a force against the formation.

The bit must also have sufficient side cutting action to translate an increase in side force into a directional tendency. Under certain situations, the pads are not able to apply a side force of great enough magnitude to effect a significant side cutting action. A situation in which this may occur is the case where the hole gauge at the pad position is of the same or greater diameter as the fully extended pad. The point-the-bit system described here poses no such limitation, since the steering ability is less a function of the side force and more a function of system geometry. [5]

3.2.5 Selection method:

A more system of selectivity whether rotary Steerable are applicable for a well was required. The following formula was therefore generated based on the initial cost Vs benefit analysis.

Equation: $Y = C/D\,[2BE - A] - 12E$

A: Cost per hour of tool operating, pounds

B: Sliding factor, percentage sliding planned over the entire hole section /100

C: Section length, Ft

D: Average daily ROP in rotary, fr/hr

E: Rig operation rate / hr, pounds

Y: Economic benefits pounds

If y yields a positive value the sliding factor value B can be used for inclination only tools to examine the suitability of 2D tools.

The 12E term is used to model any hidden additional Costs associated with the tool and introduce a Financial hurdle to be cleared. The term introduced an additional cost of 0.5 rig days to ensure clear financial benefits to the operation can be seen before the technology selected. [4]

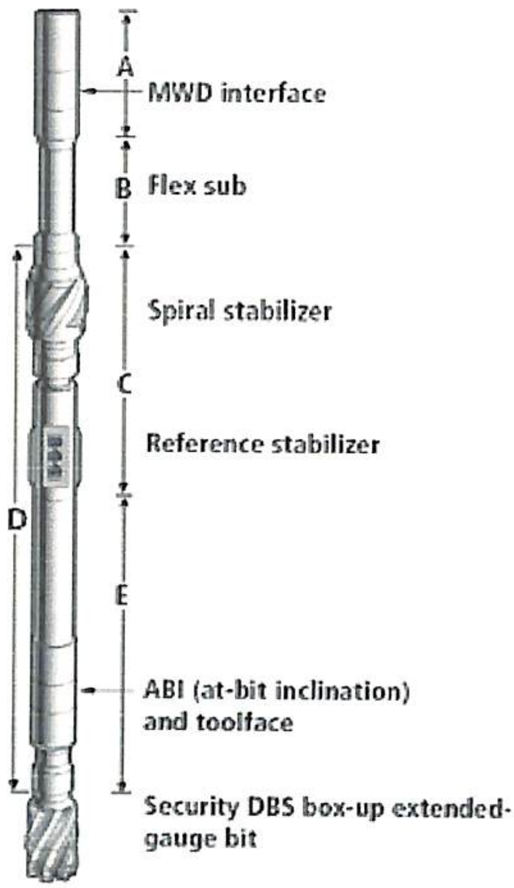

Figure 2: Configuration of Rotary Steerable Systems, Courtesy: World Oil

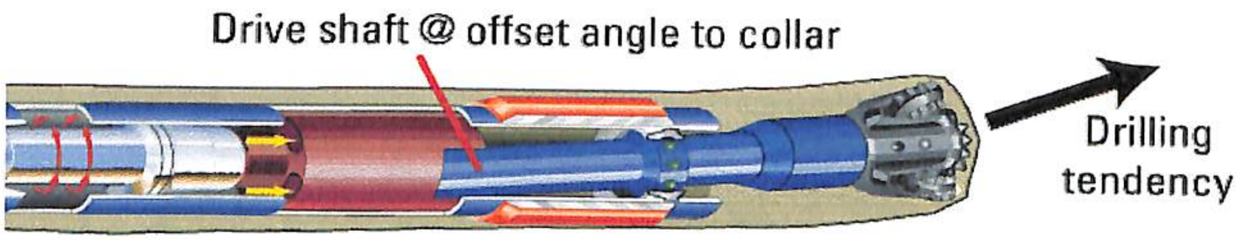

Figure 3: Point the bit Rotary Steerable system. Bit shaft is held at an offset to the axis of the tool. This offset is maintained geo-stationary through the use of a counter rotating electric motor. The tendency of the drilling is a result of standard 3 point contact using the bit and two stabilizers. [4]

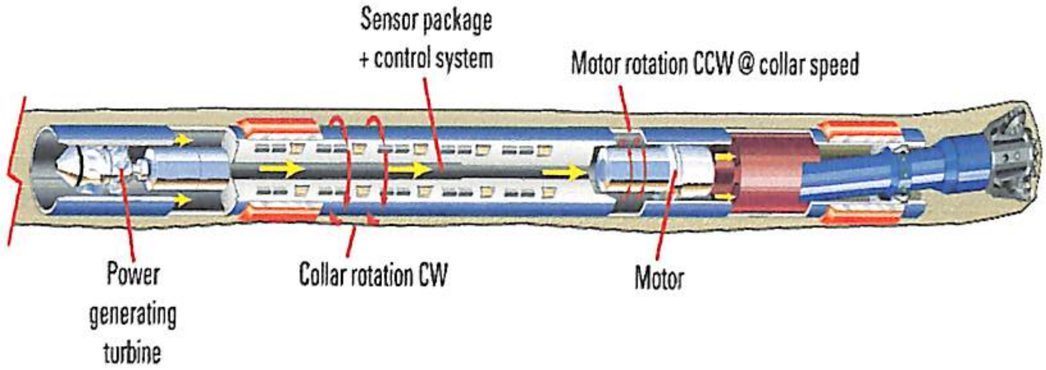

Figure 4: Point the bit system in bent mode. [5]

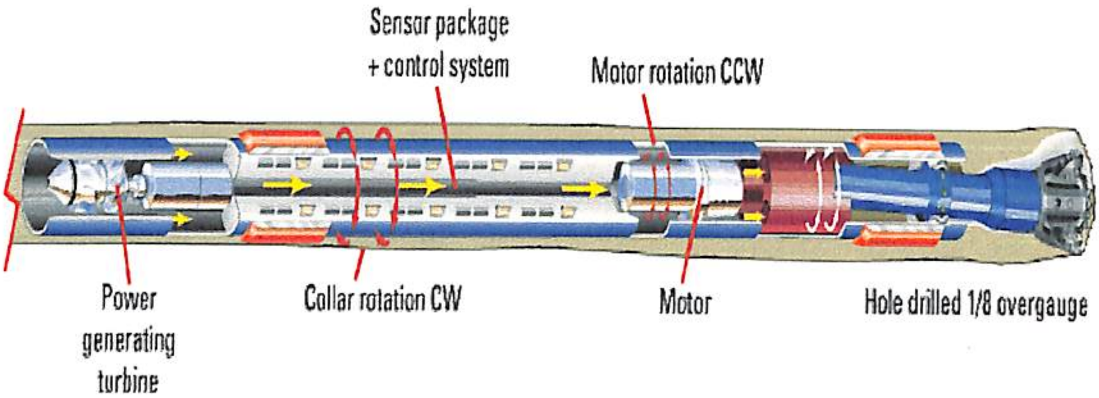

Figure No.5 Point the bit in straight mode; bit shaft allowed to nut ate resulting in slightly over gauge hole [5]

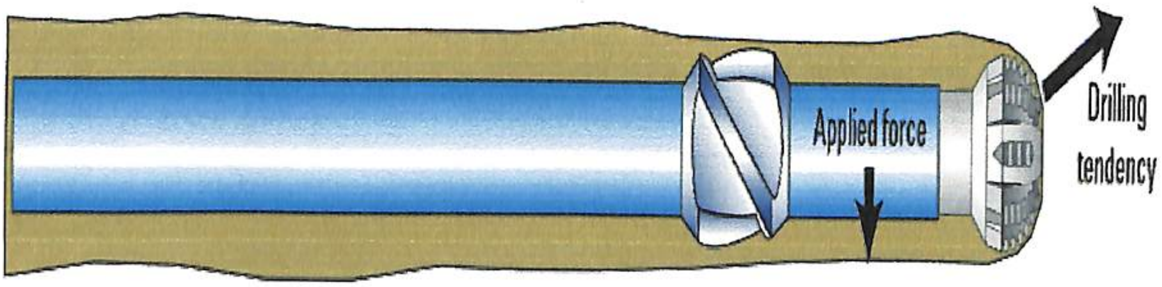

Figure 6: A push the bit Rotary Steerable system. Side force against the formation causes a hange in the tendency of the well being drilled. [5]

3.3 TOP DRIVE SYSTEMS

In this method (also known as the power swivel), the conventional method of rotating the drill string with the rotary the drill string with the rotary table and Kelly is replaced by a motor mounted beneath the swivel that rides up and down the derrick on a pair or rails. The drill string is connected directly to the motor drive package without the Kelly. The traveling motor rotates the drill stem from top, with torque reaction taken through the guide rails. After the stand is drilled down, the connection is broken at the floor, the unit hoisted to the top of the derrick and another 90 ft stand is picked up, connected and drilled down.

Most top drives are D.C. electric with an occasional A.C. or hydraulic version. A critical part of the system is the pipe handler, which provides the means for efficiently handling drill pipe during tripped and connections. There are two successful components, a standard drill pipe elevator and links and a torque wrench to break connections at any positions in the derrick.[7]

The advantages of the system are:

A: The ability to drill ahead with 90 ft stands which eliminates two of every the connections.

B: Much longer continuous core samples can be taken.

C: When tripping into hole , any bridge or obstructions can be quickly reamed out by stabbing the power sub at any positions in the derrick.

D: The really significant advantages is the ability to ream while tripping out (back reaming), thereby avoiding struck pipe . This is particularly attractive in high angle wells.

E: Well control during tripping is improved with in stand stabbing and circulation in any position on the derrick.

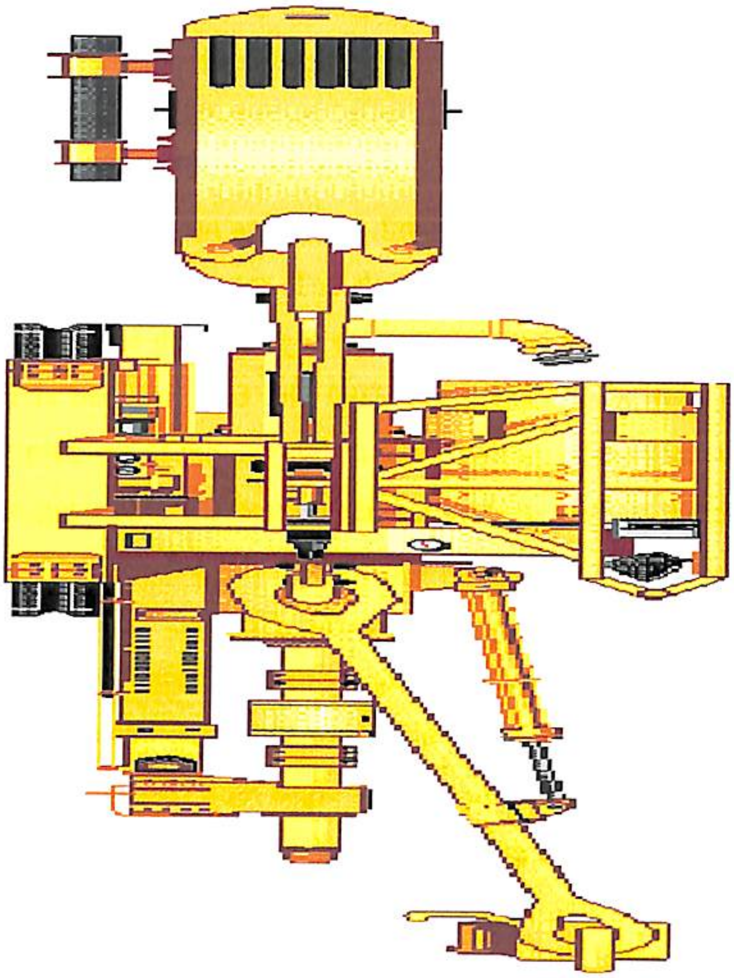

Figure No.7: Top Drive System

3.4 NEAR-BIT-REAMERS

Near-bit reamers are concentric reaming tools that can be run anywhere in the BHA to increase the hole diameter. This tool can be run either above or below the motor and logging-while-drilling tools.

3.5 THRUSTERS

Thrusters generate weight-on-bit by using drilling fluid hydraulics. The pump-open behavior of thrusters decouples the lower part of the bottom hole assembly from the remainder of the drill string, and in so doing provides a constant, controllable weight-on-bit (WOB) that dampens out axial vibrations and shocks.

3.6 TORQUE AND DRAG

Drilling shallow ERD horizontal wells in which the ratio of displacement to TD is greater than 3:1 poses difficulties in maintaining enough weight to push the drill string towards ultimate TVD. If the drag forces are large, then more weight is needed. Drag forces are much higher when the drill string is not rotating, which occurs when tripping the string in at the beginning of a bit run and when directional drilling with a positive displacement motor (PDM) or steerable motor. The sliding friction factor, f_s usually is in the range of 0.30 to 0.50. When the drill string is rotated, the drag forces are greatly reduced and the friction factor is between 0.03 and 0.07. The reduction in drag forces during rotation eliminates the problem of moving the bit to the bottom of the ERD wells. This is the main reason for the popularity of rotary steerable systems. When the drill string is rotating, torque is seen at the surface. This torque is a function of the tool joints in the drill string and stabilizer blades in the BHA. Many techniques like use of mechanical tools, mud lubricants and drill collars for extra weight have been used for reduction of torque and drag, but all these techniques have their side effects. Use of smaller diameter drill pipe may be used in the deeper, high angle sections of ERD wells to reduce torque, drag and equivalent circulation density (ECD). Hole cleaning in high angle boreholes can reduce torque and drag losses.

Torque Reduction

In minimising torque and drag levels, a smooth well profile is important. Low dogleg severity and well tortuosity all assist in reducing torque and drag. Many operators have adopted a well path with a modified catenary profile to reduce frictional losses along the drill string. Rotary Steerable systems control borehole inclination and azimuth while continuously rotating and result in a smoother well bore with the added benefit of improved hole cleaning. Remedial torque reduction techniques include the use of drill-pipe protectors and torque reduction bearing subs. Substantial torque reduction on ultra-extended reach wells, at Wytch Farm and Tierra del Fuego, has been achieved as the result of additions of a proprietary fibrous lost circulation material to the active system. [21]

A reduction approaching 25% has been observed on these wells and the use of this material proved a major factor, along with the advent of rotary steerable systems, in achieving 11 kilometer offset, world record wells. Controlled continuous additions are required while drilling to maintain the concentration above a threshold level that must be reached before a significant reduction in torque and drag becomes apparent. Water-based muds have been used to drill ERD wells with horizontal departures up to 7.6 km. The horizontal departure of the current world record ERD well, drilled by BP at Wytch Farm using oil-based mud, is 10.7 km. When long tangent sections are drilled with water-based fluids, considerable dilution and centrifugation is often required to control the drilled solids content of the mud. Oxygen corrosion can also be a concern when drilling long sections with polymer muds. The use of a lubricant cocktail has achieved dramatic reductions in the torque inside casing in high departure wells in Alaska, with reductions of up to 50-60% at two fields on the North Slope. Friction factors were reduced to around 0.12- 0.20 from 0.28-0.38 for the untreated mud system.

The lubricant cocktail has the ability to endow a water-based fluid with a lubricity approaching that of oil or synthetic base mud and substantial cost savings have been made, together with reduced environmental impact. In one case, their use eliminated the requirement for oil-based mud or a rig upgrade to complete an ERD project. For reduction in torque whilst running casing, the use of solid glass beads has been developed, which act as "ball-bearings" between the casing or open hole and the drill pipe or casing. These beads can withstand temperatures up to 1400°F and down-hole pressures up to 48,000 psi. The glass beads are chemically inert and do not affect the base mud system. Procedures have been developed for ensuring the maximum benefit is derived from their application. [11]

CHAPTER 4

DRILLING FLUID DESIGN AND MANAGEMENT FOR ERD

4.1 INTRODUCTION

Drilling extended reach wells involves some critical issues that can pose significant challenges for the operator. From the Drilling fluids' .Perspective, these include:

- Narrow Mud Weight/Fracture Gradient Window
- ECD Management.
- Hole cleaning
- Borehole stability

The drilling fluid is a key success factor in extended reach drilling (ERD) and historically, oil or synthetic base muds have tended to be the fluids of choice) 10wever, in the current era of increasingly stringent environmental constraints, the industry is striving to expand the fluids technology envelope with the development of more inhibitive water-based mud systems, in conjunction with suitable lubricants, to replace invert emulsion muds.

Drilling fluids for ERD wells are engineered to provide a flatter rheological profile in order to minimise the effect of the fluid rheology on ECD. Performance enhancing products are used to boost the low shear rate viscosity, a critical factor in achieving good hole cleaning and avoiding barite sag. Experience on some of these ERD operations has led to the development of many torque and drag reducing products and techniques. For example, a novel fibrous lost circulation material was found to dramatically reduce torque and played a major part in the successful drilling of world-record ERD wells at Wytch Farm and Tierra del Fuego. Unique down-hole hydraulic sand hole cleaning modeling software has been used in conjunction with down-hole pressure while drilling (PWD) tools to accurately plan and predict fluid hydraulics and cuttings transport to great effect on the world's longest wells. Now in corporations the effect of cuttings loading in the annulus, together with the effect of pipe rotation and pipe eccentricity, this software has become an invaluable operational tool.[8]

4.2. FLUID SELECTION

Invert emulsion muds have been the key ingredient in successful long reach drilling developments in many areas of the world, e.g. Wytch Farm, Argentina and the Gulf of Mexico. This is the direct result of their ability to provide high lubricity, stabilize reactive clays, preserve hole stability, resist contamination and produce firm, dry cuttings. Torque and drag readings and the potential for differential sticking are substantially lower, using an invert system, with an enhanced ability to slide and less tendency for cuttings bed compaction. All these factors combine to make invert emulsion muds the fluids of choice for extended reach wells. Invert emulsion muds, based on mineral or synthetic base fluids with low kinematics viscosity, are well proven in the field and provide a low ECD, excellent hole cleaning and cuttings suspension and extremely stable mud properties. The most suitable water-base fluids currently available for ERD drilling, when shale inhibition is required, are potassium based, non-dispersed, polymer muds containing glycol or silicates. When inhibition is not required, low solids polymer formulations or mixed metal silicates may be used. These systems will provide the required hole cleaning and their use, with a suitable lubricant, can be highly effective. Current inhibitive water-based mud systems containing glycols, etc., while achieving excellent results, still do not match the performance of oil or synthetic base muds. They produce aqueous filtrates that can result in the onset of time dependent hole instability effects over an extended drilling period. This increases the potential for packing off and mechanically stuck pipe. However, these problems occur to a much lesser degree with silicate muds. Silicate drilling fluids exhibit remarkable shale stabilizing properties, resulting in gauge hole and the formation of firm, discrete cuttings when drilling reactive shale's. Silicate muds are now replacing inverts in certain applications. Silicate muds are low solids polymer systems formulated in seawater or monovalent brines with the addition of a soluble silicate complex for inhibition. The mechanism of inhibition is due principally to a precipitation reaction, which occurs on contact with divalent ions present at the surface of the shale, rapidly sealing or partially sealing the pore spaces.

A silicate skin or pressure barrier forms which allows mud hydrostatic pressure to support the borehole wall in a similar manner to an invert emulsion mud. The transmission of mud pressure to the shale and time-dependent increase in near-well bore pore pressure are thus significantly reduced compared with conventional water-based muds. Where the required mud weight is not a constraint, mud salinity can be raised to control osmotic pressure and further restrict water migration. Glycol-enhanced water-based mud systems offer the advantages of enhanced shale inhibition, improved filter cake quality, reduced fluid loss and reduced dilution rates. Shale destabilisation, leading to borehole breakout, is reduced when using a glycol enhanced mud. Glycol solubility with temperature can be adjusted by altering the glycol concentration or the salinity of the mud system. As the temperature of the mud system increases, under conditions of constant salinity and glycol concentration, a micro-emulsion begins to form in the water phase above the cloud point. Eventually, the glycol is completely 'clouded-out' and is totally immiscible. Research and field experience suggests that maximum inhibition is provided by the glycol within this temperature window. For most glycols to be effective, an inhibiting ion (preferably potassium) needs to be present. In environmentally sensitive areas, the use of potassium acetate or potassium chromate may be preferred to potassium chloride. Whether an oil-based, a synthetic based or a water-based drilling fluid is selected, solids control efficiency is paramount for the control of low gravity solids and minimisation of dilution volume. Optimal solids control equipment for an ERD well would include four linear motion shale shakers, ideally preceded by four scalping shakers, plus two high speed centrifuges.

4.3. DOWN-HOLE-MODELLING

To successfully drill an ERD well, it is crucial to be able to accurately predict the following parameters under actual down hole conditions:

- Static and dynamic temperature profile in the well
- Hydraulic pressures
- Annular pressure
- Loss and ECD

➢ Mud rheology Pressure to break gels

Specially designed proprietary software is used to predict down-hole rheology and mud density under static and dynamic conditions, taking&. Into account down hole pressure and temperature effects. Down-hole pressure drops, surge and swab pressures and pressure required to break mud gel strength in the hole may be accurately predicted. This software may be used during pre-well planning and subsequently at the well site in real-time to calculate hydraulics and ECD under down-hole conditions. Field validation by comparison with down hole. PWD tools has provided invaluable feedback and demonstrated excellent agreement between the model and real-time data. Fluid volume changes in the well due to expansion or contraction are calculated for shutdown periods without circulation, when surface mud cools down and mud down-hole heats up. The software is used to perform look ahead, "what if' scenarios for ECD, swäb/surge, etc. and has proven useful in extended reach, HPHT, deepwater and slim hole drilling. Drilling fluid rheology and hydraulics are optimised for the anticipated drill rates. By establishing guidelines for drilling and tripping, use of the down hole rheology/density model, during the planning phase of the well, can reduce the lost circulation risk. The model is subsequently used at the rig-site to manage ECD while drilling. The software predicts the cuttings loading in the annulus, cuttings bed height, the effect of drill string rpm and pipe eccentricity and the maximum recommended drill rate for the given conditions. Use of the software assists in optimising hole cleaning efficiency while minimising ECD. The downhole model incorporates Bingham Plastic, Power Law and the Yield Power Law or Herschel Bulkley model. Of these, the Herschel Bulkley model is typically used for annular hydraulics calculations since it most closely simulates actual mud behaviour over the shear rate range encountered. This model is seeing increasing application, especially in the realm of high angle wells, as it allows more accurate modeling of fluid flow in the area under the drill pipe, i.e. on the low side of hole, where very low shear rates occur. Gels strengths play a major role in downhole pressure changes. In wells with a small mud weight/fracture gradient, drilling window, the pressure required to break circulation can easily result in fracturing the formation if simple precautions are not taken. High gels can also cause problems of excessive swab and surge and, during a well-testing phase, can hinder the transfer of pressure required to operate down-hole test tools. The in-built routine, designed to calculate the pressure required to break gels, can be used to minimise the potential for losses when breaking circulation and to predict the requirement for treatment of the mud to reduce gels prior to running casing.

4.4 HOLE CLEANNING

Hole cleaning is critical in the high angle sections of ERD wells, particularly in long 121/4" tangent sections, and the provision of three mud pumps is considered essential in extended reach drilling. Cleaning the hole without inducing excessive ECD, resulting in down-hole losses, is a major issue. Experience has shown that deviated holes with hole angles in the 40 to 65 degree range are the most difficult to clean. This is due to the tendency of cuttings to form beds and to slide back down the hole. Formation of cuttings beds can be suppressed to a degree by using good suspension characteristics, i.e. by boosting the low-end rheology. Continuous monitoring of standpipe pressure/pump output ratios, cuttings' volumes and torque and drag will help in detecting cuttings bed formation. Flow rate is the primary hole-cleaning parameter and maximum pump rate, within the constraints of maximum ECD and the potential for downhole losses, will provide optimal hole cleaning. On one, high profile ERD project, a flow rate of 1000-1100gpm is used in the 121/4"hole section. Use of 6 5/8" and *5-1/2"*drill pipe allows a 1,000 gpm. flow rate to be maintained to a depth in excess of 5,000 meters. Relatively high rheology mud is used in this section, keeping Fan six speed rheometer 6 and 3 rpm readings around 20 and yield point around 30 Ib/100 ft^2. As a result, neither pills nor back reaming are generally required. One option, when ECD is a constraint, is the use of circulation subs with bypass flow to boost annular velocity. These help achieve a more uniform fluid velocity when placed in the string near diameter changes in the annulus, e.g. above the top of a liner. Their use can improve hole cleaning without exceeding ECD limits. Controlled drilling (where practicable), sweeps, short trips and Optimised flow rates can all have applicability. By coordinating flow rates and rates of penetration, the annular cuttings concentration can be minimised and the potential for losses reduced.

In deep deviated wells, the pump pressure can be a limiting factor in achieving the required flow rate for hole cleaning and consideration is frequently given to the use of larger diameter drill pipe *(5 7/8"*or 6 5/8")to allow higher flow rates. Of course, annular pressure loss and ECD limits have to be taken into consideration to avoid losses and this may preclude the resulting reduction in the annular clearance.

Torque and drag monitoring, recording drill string pick-up weight and slack-off weight, will provide a good indication of hole cleaning efficiency and borehole stability Inadequate hole cleaning may require the use of high density or tandem pills, increased rpm while circulating off-bottom or back reaming. Monitoring of cuttings volume and weight at the shakers, e.g. by using a trough which fills and automatically dumps the cuttings at a pre-set weight, provides continuous real-time feedback on hole cleaning and cuttings transport. As a result of cuttings regrinding by the drill string, there is a tendency for fines to build up on the low side of the hole as a compacted bed and cleaning this out can be difficult. Use of a novel synthetic fiber material, in hole cleaning sweeps, helps to minimise and clean out fine solids build up on the low side of the hole. The fibers tend to form a mat that carries solids to the surface. Flow Regime, Field and laboratory experience has shown that horizontal hole cleaning can be optimized by pumping in turbulent flow, as the ability of laminar flow to move cuttings off the low side of the hole is limited. On the other hand, turbulent flow can result in hole erosion, with increased levels of filtrate invasion as filter cake is removed or fails to form, and drilled solids are not held in suspension during connections. The use of a laminar flow regime, at maximum flow rate, coupled with sweeps and mechanical methods for moving cuttings' beds, is usually the preferred option. In a reservoir with a low fracture gradient, hole cleaning calculations suggest that a drilling fluid with a low yield point will provide minimum ECD. However, in practice, a compromise must be reached to minimise the potential for sag. [10]

4.5 BORE-HOLE-STABILITY

Hole Stability plays a major role in extended reach drilling. In ERD wells, well construction time increases almost exponentially with horizontal departure, resulting in increased trip times and increased open hole exposure at high angle. An in-house proprietary borehole stability model takes into account both physical and chemical aspects of the interaction of drilling fluid with the shale and can accurately predict a safe mud density window and optimum salinity as a function of hole inclination and azimuth. Key success factors in the prevention of well-bore instability include:

- Drilling fluid design in line with geo-chemical and geo-mechanical properties
- Design of the fluid with a flat rheological profile to avoid high ECD and minimise pressure transients.
- Optimisation of well bore azimuth and inclination relative to in-situ rock stresses and bedding planes.
- Design of the fluid to eliminate flow regimes that may promote formation washout
- Optimised procedures for hole cleaning, tripping, surge/swab reduction and mud loss avoidance. [8]

4.6 ECD MANAGEMENT

ERD wells are characterised by a high ratio of horizontal departure to total vertical depth (TVD) and this gives rise to a fundamental problem. The increasing length of the annulus and the associated increase in annular pressure loss (APL) with depth, for a given circulation rate, is not matched by an equivalent increase in formation strength. This reduces the mud weight/fracture gradient window and can limit pump rate to the extent that achieving adequate solids transport can be ditlicult, particularly in enlarged hole sections. Thus, on ERD wells, minimising ECD can be critical to the success of the project. A balance has to be established between running the fluid with a minimum plastic viscosity and the requirement to clean the hole and suspend solids. At the same time, sufficient flow rate is required to minimize cuttings bed formation without producing excessive ECD. An invert emulsion drilling fluid should ideally be built around a base fluid having a low kinematic viscosity, coupled with effective emulsifier and fluid loss additives and atop grade organophilic clay. The quality of the weighting agent will also play an important role in optimising rheology. Specialised organ clays have been developed as suspending agents to enhance yield .stress while avoiding significant impact on plastic viscosity. A base fluid with a low kinematic viscosity will aid in achieving a flatter rheological profile, enhancing hole cleaning in large diameter hole sections, ratholes, riser etc., while contributing to lower ECD. [8]

CHAPTER 5

LOGGING & COMPLETION AND WORK-OVER

5.1 MEASUREMENT –WHILE -DRILLING

MWD is the down-hole measurement of important parameters and the simulations transmission of those measurements to the surface while drilling. The type of information may be:

- Directional data (Inclination, azimuth, tool face);
- Formations characteristic (gamma ray, resistivity logs, temperature, pore pressure);
- Drilling parameters (Down hole WOB, torque rpm)

In the past, drilling and formation evaluations processes have been accomplished with different technologies, separated in time. Ignorance of what is taking place down-hole during the drilling process has caused it to be viewed more as an art than a science. The great advantage of MWD is that it allows the driller and the geologist to effectively "see" what is happening down-hole in real time. It therefore improves the decision –making process, since there is a delay of only a few minutes between measuring the parameters down-hole and receiving the data at the surface:

- Rugged reliable sensors that could measure the required data at or near under dynamic drilling conditions;
- A simple but effective method of transmitting the information to surface ;
- A system that could be easily installed and operated on any rig without causing too much disruption to normal drilling practices;
- A system that would be cost effective:

The major problem of the MWD system is the telemetry link between down-hole and surface. There are four alternative methods:

- electric conductor (hard-wire systems)
- electromagnetic radiation ;
- seismic (acoustic) waves;
- mud pressure

Of these, only telemetry has proved to be economically attractive . this is a method of transmitting information through a flowing mud column . In this process , the pressure in a flowing at a point down-hole is modulated by mechanical means (mud plus valve) and the resulting pulse are detected by a pressure transducer conveniently located at the standpipe.

5.2 THROUGH- BIT-LOGGING

ERD wells are considered to be more difficult to work on in comparison to the conventional wells. Logging is one of the operations, which might prove a difficult task in some of the ERD wells. Through bit logging technology can be an efficient logging technology for difficult ERD wells. Through bit logging is a method for data acquisition using the drill string and bit as a conduit to the well bore. In this new system, the logging tools are conveyed via the drill string and pass into the open hole through a specially designed bit, with formation evaluation data being acquired with either wire line or memory tools, unlike LWD where tripping drill pipe out of the well is necessary. Thus, rig time can be saved. Thus, TBL offers the following advantages: [3]

- Reduced operation risk
- Security of data acquisition
- Rig time savings
- Continues wire line quality data

5.3 SOLID EXPANDABLE TUBULAR TECHNOLOGY

Introduction

Solid expandable tubular (SET) have evolved over the last few years into a proven open-hole drilling-liner and cased-hole-remedial-liner alternative to conventional technology. A well-design feasibility study was conducted as part of the front-end engineering and design for a major North Sea operator. The study was performed to evaluate the relative merits of using conventional drilling technology vs. expandable-tubular technology for lateral reach and the effect on capital efficiency and potential field development. This well-design study indicated potential lateral-reach increases of 25 to 100%. Drilling-performance and cost studies indicated that existing and planned well costs and times in the same North Sea fields could be reduced by more than U.S. $40 million or 30 to 50% of the current drilling cost and time.

Drilling and completion of ERD wells is considered as a difficult task due to the many problems associated with ERD wells like high torque and drag, hole cleaning and hole stability.

- Solid Expandable Tubular (SET) Technology has two important advantages in ERD wells:
- Favorable drill string casing geometry is possible which can reduce the tendency for drill string lockup.
- Use of Larger drilling tubular is possible
- ERD wells extend up to large horizontal distances, which require running additional casing strings. SET is useful in these cases.

In SET, the casing is being cold worked to expand it to the required size downhole. Many other technical aspects are taken care of, as cold working is an unstable process for the tubular. The required length of the expandable casing is then connected and is run in the wellbore which is followed by running the drillstring concentrically into the liner till it is with hydraulic pressure from the drillstring. The expansion process is verified by decrease in the hook load. The progress of the cone through the tubular deforms the steel past its elastic yield limit into its plastic deformation region, but not its ultimate yield strength. Expansions of over 25percent, based on the diameter of the pipe, have been accomplished.

- SET are very useful in transversing severely depleted zone especially when the zone lies in an abnormal pressurized environment.
- Thus, vertical wells can easily be completed with the conventional casing systems, but for long ERD wells, in some cases, SET become the only option.

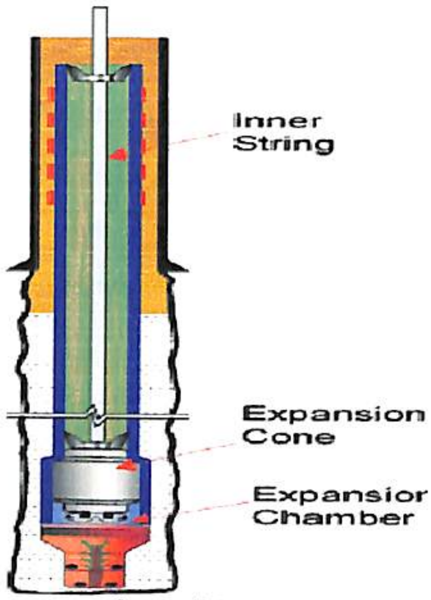

Figure 8: Expansion process for Solid Expandable Tubular

Expandable ERD Well Design

All aspects of SETs and single-diameter liners were considered in the context of ERD beyond conventional-technology limits, including the unique force transmission during expandable- technology operations. Optimal well paths were planned by use of con- strained optimization methods. Wear analysis was based on an adhesive-wear model that is the basis of all industry wear-analysis programs. Casing integrity was evaluated with the working stress design approach (deterministic design) and supplemented by probabilistic design where appropriate. Drag risk was evaluated.

evaluated with the working stress design approach (deterministic design) and supplemented by probabilistic design where appropriate. Drag risk was evaluated.

The base well-design model evaluated the achievable lateral reach and drilling- trouble reduction with the following.

- Conventional drilling technology.
- Conventional technology with improved drilling practices.
- Installation of two SET liners to preserve the desired completion size.
- Installation of multiple, successive single-diameter drilling liners.

Initial modeling work indicated that the practical drilling limit with conventional technology was approximately 26,400-ft lateral reach, with significant drilling risk. This modeling was validated by the operator's recent lateral-reach drilling record, established with significant drilling trouble. To mitigate the primary drilling trouble and optimize the lateral reach, two SET liners were engineered into the well-design model, which indicated a potential lateral reach of approximately 39,600 ft.

To increase the lateral reach to the desired 50,160 ft, the model included various single diameter liner lengths, number of liners, and installation depths. The model indicated that a 50,160-ft lateral reach was achievable with 9 to 11 successive single-diameter liners varying in length from approximately 3,000 ft up-hole to 1,000 ft near total depth (TD).[15]

The Expandable Legacy

SET technology is an industry-changing drilling and completion technology that results in greater drilling-related capital efficiency and improved field- development flexibility and economics. This enabling technology has pushed the applications envelope progressively and to date has had successful installations in the following.

- Well depths greater than 28,000 ft.

- Bottom-hole temperatures reaching 400°F.
- Mud weights greater than 19 lb-m/gal.
- Expanded liner lengths of more than 6,000 ft.

SET systems currently are available in pre-expansion sizes from 41/4 to 16 in., with expansion ratios ranging from 5 to 17%. The initial concept for application of SET technology was as an enabler for geologically complex, ultra deep-water exploratory wells and as a contingency to isolate depleted zones in abnormally pressured environments. The application of SET technology later included open-hole shoe extensions and lost-circulation mitigation in addition to cased- hole remediation and water shutoffs.

Single-Diameter Technology

The single-diameter system is the natural progression of SET technology. This system installs similar-sized liners sequentially in a well without a decrease in the inside diameter (ID). This process can be repeated to maintain consistent well bore ID to TD, virtually eliminating the telescoping effect that occurs when running conventional casing. Benefits of this technology include bcost reduction, reduced environmental impact, operations efficiency, and reservoir optimization.

The promise of the single diameter well, when fully realized, could change forever the development and economic models for the exploration and development of hydrocarbons. The basic concept involves mechanical expansion to create a single-joint down-hole "bell section" with a resultant 10.95-in. ID followed by a single- joint 10.4-in.-ID section. The larger-ID bell section accommodates the next expanded liner section with a metal- to-metal clad hydraulic seal to facilitate the single-diameter wellbore. The initial 10.4-in.-ID expanded section provides a packer-setting section to facilitate the subsequent 10.4-in.-ID, and more-efficient, hydraulic expansion. [14]

5.4 CASING FLOATATION

As stated earlier that overcoming torque and drag is one of the major challenges in an ERD well. This becomes one of the major hurdles when completing a well to a departure beyond 8000m. The ERD well drilled at the Wytch Farm showed that running the 9-5/8in. became increasingly difficult with greater departures. It was analyzed that drag would be to run the casing even with full weight from the traveling block. Casing floatation was the method, which can get the casing to the total depth.

In casing floatation, casing is not filled as each joint is run into the wellbore, as is done in typical casing operations. The goal is to have the casing close to neutrally buoyant, so it becomes virtually weightless in the mud, and drag is minimal. In a long extended-reach section, an entire air-filled casing string can become positively buoyant and resist being pushed farther into the well. Thus, partial casing floatation was taken up and the casing string was divided into two sections; the upper section filled with mud and the lower section filled with air. Thus, double floatation collars were used. The section filled with mud is in the vertical section of the well and provides weight to help push the lower, buoyant casing into the well. [20]

BP completed three of its wells with casing floatation namely M08, M09 and M11. Thus, casing floatation proved to be an important technology for ERD wells.

5.5 COILED TUBING CASING PATCHES

This technology is an external casing patch system. The tool is a high pressure hydraulically actuated dual packer expansion device. After the two rubber seals are actuated, high-pressure fluid is pumped between the seals. The pressure is increased and expands the patch first elastically then plastically with approximately 5,000 psi hydraulic pressure. The pressure on the seals is controlled to ensure that the seal is maintained until full contact with outer tubing/casing is achieved. As the pressure continues to increase, the outer tubing is elastically strained until the predetermined and preset final swage pressure is achieved. The pressure is then bled off, and the seals are retracted by use of a 1500 psi retract cycle.

Other conventional fishing tools are also used like:

- Junk baskets
- Junk mils
- Wireline spears
- Overshot

5.6 WELL CONTROL

Gas kick is one of the most dangerous situations which can cause a blowout of the well. ERD wells are more prone to kicks and lost circulation due to the large distances up to, which they are drilled. Though, ERD wells have some advantages when the well takes a kick because gas migration rates are slower. Gas migrates at a rapid rate when the inclination is 45 and its migration rate decreases as the well becomes horizontal. As long as the kick is in the horizontal section, the shut in casing pressure (SICP) and shut in drill pipe pressure (SIDPP) are about the same because hydrostatic pressure on both sides of the U-tube is the same. [3]

The following well control procedures should be taken in ERD wells.

1. Driller's method should be used to control the well. The driller's method uses the old mud to circulate out the influx and requires two circulations to kill the well. The first circulation displaces the influx with old mud from the pits, and the second circulation replaces the old mud with the new kill mud. The kil weight mud will take a long time to get prepared for the long ERD wells, which could worsen the conditions. So, driller's method is the most preferable method.

2. Start circulating at a high rate for a short time to remove gas from the horizontal section of the well-bore.

BENEFITS

Extended Reach Drilling (ERD) service gives you the solutions for restricted reservoir production. Eliminate additional platforms. You'll be able to use land-based drilling in fields that normally would require costly offshore operations.

This technology also lets you reduce well site foot prints and minimize environmental effects. You'll dramatically improve reservoir drainage at the least cost. Describe down hole conditions accurately

Extend the life and productivity of new and existing wells

A variety of drilling performance measurements give you vital data about down hole conditions. These data identify the factors that cause harmful vibrations, BHA damage and poor performance.

APWD (Annular Pressure While Drilling) data monitored in real time give you crucial hydraulic information for proper ECD and hole cleaning control.

SUGGESTION

The following suggestions have been given keeping in mind the logging, drilling and completion aspects of ERD wells.

- **Swell Packers**: Solid Expandable tubular technology is one of the main technologies used in ERD wells. This technology can be complimented with the use of swell-able packers. Swell-able packers can be easily customized to suit a variety of completion scenarios. Moreover, they are less costly than the mechanical packers. Also, swell-able packers can eliminate cement jobs in many cases, particularly where the cement is being used to achieve zonal isolation.

- **Offset Stabilizers**: the use of offset stabilizers allows better rotary steerable operations. The new stabilizer drills a curved path by using an offset stabilizer to achieve the desired well trajectory. Orientation of the control stabilizer is maintained by an eccentric mass, which hangs to the low side of the hole. The new offset stabilizer accurately geo-steers as per the target requirements. The new stabilizer requires a hole inclination in excess of 45 to maintain orientation of mass. The new offset stabilizer offers the following advantages:[3]

- Improves ROP
- Elimination of bit trip
- Ability to geo-steer along the extended section

Thus, due to these advantages, the offset stabilizer proves to be an important technology for ERD wells.

- **Through Bit Logging**: ERD wells are considered to be more difficult to work on in comparison to the conventional wells. Loggings is one of the operations, which might prove a difficult task in some of the ERD wells. Through bit logging technology can be an efficient logging technology for difficult ERD wells.

Through bit logging is a method for data acquisition using the drill string and bit as a conduit to the well bore. In this new system, the logging tools are conveyed via the drillstring and pass into the open hole through a specially designed bit, with formation evaluation data being acquired with either Wireline or memory tools, unlike LWD where tripping drill pipe out of the well is necessary. Thus, rig time can be saved. Thus, TBL offers the following advantages:

- Reduced operation risk
- Security of data acquisition
- Rig time savings
- Continuous Wireline quality data

Thus, the following table gives a summary of the best technologies for ERD wells:

Logging	MWD, Through Bit Logging
Drilling Technology	Rotary Steerable Systems (RSS)
Drill Pipes	5-7/8 in.
Drilling Fluids	Potassium based, non dispersed, polymer mud's containing glycol or silicates
Completion	Solid Expandable Tubular (SET), Casing Floatation, Swell Packers,
Well Control	Driller's Method
Fishing & Work over	Coiled Tubing Casing Patches

FUTURE DEVELOPMENTS

Looking to the future, we can predict major technology developments that will dramatically change the well construction, productions and asset management process. In all likelihood, these changes will lead to increased reserves, improved recovery techniques and reduced costs, making operations more competitive. Indeed it is quite possible that within the next two or three years, some of these technologies will help cut well constructions costs by as much as 50 percentage.

The mono-diameter well is one of these exciting new technologies. In conventional wells, smaller and smaller casing is used to extend the reach unit the driller eventually runs out of hole. The mono- diameter well does not have this problem, because it is essentially a single diameter from top to bottom. Imagine what if would be like to design wells without having to worry about casing points. Suddenly, what is now a very complex drilling operational becomes as simple as knowing how large the pipe needs to be and where it should end. This paradigm shift will bring radical changes to the drilling process and in requirements for personnel and equipment. Mono-diameter wells can also reduce the cost of well construction by allowing deeper wells to be drilled using smaller rigs and platforms, making the well site a safer place to work .In addition, these wells will produce fewer cuttings a very appealing environmental advantage. In all likelihood, the first deepwater mono- diameter well will be drilled in the near future, with 9.625- or 7.0 inch casing running all the way from top to bottom. [19]

As drilling conditions grow economically and technologically more challenging, advance horizontal, multilateral and extended reach technologies will continue to provide solutions. Proof of that is how far the industry has already come since the 1980s, when horizontal wells were first developed commercially. As we look toward the future, advancements in real time technology and other "hole in one" creativity will provide the widest possible range of new ideas to make drilling wells safer and more efficient, productive and environmentally sound.

CONCLUSION

ERD is a pivotal industry activity which has already provided major financial impact on a number of projects world-wide. ERD capabilities are expanding rapidly and limits for ERD with current technology remain undefined.

ERD opportunities are growing rapidly. Dedicated effort will be required to access and implement expanding ERD technologies. Wellbore stability is critical to assessing feasibility of ERD projects and for detailed ERD well planning.

Major Conclusions from well bore stability include:

There is a range of trajectories where drilling and stimulation will be most difficulty because of high stress concentrations around the well bore. This is a function of institution stresses and formation strength time dependent strain is still difficult to predict but is receiving continued research focus.

Drilling fluid design is another critical aspect of ERD well planning performance characteristic favor the use of oil based or synthetic based mud systems for ERD but progress continues with specialized water based mud development. The design of an optimal ERD drilling fluid must consider several critical factors. Including well-bore stability. Lubricity cutting transport, hole problem and formation damages avoidance and environment impact. Optimized design of drilling equipment is necessary for successful ERD operations. Key equipment components include drill-string design, torque reduction tools, rig equipment, directional drilling systems and dynamic mitigation methods.

3. Chavyo Field

1. The well design tailored to the regional rock properties enabled successful execution of the drilling program

2. The rig & pipe barn concept enabled safe and fast operations under arctic conditions

3. Casing installation procedures enabled the running of all casings to TD

Drilling fluid design is another critical aspect of ERD well planning performance characteristic favor the use of oil based or synthetic based mud systems for ERD but progress continues with specialized water based mud development. The design of an optimal ERD drilling fluid must consider several critical factors. Including well-bore stability

Ultra - Extended Reach Drilling (UERD).

The proven feasibility of ERD drilling technology at Chayvo opens opportunities for increased usage of this technology. The potential exists to drill longer ERD wells from land into the Chayvo reservoir because of the favorable geologic conditions. Wells approaching 15 km with displacements of up to 14 km are being considered. TVD vs. Reach plot for worldwide ERD wells and shows drilled and the planned Chayvo ERD wells. Areas that need to be studied for these projects to succeed include, but will not be limited to:

- Torque reduction and/or torque capacity improvement
- Drilling issues (RSS performance, reliability, number of trips)
- Validation of MWD Telemetry to 15 km
- Increased true vertical depth uncertainty with longer reach wells
- Casing running issues (flotation, mud weights)
- Completion issues (coiled tubing perforations, tractor hydraulics).

Lubricity cutting transport, hole problem and formation damages avoidance and environment impact. Optimized design of drilling equipment is necessary for successful ERD operations. Key equipment components include drill-string design, torque reduction tools, rig equipment, directional drilling systems and dynamic mitigation methods.

Design of Extended Reach Well Trajectory

1.Extended reach well profile design is one of the critical technologies for success in ERD. ERD well path is designed with 3-section trajectory generally.

2.The principles of planning are making torque and drag as small as possible and making well length as short as possible in typical drilling operations (tripping out, sliding drilling and rotating drilling).

3.Nine types of shapes in build section are optimized. Three kinds of sideway curves especially sideway parabola are better, curvature decreasing curve is second and circular arc is third.

4. A further discussion of design parameters' impact on selected optimum curve is given in the paper and guidelines are provided for future ERD well planning.

5.There are many factors affecting ERD well path. The optimum profile should be-selected with actual operations. Torque and drag must be calculated in three typical drilling operations simultaneously, as must verify rig and top drive capability.

APPENDIX-I

Design Of Extended Reach Well Trajectory

Extended reach drilling (ERD) is mainly used to develop reservoirs from the present drilling sites far away from each other when the drilling site and units could not be set up at the surface(mainly water surface)or the projects need considerable costs. For greatly reduction in offshore drilling costs ERD technologies develop rapidly from late 1980s. Well profile design is one of the critical technologies for success in ERD. Commonly ERD well path is designed with a vertical section, build section and hold section so-called 3- section trajectory due to concerns over using shorter vertical depth to achieve longer horizontal reach. The purpose of this paper is to study which well profile is optimal in build section. The beneficial reductions in torque and drag achievable with different well shapes are discussed as early as 1980s in China. Many mathematical models are presented such as catenary, parabola and circular arc and so on. We will benefit from these I-7 In 1997 reference discussions on today's research. [8] Gave a new concept on trajectory design. Unfortunately the conclusions are questionable for lack of further research.

Since 1990's, at Wytch Farm field in British, the ERD wells were drilled using catenary or pseudo-catenary profile with initial build rates of 1-1.50 /30m ,increased in steps to maximum build rates of 2.50 /30m. The increase in build rate is designed at about 0.50 /400m. They declared that the use of this type of profile has resulted in an increase in casing running weight of 20-25%9. However when we design ERD well using
this method and simulate with computer, pseudo-catenary does not exhibit so significant benefits in term of increasing the ability to run casing.

To deepen this study, this paper discusses and compares nine types of well profiles. The method we used is to take XJ24- 3-A 14 well located South China Sea as an example. Different profiles are planned using nine different shapes, torque and drag are calculated using computer model we developed before in three operating cases: sliding drilling, rotating drilling and tripping out. The conclusions come from analyzing results.

The concept and theoretical curves are appended in appendix A.

To assure the reliability of our computer model for calculating torque and drag, we valid the program with drilled well path and measured torque and drag in XJ24-3-A 14 well.

The result proves that calculating values conform with measured values very well, see appendix B.

Principles of Well Path Optimization

There are many factors that need to be considered to achieve an optimum well path. Drill-string stress and casing wear must be taken into account, as must rig and top drive capability, value of torque and drag and easy operation or not. ERD well profile design is not just a simple geometric curve design, it is an integrated project closely related to drill-string mechanic and drilling engineering. There are three main principles that should be obeyed when planning an extended reach well.

Minimizing Torque and Drag

The key features of ERD are that horizontal departure is long and inclination is high which will give rise to considerable torque and drag for drill-string and casing string. Torque and drag become main limitations for horizontal reach in ERD.There are many ways to reduce torque and drag. Optimization of profile is one. We should select well trajectory that makes torque and drag as low as possible.

Minimizing Well Length

Well length is different for different type of curve shapes. It is very clear that we should select well trajectory as short as possible because significant benefits come from reduction of footage.

Drilling Operation Need

In practice, drilling operations include tripping out, tripping in, sliding drilling, rotating drilling, forward reaming, back reaming and running casing etc. There are different

forces exerting on drill-string in different operations. Torque and drag is different, too. The operation that has profound impact on project and turns out to be main limiting factor for successful ERD should be considered while planning. Tripping out, sliding drilling and rotating drilling are typical. One of them may become the most difficult case in different conditions. We calculate torque and drag simultaneously and find out optimum well path through comparison in three drilling operations.

Optimization of ERD Well Profile

As described above, we take XJ24-3-A 14 well as an example. Different well profiles planned with nine types of well shapes are optimized on torque and drags calculated from the soti are. Xj24-4-A 14 well profile design conditions are as follows:

Target vertical depth 2576m; target horizontal departure 7543m; kick off point 442m; hold angle 79.120 ; friction coefficient O.19; hole diameter 2 1.59cm; mud density

1. lg/cm3; weight on bit 100KN. Table 1 shows torque and drag in three typical drilling operations. Findings are below:

2. Torque and drag and well length of number 5,6,7 sideway curves are less than number 1,2,3 curves in any cases. Reasonable approximations of sideway curves should be used in any critical ERD project to obtain benefits.

3. Among three of sideway curves, parabola has the smallest drag and the shortest well length in sliding and tripping out operation, and torque in rotating operation is not too high. Disadvantages of this profile are high build up rate and long build up length.

4. Comparing number 1, 8, 9 curves, curvature-decreasing curve is better than circular arc. And circular arc is better than curvature increasing curve. The curvature-increasing curve is pseudo-catenary in fact. The predominance of pseudo-catenary is not significant from Table 1.

The main conclusions of study are as follows: With advanced steerable drilling system and easy trajectory controlling, sideway curves should be adopted firstly for they have smaller torque and drag and shorter well length. Secondly it is curvature-decreasing curve that has lower build rate and shorter build section. Circular arc should not be ignored. It has smallest and constant build up rate that is favorable for trajectory control. Moreover torque and drag is small. The disadvantage is longer well length. The choice of build section should be determined in specific objectives and actual operating environment.

Impacts of Design Parameters

Sideway Curves

Kick off Point. Fig.1 and Fig.2 show that maximum wellbore curvature, well length and torque and drag increase with the increase of kick off point depth. This indicates that kick off point is as good as shallow providing it meets needs of surface casing length and vertical well length and can generate sufficient weight on bit. Hold Angle. Fig.3 and Fig.4 illustrate that maximum wellbore curvature, torque of rotating drilling and drag of tripping out decrease with the increase of hold angle, on the contrary drag of sliding drilling and well length increase. Hence the choice of hold angle must be thought thoroughly. Comparisons of Sideway Curves. Well length of. Sideway parabola is the shortest among three curves. Torque and drag is smaller, too. The disadvantage of it is maximum wellbore curvature that may cause local high casing wear. Parabola should be used if casing wear is solved, otherwise other sideway curves must be alternative.

Curvature Decreasing Curve

Kick off Point. Fig.5 and Fig.6 .show that well length and hold angle increase with the increase of kick off point depth, and torque and drag of tripping out decrease. The relation between drag of sliding drilling and kick off point depth is more complicate (see Fig.7). The choice of kick off point depth depends on specific conditions.

Curvature and Curvature Gradient. Well length decreases and drag & torque of tripping out and rotating drilling increase with the increase of average wellbore curvature. Build rate should be as small as possible to reduce torque and drag and casing wear.

Circular Arc

Build up rate. As shown in Fig.8 and Fig.9, drag and torque of tripping out and rotating increase with the increase of build rate. Build rate should be lower to diminish torque and drag. But low build rate causes large hold angle and long well length. Build rate must be suitable. Kick off Point. As shown in Fig. 10 and Fig. 11, maximum wellbore curvature and torque and drag of tripping out and rotating drilling decreases with the increase of hold angle, and drag of sliding and well length increase. The choice of hold angle should be made comprehensively.

Concepts and Formula of Nine Kinds of Curves

1.CircularArc here does not list anymore.

2.Catenary

3.Modified Catenary

Relation between catenary curvature and well inclination is modified artificially as

$$K = -\frac{1}{q} \cdot \sin\alpha$$

4.Parabola

5.Sideway Catenary

Normal catenary is rotated 90 degree in clockwise and the under-section of curve is used as build up section. There is no transitional section in profile. Expression for key parameterALC and sideway catenary constant q is

$$\Delta L_{cd} = \frac{\frac{(D_d - D_a)(1-\cos\alpha_c)}{\cos\alpha_c} - S_d \ln tg(\frac{\alpha_c}{2}+\frac{\pi}{4})}{(1-\cos\alpha_c) - \sin\alpha_c \cdot \ln tg(\frac{\alpha_c}{2}+\frac{\pi}{4})} \quad \text{(A-1)}$$

$$q = \frac{D_d - D_a - \Delta L_{cd}\cos\alpha_c}{\ln tg(\frac{\alpha_c}{2}+\frac{\pi}{4})} \quad \text{(A-2)}$$

6. Modified Sideway Catenary

Normal modified catenary is rotated 90 degree in clockwise and the under section of curve is used as buildup section. This type of profile does not need transitional section. We obtain following formula:

7. Sideway Parabola

Normal parabola is rotated 90 degree in clockwise and under section is used as build up section. This type of profile does not need transitional section. Formula of calculating key parameter L cd ,i and sideway parabola constant p are

$$\Delta L_{cd} = \frac{2S_d}{\sin\alpha_c} - \frac{D_d - D_a}{\cos\alpha_c} \quad \text{(A-5)}$$

$$p = \frac{D_d - D_a - \Delta L_{cd}\cdot\cos\alpha_c}{tg\alpha_c} \quad \text{(A-6)}$$

8. Curvature Increasing Curve

The curvature of build up section is changing with well length Increasing. The gradient of curvature is constant, that is dK/dL=G= constant. Curvature of any point in profile is to be $K=K_b+G*AL$.

9. Curvature Decreasing Curve

It is same as curvature increasing curve except that G is negative.

Validation of Torque and Drag Software

As shown in figure B-1, Simulating results are in line with to measured values of hook load very well in three typical operations (tripping out, tripping in and rotating off bottom). The results indicate that our program is valid and reliable.

Table: 1 Torque and Drag Three Typical Operations

Sr. no.	Curves in build up section	Maximum build rate °/ 30m	Sliding drag (KN)	Rotating Torque (KN	Trip out Drag (KN)	Well length (m)
1	Circular arc	2.08	437.69	30.28	594.43	8595.07
2	Catenary	5	438.32	31.87	623.23	8601.07
3	Modified catenary	5	440.4	32.34	631.91	8629.61
4	Parabola	5	437.58	31.65	619.13	8594.5
5	Sideway Catenary	3.83	430.35	30.45	529.88	8493.61
6	Modified Sideway catenary	2.66	433.5	30.04	547.21	8544.76
7	Sideway parabola	6.54	428.17	31.27	540.29	8432.29
8	Curvature increaseing curve	3.76	438.68	31.94	624.4	8628.2
9	Curvature decreasing curve	3	431.49	30.24	557.94	8519.7

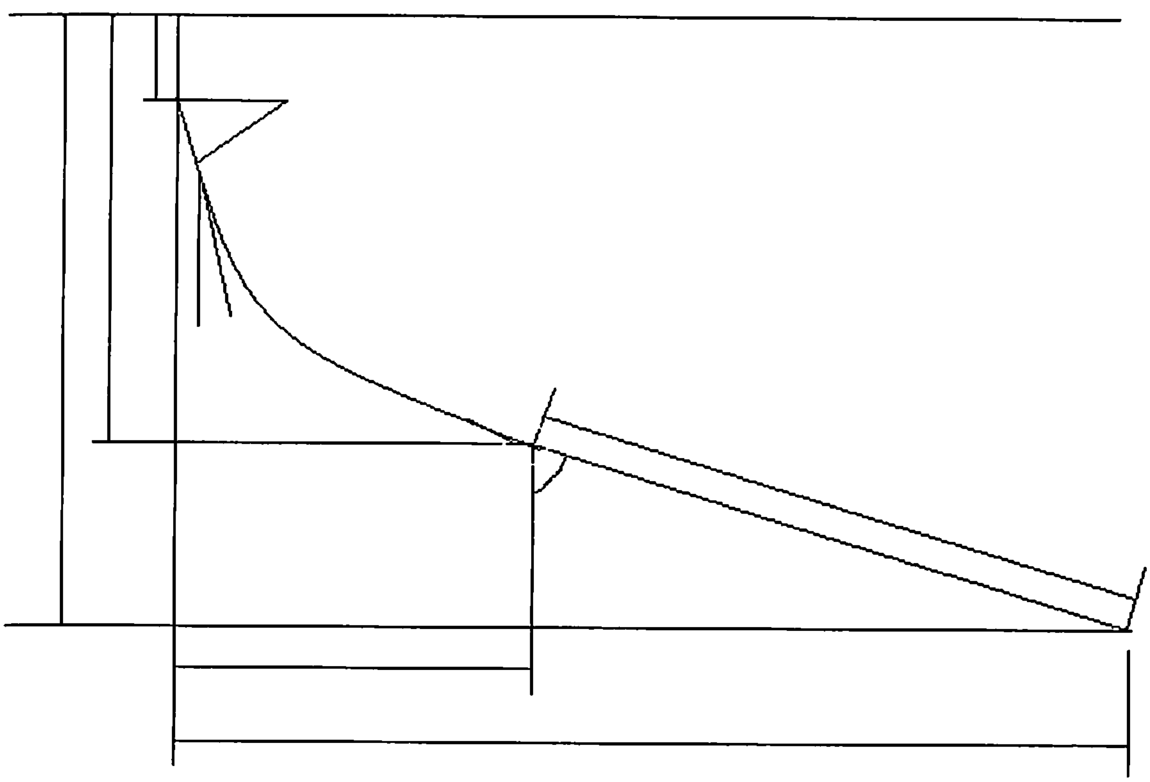

Figure: Extended Reach Well Trajectory

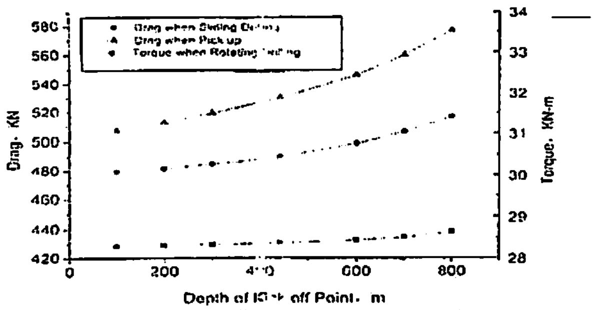

Fig 1 Effect of kick off point depth on torque and drag in the sideway catenary path

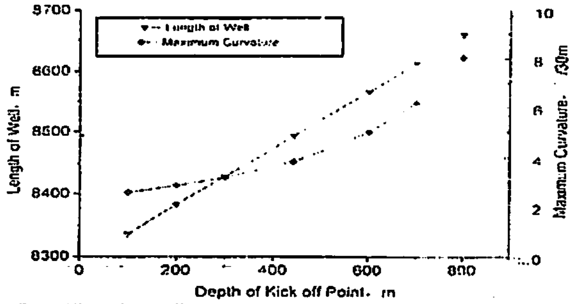

Fig.2 Effect of kick off point depth on well length and maximum curvature in the sideway catenary path

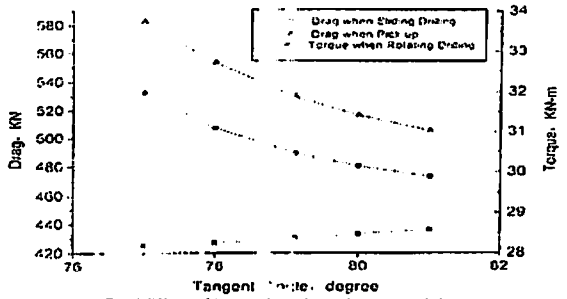

Fig 3 Effect of tangent angle on torque and drag in the sideway catenary path

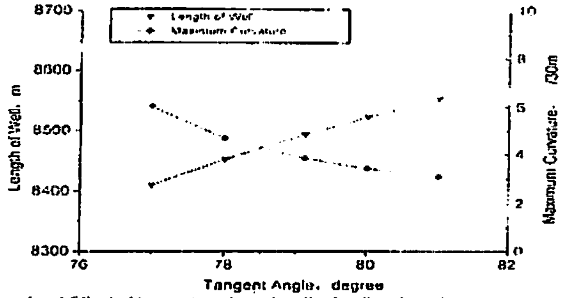

Fig 4 Effect of tangent angle on length of well and maximum curvature in the sideway catenary path

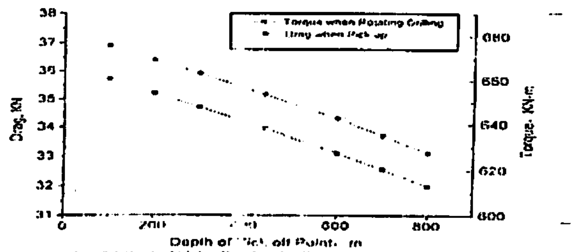

Fig 5 Effect of kick off point depth on torque and drag in the curvature decreasing curve path

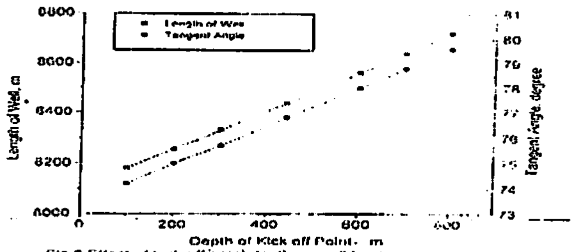

Fig.6 Effect of kick off point depth on well length and tangent angle in the continuous curvature decreasing curve path

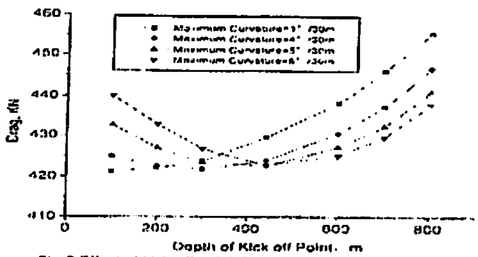

Fig 7 Effect of kick off point depth on drag in sliding drilling case in the curvature decreasing curve path

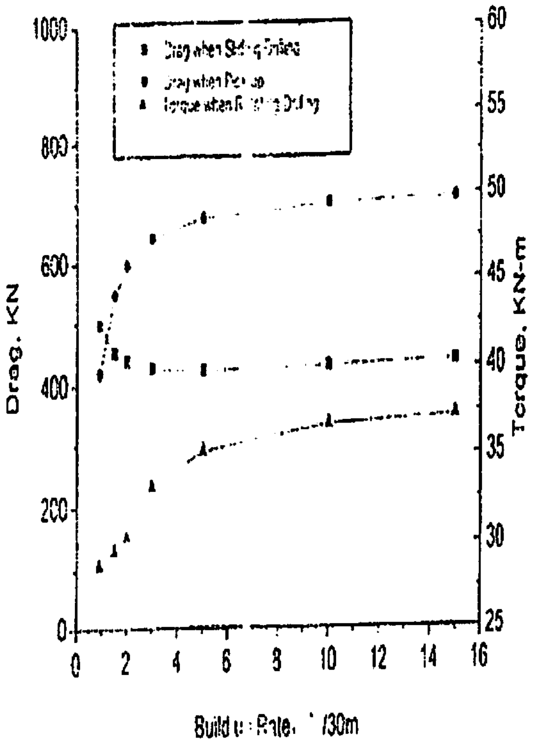

Fig 8 Effect of build up rate on torque and drag in the circular arc path

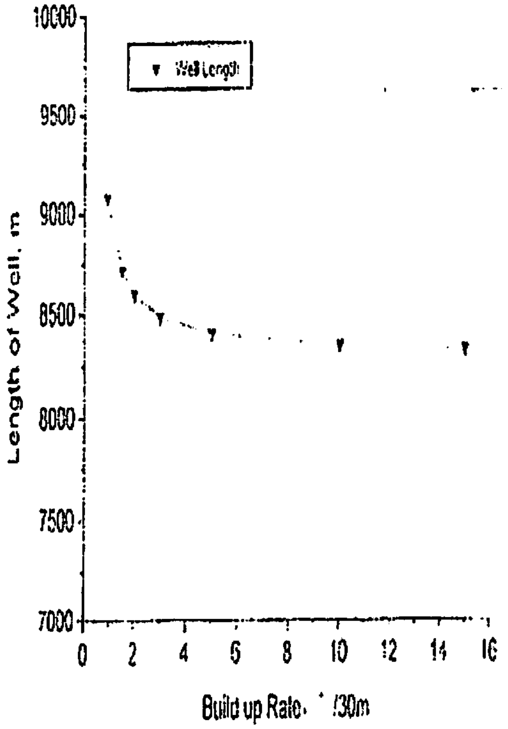

Fig 9 Effect of build up rate on length of well in the circular arc path

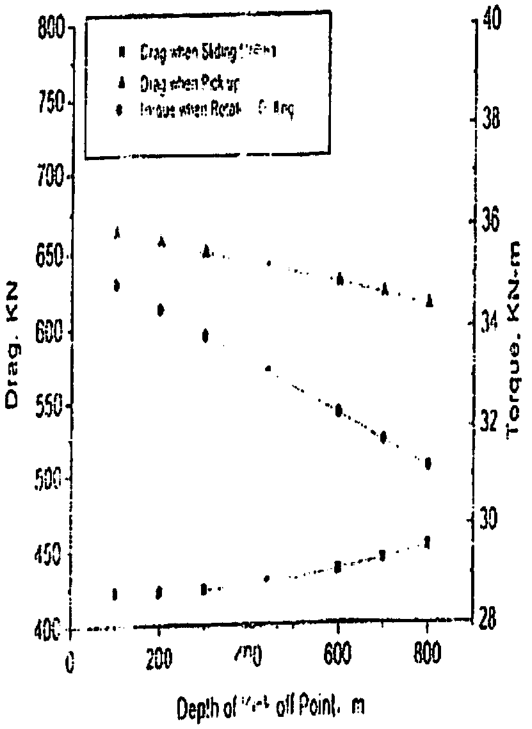

Fig 10 Effect of kick off point depth on torque and drag in the circular arc path

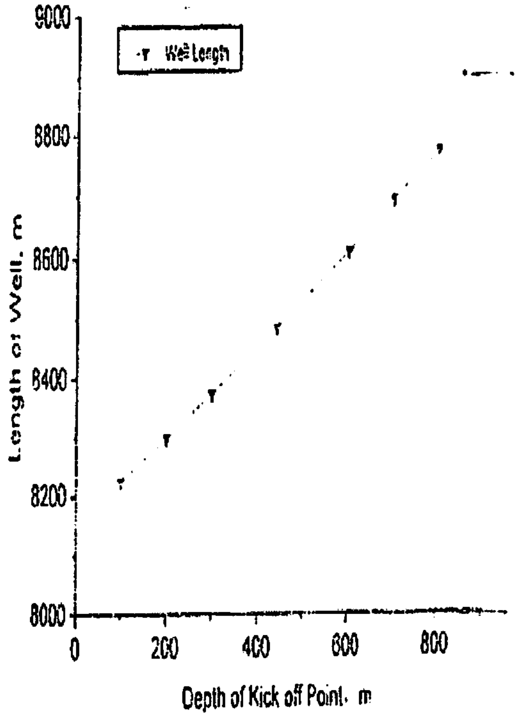

Fig 11 Effect of kick off point depth on length of well in the circular arc path

APPENDIX-III

Case Study-Chayvo Field Russia

1. Introduction

ERD wells were drilled in several fields around the world 1-7 each project had justification for the increased technical risk, required research work and upfront capital expenditure. Chayvo onshore well site from which the first two pilot ERD wells, Chayvo Z-6 and Z-4, were drilled. The success of these two wells proved the feasibility of developing the northern portion of Chayvo field, shown in Figure 2, with ERD wells and creates significant opportunities for the Sakhalin I consortium, Enhances project economics through application of ERD technology Reduces or eliminates the capital cost of large offshore structures Offsets high offshore operating costs with lower onshore cost Reaches additional resources from the same infrastructure Reduces environmental exposure of project Critical to the success of the Sakhalin drilling program is utilization of evolving ERD well technology. Several initiatives were put in place to identify and progress specific technologies deemed beneficial to the project's successful implementation. This project will rely on best available technology but given the duration of the drilling program, several new or enhanced technologies will ultimately have significant impaction wells drilled during the program.

2. Design Issues and Challenges

Significant engineering planning and research was required for the highly complex ERD wells in the Sakhalin development. The project team overcame the following technical challenges:

- Environmental and infrastructure
- Rig availability and design
- Well bore stability, hole cleaning and ECD management
- Casing installation
- Completion and intervention

The following sections give detailed information on each topic.

2.1 Environment and Infrastructure

The very harsh Sakhalin climate and limited local infrastructure created numerous challenges for the complex drilling start-up operation. Figure 3 depicts the remoteness of this drilling operation.

2.2 Weather Conditions.

The northeast Sakhalin Island climate is monsoonal in character and constantly changing. Spring and summer seasons are characterized by periods of low clouds and fog that form over the Sea of Okhotsk. During June and July, average wind speed is about 6 m/s and wave height is about 1.2 m. As the summer typhoon season progresses into August and September, winds become stronger and more variable in direction. During this late summer period, wind speed reaches 8 m/s and wave height is about 1.5 m. During the colder months, October through March, strong cold winds from the west and northwest are common. The wind speed averages 12 m/s and wave height increases to about 2.5 m. During storms, wind gusts can reach up to more than 50 m/s. Ice begins to form in late November or December requiring vessels with ice breaking capacity for offshore operations until May.

2.3 Rig Availability and Design

The drilling rig for this project was custom built to the unique requirements of Chayvo ERD wells. The rig incorporates design features to allow utilization of large outside diameter (OD) drill pipe, tapered drill strings, significant horizontal racking capacity, a high torque top drive and high pump pressures. The land based "Yastreb" (Russian for hawk) rig was constructed in 2001 and delivered to the island in the summer of2002. The rig is shown in Figure 4. The rig is the largest land rig in existence with the following unique features:

- Fully enclosed and winterized working areas with rig floor, pipe barn and mud plant rated to -40°C

- Drill pipe and casing laid down and stored in a pipe barn to increase rig capability to withstand earthquakes
- Rail mounted to enable batch drilling operations and enhance seismic load resistance
- Capable of running Range 3 casing and drill pipe double stands in lengths of - 27 m per stand
- 5-7/8 in. drill pipe with high torque tool joints
- Total rig horsepower of 12,000HP
- Top Drive capacity 55,000 ft-Ibs@ 150rpm
- 4 x 1,600HP mud pumps at 7,500 psi

Many times saving concepts were integrated into the design of this specialized rig. An example is the enclosed pipe barn with a pick-up and lay-down machine, which runs casing and drill pipe in doubles.

2.4 Well bore Stability and ECD Management

Well bore Stability. A key drilling concern in planning Chayvo ERD wells was wellbore stability. To help plan the mud weight for wellbore stability, knowledge of the rock strength was needed. ExxonMobil has a proprietary technology for determining rock strength from cuttings. The method involves determining the cuttings surface area by measuring the dielectric constant (DC) of the cuttings and then using a correlation between surface area and rock strength. For Chayvo ERD wells, cuttings were obtained from the vertical exploration wells, an offset ERD well drilled 100 km to the north of Chayvo, and from the vertical cuttings injection well that was drilled at the Chayvo drilling site. As shown in Figure 6 the cuttings data, along with information about likely geology between the shore and the target, were merged to estimate surface area and rock strength along the well path. While drilling the first two ERD wells, cuttings were collected and the wellbore stability model was updated to verify proper' mud weight was being used.

2.5 ECD Management.

Another key concern for Chayvo ERD wells was equivalent circulating density (BCD) management. ExxonMobil has a hydraulics model that takes into account not only standard frictional pressure losses, but also the effect of the cuttings beds in high-angle portions of the well and suspended cuttings in the low angle portion of the well. Cuttings effects were determined using a proprietary hole cleaning model. Modeling was used to help select flow rates, mud rheologies, and drill string design. In addition, ECD was carefully monitored using downhole pressure while drilling (PWD) tools. Measured ECDs have been slightly less than the originally predicted range.

2.6 Reservoir Penetration Plan.

A Chayvo Reservoir Intersection Team was formed to develop a detailed Reservoir Penetration Plan (RPP). The team included personnel From Drilling Engineering, Reservoir Engineering, Project Geology, Operations Geology, Formation Evaluation, ERD consulting and the Directional Service provider. Inclusion of representatives from each discipline involved in drilling the first Chayvo ERD well was paramount in obtaining consensus at the outset of operations. This proved to be invaluable while drilling as decisions were clearly defined in advance for each critical juncture. Throughout its development, the RPP was envisioned as a roadmap for drilling from the onshore location to an offshore target. The RPP is not an operational procedure but rather a frame work for landing Chayvo ERD wells

Horizontally and drilling horizontal sections through the reservoir. Drilling-specific objectives include the following:

- . Landing the well at target TVD
- Staying within the target box
- Obtaining required formation evaluation data
- Maintaining hole integrity over long intervals
- Maximizing resource
- Eliminate costly pilot holes

The first three drilling objectives were the basis of the RPP. Key deliverables defined in the RPP are:

- Uncertainty assessment
- Wellbore trajectory definition
- Costs for reducing uncertainties
- Formation evaluation plan
- Landing plan for the horizontal section
- Decision trees
- Role and Responsibility definition

3. TVD Verification.

One of the most significant successes achieved in the Chayvo ERD program was the TVD target accuracy achieved on the first well drilled. Various scenarios Of drilling calibration holes into the GOC and/or WOC were evaluated. The most attractive is shown in Figure 10. A risk analysis done on this least expensive alternative indicated that a calibration hole was not economically justified. Independent confirmation of the wellbore position in the oil column was performed during the initial production test. As shown in Figure 11, the planned target was 2,595 m SS. Calculated TVD was 2,591.7 m based on measured formation pressure. This 3.3 m difference compared very favorably with the pressure gauge accuracy of l: 2.5 psi (17.23 K Pa) or: 1:2.6m in a 104m oil column. TVD of the initial Chayvo ERD well was on target and well within the geologic uncertainty of 8.4 m.

4. Torque and Drag.

Thorough torque and drag (T&D) planning was done to optimize Chayvo ERD well profiles. Sensitivities included kick-off points (KOP), build rates, tangent section inclination, and mud density .and anticipated friction factors. Consideration was also given to mechanical limits of the top drive system, drill string components and casing/tubing planned for installation. All well paths are similar because wells are drilled geometrically to the same TVD. The major difference in well paths, excluding azimuths, is vertical section distance to the reservoir (heel target) and horizontal section length in the reservoir. A drilling engineer at the rig site performs T&D surveillance on a real-time basis. Rotary speed, weight on bit, back reaming on connections and pump rate are parameters that are adjusted to keep T&D at a minimum. These parameters are key to successful hole cleaning, which directly impacts T&D. Hole cleaning is also highly dependent on average drilling rate of penetration. On-site T&D surveillance proved to be the most effective way of monitoring drilling parameters and ensuring proper hole cleaning and T&D reduction.

Bit Selection. Bit design is important for drilling a smooth well bore, enhancing RSS tool response and minimizing induced vibration/stick slip. PDC bits are used for all Chayvo RSS drilling. Additional information is gathered with each bit run and modifications have been made to gauge length, passiveness of gauge cutters, back reaming features, impact resistance and cutter back rake. An assortment of PDC bits are kept on location to provide features required for these changing situations.

RSS Performance. Several changes were made to improve RSS performance. A high drilling spread rate and the time it takes to trip from depth make a RSS failure a significant cost driver. High pump rate was initially used to improve hole cleaning. However, pump rate was reduced to improve MWD pulsing unit life without impacting hole cleaning. Failure of electrical components due to vibration was addressed by improved technique of drilling through hard stringers and PDC bit enhancements.

Overall, RSS tool reliability improved from the first ERD well drilled to the second well. Sixteen BRAs were required for the first well and eleven BHAs for the second well, even though, the second well were 775 m longer. Cumulative dogleg (DL) was 26% less in the second well. An aggressive team oriented approach to applying lessons learned from the first well was the biggest reason for this improvement.

5. Casing Installation

Casing installation in Chayvo ERD wells at Sakhalin was a critical operation. The 13-5/8 in. casing, 9-5/8 in. casing and 7 in. liners were designed to be floated (or partially floated) and rotated if necessary to get to bottom. Concerns with well bore stability, lost returns and cuttings beds were issues addressed in the design of the casing strings and running operations. Partial flotation or "mud-over-air" flotation is the most reliable way to run casing in ERD wells. The operation involves running the lower portion of the casing floated (filled with air) and the upper portion filled with mud. This minimizes casing string weight in the high angle interval to reduce drag. The upper portion, which is near vertical, pushes with additional weight of the mud. A selective float collar (SFC) is installed in the casing string to isolate the mud from the air filled portion of the casing. Applying surface pressure opens this SFC. The SFC is pushed to the float collar by a wiper plug prior to starting the cement job. 13-5/8 in.

6. Completion and Intervention

Completion Design. Chayvo completions are 7-in. mono-bores with a cemented and perforated liner. This is accomplished by running and cementing a 7-in. liner to TD then running a 7-in. tieback to the surface. The 7-in. tieback is run with the drilling rig. Perforating is performed with a coiled tubing unit. Perforations are oriented upwards to reduce potential for sand production. Figure 14 shows a sketch of a typical Chayvo completion.

Coiled Tubing Works. Perforating the 7-in. liner resulted in a world record coiled tubing run of 9,328 m. To achieve this depth in a horizontal well required a hydraulic tractor to convey the perforation guns. Perforating guns, over 300 m in length, have been used to reduce the number of coiled tubing runs. This required the use of special perforating gun connections, lubricator equipment for pressure control and a pressure controlled firing head. The coiled tubing has also been used to run pressure gauges, production logs and a cement bond log. Interventions will be performed with either the coiled tubing unit or the

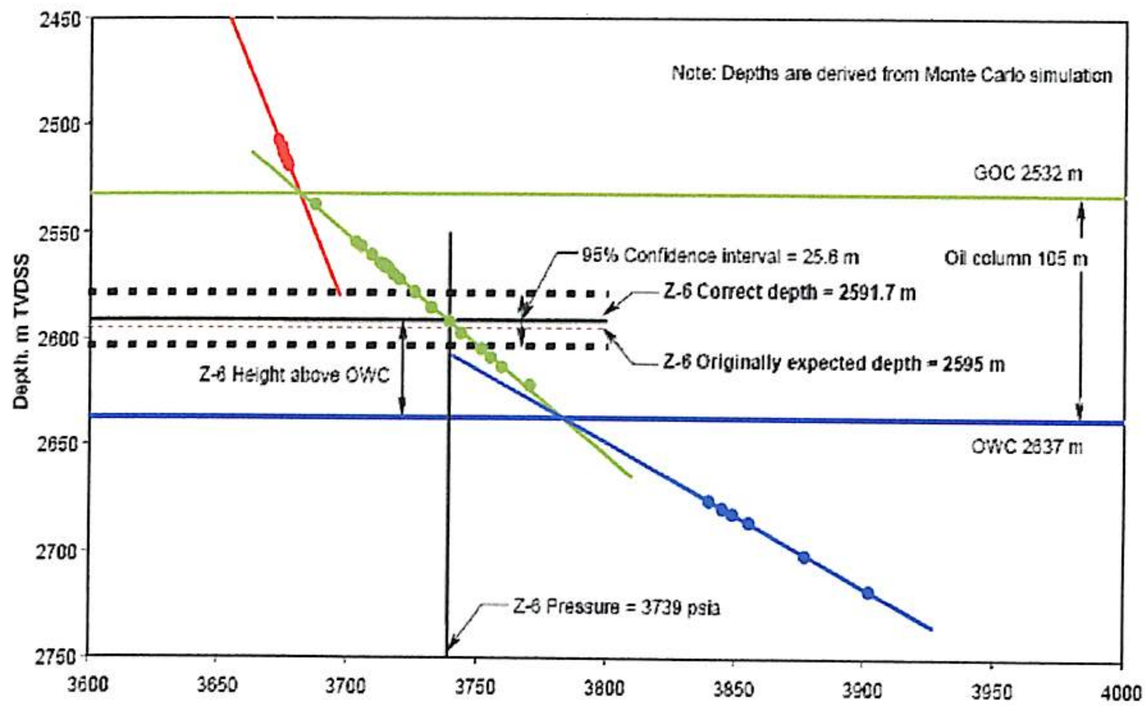

Figure 15: Chayvo True Vertical Depth Verification

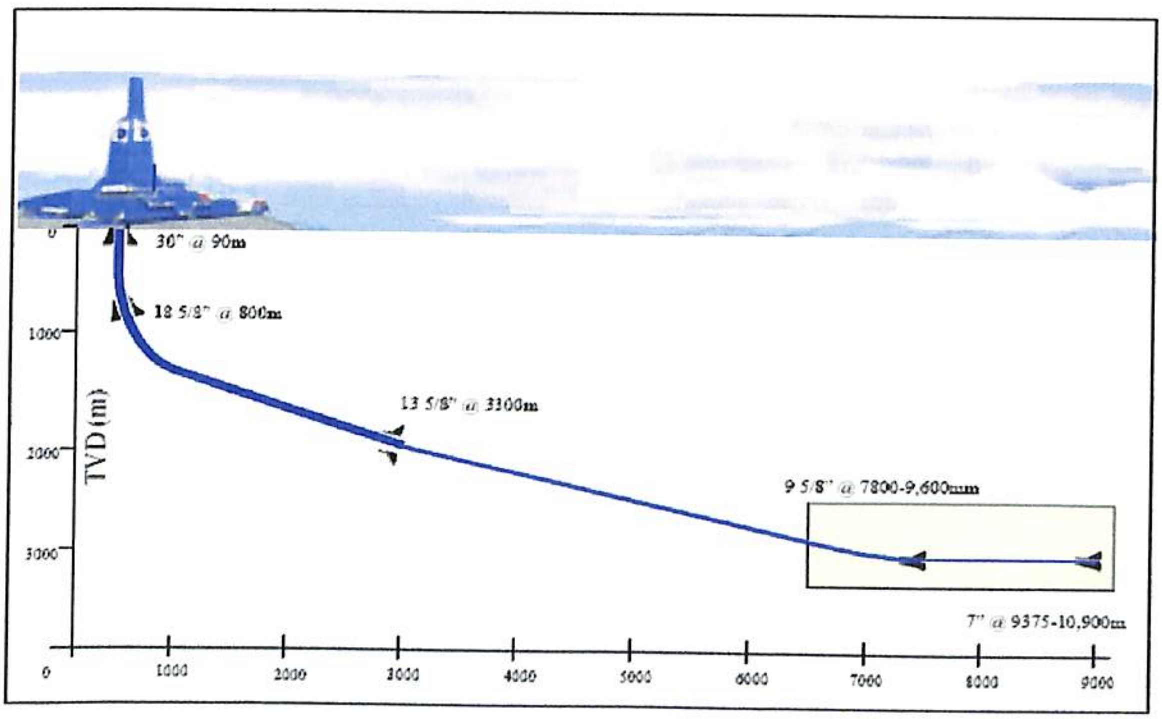

Figure 16: Schematic Chayvo ERD wells

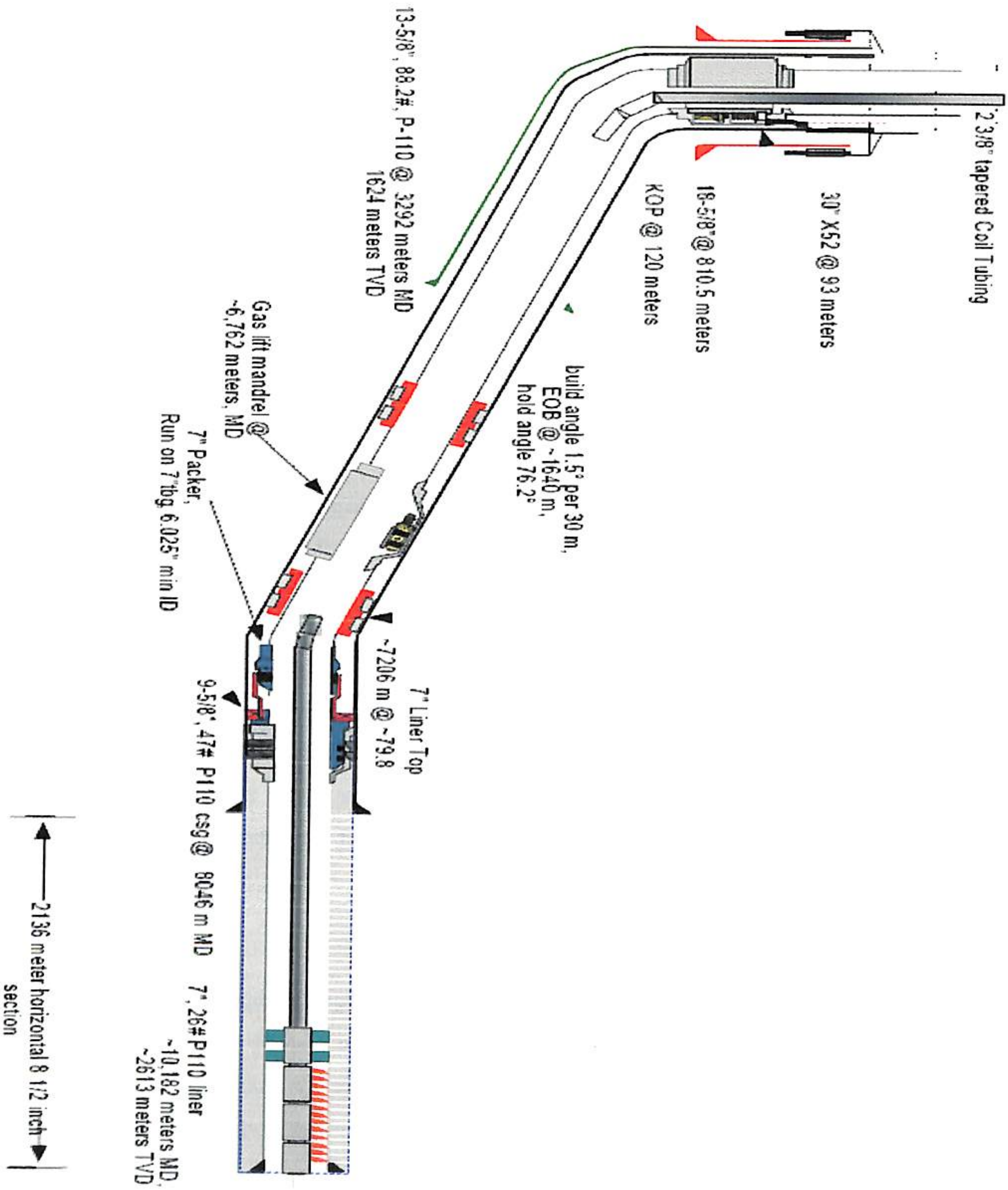

Figure17: Completion Diagram

REFERENCES

Books:

SPE Applied Drilling Engineering

Adam T. Bourgoune Jr., Keith K. Millheim, Martin E. Chenevert, F.S Young Jr.

Directional Drilling

Lance D. Underwood-Halliburton Energy Services, Michael L. Payne-Arco Exploration and Production Technology

SPE/IADC Paper

1. Andy Lane , Landmark Graphics Corporation and Phill Longorio and Randy Young , Halliburton Sperry – Sun : **Advanced Horizontal , Multilateral and Extended Reach Technologies Bring "Hole-In-One** " Possibilities.
2. C.J. Mason, SPE, BP Exploration Operating Co. Ltd. and A. Judzis, SPE, BP Exploration (Alaska) Inc. "**Extended-Reach Drilling -- What is the Limit?**"
3. Gupta, A., University of Petroleum & Energy Studies, India, "**Planning and identifying the best technologies for Extended Reach Wells**" paper presented at the SPE/IADC Mumbai, India ,
4. Schaaf ,S.A., et al . "**Application of a Point the Bit Rotary Steerable System in Directional Drilling prototype Well-bore profiles**" paper SPE 62519 presented at the SPE western regional Meeting, California ,Jun 19-22 ,2000.
5. Schaaf ,S.A., Schlumberger and C.R. Mallary , BP Amoco and Demos Pafitis , Schlumberger "**Theory and Field Results: Point the Bit Rotary Steerable System**" paper SPE 63247 presented at the SPE Annual technical Conference Dallas, Texas , 1-4 October,2000.
6. Michael J. Jellison, Grant Prideco, Mike L. Payne, BP America Inc., Jeff S. Shepard, GlobalSantaFe Drilling Company, R. Brett Chandler, Grant Prideco "**Next Generation Drill Pipe for Extended Reach, Deepwater and Ultra-deep Drilling**"

7. Ján Pinka, Jozef Lumtzer, Jamil Badran "**TDS - Top Drive System, new drilling technology** "

8. Cameron, C. , Halliburton Energy Services "**Drilling Fluid Design and Management for Extended Reach Drilling** " paper SPE/IADC 72290 presented at the Middle East Drilling Technology Conference ,Bahrain ,22-24 Oct 2001

9. Davidson , E. and Stewart , S. , Baroid : "**Open hole Competitions : Drilling Fluid Selection**" paper SPE 38284 presented at the SPE/ IADC Middle East Drilling Technology Conference ,Bahrain, Nov 1997

10. Hemphill, T, SPE, and Pogue, T, SPE Baroid drilling Fluids: "**Field Application of ERD Hole Cleaning Modeling**" paper SPE 37610 presented at the SPE/IADC Drilling Conference Amsterdam march 1997

11. Meader, A and Allen , F , BP Exploration , Rliey ,, G, Schlumberger "**To the limit and beyond – The Secret of World Class Extended Reach Drilling Performance at Wytch farm**" paper SPE/IADC 59204 presented at the SPE/IADC Drilling Conference New Orleans February 2000

12. Power , D.J. , SPE and Hight C., Weisinger D., and Rimer C., SPE vaster Resources Inc. "**Drilling Practices and sweep selection for efficient hole cleaning in Deviated well bores** " paper SPE 62794 presented at the 2000 SPE/IADC Asia pacific Drilling Technology, kuala Lumpur Malaysia ,September 2000.

13. Rojas J.C., SPE, BP Exploration and , Bern, P.A. , SPE ,BP Exploration, Fitzgerald, B.L. baroid , Modi, S. SPE , BP Exploration, Bezant, P.N. SPE, BP Exploration, : "**Minimising Down Hole Mud Losses** " paper SPE 39398 presented at the SPE/IADC Drilling Conference Dallas , March 1997

14. Filippov, A., et a!.: '**Expandable Tubular Solutions**', paper, SPE 56500 presented at the 1999 SPE Annual Technical Conference and Exhibition, Houston , Texas U.S.A., 3-6 October 1999.

15. Karl DeMong, Halliburton Energy Services; Mark Rivenbark, Enventure Global Technology **"Planning the Well Construction Process for the use of Solid Expandable Casing"**, paper, SPE 85303.

16. Petter Kostel, SPE and Knut Ostvang , SPE, Statoil A/S " **Completion and Work over of Horizontal and Extended Reach Wells in the Statfjord field"** paper SPE 28559 presented at the SPE Annual Technical Conference & Exhibition , New Orleans ,25-28 September 1998

17. G.N. ,Kidd, A. Tukshaitiov and F. Najafov, BP Exploration Ltd" **Learning Cthr right Lessons-The Key to delivering a Record Extended Reach Wells in the Caspian Sea"** paper SPE 95590 presented at the SPE Annual Technical Conference & Exhibition , Dallas .Texas , USA, 9-12 Oct 2005

18. J.R. Mc Dermott, R.A. Viktorin, J.H. Schamp, M.W. Barrera, SPE and j. M. Fleming, Exxon Mobile development Company, S.R. Keller, SPE, Exxon mobile Upstream Research Company: **"Extended Reach Drilling(ERD) Technology Enables Economic Development of Remote offshore field in Russia"** paper SPE/IADC 92783 presented at the SPE/IADC Drilling Conference Amsterdam, The Netherlands . 23-25 Feb. 2005

19. J.R. Mc Dermott, R.A. Viktorin ,J.H. Schamp, R.E. Rush Jr., Exxon Mobile development Company:" **Extended Reach Drilling(ERD) Technology Enables Economic Development of Remote offshore field in Russia"** paper SPE/IADC 99131presented at the SPE/IADC Drilling Conference Miami, Florida,USA.21- 23 Feb. 2006

20. G. Rae,SPE ChevronTexaco Upstream Company, Europe., H. Williams ,SPE K& M Technology Group and J. Hamilton SPE, SPS International " **Selective Flotation of Caspian From A Floating Vessel"** paper SPE/IADC 79814 presented at the SPE/IADC Drilling Conference Amsterdam, The Netherlands,19-21 Feb. 2004

21. N. Robertson, SPE, BP Exploration Ltd, S. Hancock Engineering and L.Mota, Halliburton Energy Services" **Effective Torque management of Wytch Farm Extended Reach Sidetracks Wells"** paper SPE 95430 presented at the SPE Annual Technical Conference & Exhibition , Dallas .Texas , USA, 9-12 Oct 2005

22. Ma Shanzhou, Huang Genlu, Zhang Jianguo and Han Zhiyong, Petroleum University, East China "**Study on Design of Extended Reach Well Trajectory**", SPE 50900 presented at the 1998 SPE International Conference and Exhibition in China held in Beijing, 2-6 November 1998