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Abstract

An effective approach for enhancing production and improving hydrocarbon recovery has been to integrate production engineering with drilling strategies to design programs that optimize all aspects of well construction for optimum, long term exploitation of reserves.

This paper describes the use of such a multi-faceted approach in North Dakota Bakken wells and West Sak heavy oil sands in Alaska, both of which require long horizontal wellbores to be completed with multiple swell packers and/or liners. For maximum production, a smooth, well-conditioned, gauge hole is vitally important to enable the largest, most-effective and highest number of packers to be run.

Successfully getting liners to bottom so as to achieve optimum completions in these wells requires a repeatable process that is effective 100% of the time; therefore, requirements of both the drilling and production groups were combined in a strategy that integrates technologies specifically for improving the success of landing the liner on depth and helping drill a cost-effective, smooth, gauge hole. When these reaming while drilling techniques are used, excellent hole quality can be achieved without the need for dedicated clean out runs.

In addition to the type of packer design / reamer/ centralizers / T&D equipment utilized, the paper describes how Torque & Drag (T&D) modeling in both the drilling and liner running intervals of these wells provided a number of strategic options for achieving a useable, quality wellbore that would facilitate running liner/packers into hole without damage.

Demonstrating its effectiveness and applicability, this integrated approach has been employed on more than 100 wells to date, with more than 2 million feet of reamed hole alone, and more than 1,000 packers run on variety of wells, including runs in excess of 20,000’ and laterals exceeding 10,000’ in tri-lateral and penta-lateral wells.

Introduction

Today, the industry is moving toward solutions that take a long-term view of the life of the well, requiring a more integrated approach to the way wells are planned, drilled, completed, and produce.The ultimate goal is construction of a safe, cost effective well that comes on line quickly and can maximize production for years to come.

However in some applications, such as extended horizontal wells like those described in this paper, production liners do not reach the specified targeted landing depth, which not only increases the short term costs of the well – through damaged equipment, extra demands placed on rig personal, and increased time -- but also adversely affects long term production.

Thus, achieving the ultimate goal requires a repeatable process for running liners to depth that is effective 100% of the time.

To enhance production and improve recovery processes, one approach integrating production engineering with drilling strategies has been implemented to design well programs that optimize hole sizes, casing sizes, well positions and other factors, to maximize long-term hydrocarbon production.

Use of such a multi-faceted approach begins with combining the requirements of both the drilling and production groups, again, with the ultimate objective being to increase and maximize production from a safe, cost-effectively drilled well. Additionally, for the subject wells, this strategy integrates specific technology for improving the success of landing the liner on depth and helping drill a cost effective, smooth, gauge hole.

Specifically, this paper describes application of a PDC reaming tool for reaming-while-drilling (RWD) operations that minimizes the need for the standard procedure of including a dedicated reamer run. The RWD technique provides the enhanced wellbore geometry needed to engineer and achieve horizontal completions using maximum size (OD) conventional and expandable casing, liners, and multiple swell packers. Documented utilization of the PDC reamer in executing RWD operations in multiple Williston Basin wells in North Dakota shows the technique to consistently result in shorter drilling time and successful first casing and liner runs [1].

Background

The well-known Bakken shale is an oil reservoir contained within a dolomite formation and layered between two shales. Because it is not as naturally fractured as other shale plays, almost all Bakken wells are drilled horizontally and completed using open-hole multistage fracturing methods which utilize external packers to isolate sections of the wellbore.[2]

While most wells are completed on 640- or 1280-acre spacing, resulting in 5000- and 10,000-ft horizontal wellbores, respectively, a recent increase in activity is toward longer laterals – up to 15,000 feet for a single lateral in some cases. In addition, some operators are drilling below the lower shale and fracturing upwards. In all cases, wells are lined with casing from the surface to the base of the curve.

In the Williston Basin, where wells can have large numbers of fracture stages, running uncemented liners with swell packers is the most common completion option and is the option used in the subject wells of this paper. In fact, because of its high degree of fracture control and long-term success rate, the uncemented, preperforated liner isolated with swell packers has become the most commonly employed method of completion in most Bakken wells.[(3)]

Historically, best practice required a dedicated reamer run at TD to ensure subsequent swell packer installation in a single run. However, through combined efforts of proven North Dakota operations groups, rigs and service companies, utilization of a PDC reaming tool for reaming-while-drilling operations has helped to eliminate the dedicated reamer run at TD while delivering good wellbore condition that enables multiple swell packers to be run in a single, fast trip.

This RWD approach using a PDC reamer potentially saves two to three rig days, including a full round trip from 20,000ft plus actual reaming time; in some cases previously, the dedicated reaming operation actually took more than five days to complete. With price change in oil, many operators are looking to reduce costs even further. These tools are designed to lower both trouble time hrs. As well as non productive time which can contain several “hidden” expenses from costs derived from short trips, back reaming to the shoe or dedicated clean out runs

In addition, current BHA modeling and field results document that the use of PDC reamer tools presents no significant steering control issues or any loss in penetration rate while still enabling subsequent installation of multiple packers. This can be critical in the North Dakota wells, where the application can require running as many as 35 swell packers or more. (Figure 1. Typical Bakken Well Design)

Williston Basin Well Designs. The Williston Basin presents more than 30 formations from surface to the targeted zones, with challenges that include potential aquifers, sticking salt and bentonite beds, sloughing shales and known H_2S hazards. In a typical subject well design, the 8 ¾-inch hole section is drilled vertically through 20 or more formations to a kick off point in the target formation at around 9,000 to 10,000 ft true vertical depth (TVD).

From there, 8 ¾-inch hole builds angle to horizontal in the Bakken target formation at around 11,000 ft TVD. Once the wellbore is landed and horizontal, a 6-inch hole is drilled laterally for up to 10,000 feet, and typically is completed with uncemented liners and mutiple swell packers.

With such extreme wellbore geometry, producing a maximum size, gauge hole is a mandatory precondition for successfully running long completion strings, liners, and expandable tubulars on the first run. Having a smooth, well-conditioned, non-spiraled, gauge hole enables the largest, most-effective and highest number of packers to be run, and maintains the highest possible differential sealing action of the packers.

Historically in these wells, a dedicated reamer run is required at TD to facilitate installation of swell packers. Oil and water based mud is used during swell packer installations, and as many as 20 or more zones are isolated, with some additional zones plugged and perforated.

In the subject wells, a 5 7/8-inch OD PDC reamer was introduced to ream-while-drilling the 6-inch lateral section. Positioned anywhere in the BHA, the steel or non-magnetic (non-mag) PDC reamer can be can be used to drill out as well as for RWD, and reduces spiraling in the wellbore, thereby reducing the risk of sticking the liner assembly before reaching TD. In this case, the objective was to enable successful installation of multiple swell packers – up to 40 – while providing significant time savings of up to three days rig time per well.

PDC Reaming Tool Design. The PDC reaming tool is a drilling enhancement reamer equipped with PDC cutters on a beveled profile to maintain wellbore gauge even in cases of severe swelling and/or borehole instability. The tool also improves borehole shape, straightness and quality by removing ledges and micro-doglegs, and features a hydraulic profile that optimizes mud flow and resists balling. (Figure 2. PDC Reamer Tool photo/diagram)

In addition to drilling, the PDC reamer enables efficient reaming through its integral chamfered blade design. Providing 360- degree cutter coverage, the spiraled blades incorporate tungsten carbide inserts (TCI) to provide additional reaming or stabilization according to drilling and formation conditions.

TCI distribution is optimized for specific conditions to provide continuous reaming in longitudinal and radial directions, while PDC distribution is in accordance with an axi-symmetric design technique that allows for balanced drilling and reduced vibrations. The stud cutters are oriented for optimum cutting action, and are deeply inserted in the blade to eliminate the shear plane and prevent failure. (Figure 3. Close up of TCI Stud Cutters on PDC Reamer)

As a result of having both PDC and TCI cutters, the PDC reamer executes a unique cutting mode of both scraping and shearing that smooths the wellbore and is effective in delivering a high quality hole through changing formations. Available for use in hole sizes from 4 1/8 to 26-inches, the tools offer a wide range of versatility, as cutter structures are easily modified to handle more abrasive formations, longer runs, highly steered applications, and those with low torque requirements.

Ideally the PDC reamer is installed as the uppermost gauge device in the BHA to prevent sticking by back reaming and drilling the way for the rest of the BHA while pulling out of hole (POOH). While the PDC reamer typically replaces the topmost stabilizer, it can be placed on top of the downhole motor in cases where unconsolidated formations or hole cleaning problems are expected. (Figure 4. Typical Reaming-while-Drilling BHA diagram)

In the subject wells, the PDC reamer was 5 7/8-inch OD, with a four-bladed, bi-directional design which enables the tool to act as backup hole opener when bit gets under-gauge. Specifications are given in Table 1.

Table 1. PDC Reamer Tool Specifications

Cutting Elements	PDC Cutters
Reaming Elements	Tungsten Carbide
Coverage	360 Deg.
Blade Width	1-1/2”

Equivalent Drill Collar Size	5.33” Diameter
Total Flow Area	4.76 Sq. Inches
Tool Total Length (L)	63”
Tool Gauge Diameter (OD)	5.875”
Fishing Neck Length min. (FN)	18.57”
Bottom Neck Length min. (BN)	21.57”
Neck Diameter (D)	4.875”
Tool Bore Diameter (d)	2.5”
Wall Contact Length (B)	11.65”

Typical Packer Design. The swell packers being installed in Williston Basin wells comprise a standard oilfield grade tubular with layered rubber bonded along its length. (Figure 5. Swell Packer Design diagram) With the packer installed downhole, the rubber swells through absorption of hydrocarbons or fresh water, resulting in an annular seal. Swelling is time-dependent, and is homogeneous along the length of the element, although in the subject wells the packers have a minimum swell time of five days, with 14 days maximum swell time.

Self-healing swell packers use oil- or water-swelling elastomers to provide long-term zonal isolation in temperatures from 35° to over 400°F, and can support differential pressures up to 10,000psi, in oil or water environments with varying salinity concentrations.

The focus with use of the PDC reamers is to drill a smooth wellbore that is as close to 6-inch gauge as possible to optimize sealing capability of the swell packer. Some eccentric or bi-center tools can drill an over-gauge hole (for example, 6 1/8-inch or 6 ¼-inch in a 6-inch hole) which may reduce the efficiencies and sealing effectiveness.

Application: Reaming-While-Drilling Performance

In the subject wells, the PDC reamer was run to ream-while-drilling the production hole section to enable subsequent installation of multiple swell packers. Multiple RWD BHA designs were run, incorporating both non-magnetic and steel body PDC reamer tools, to test steering capability and torque performance for comparison with previous lateral BHAs, both slick and stabilized.

Sample Well #1: Picked up two non-mag PDC reaming tools after MWD failure at 19,495 ft depth left another 800 feet to TD. The BHA was made up with one PDC reamer positioned above the 5 ¼-inch 6/7 motor with 1.5° bend, followed by UBHO and 2 x NMDC, and a second PDC reamer. The 6-inch PDC bit was green from previous run with an average ROP of 18 ft/hr.

Table 2. Bottomhole Assembly Well #1

Type	OD (in)	ID (in)	Length (ft)
PDC Bit	6		1
Motor 5.25 OD 6/7 8 stage 1.5 fixed	5		28.9
Non-Mag PDC reamer	5.875	2	3.02
NMDC	4.5	2.3	30.39
NMDC	4.25	2.3	30.57
Non-Mag PDC Reamer	5.875	2	5.09
XO	4	2.1	2.49
31 stds DP	4	3	2939

Agitator	4.94		11.22
Shock Sub	4.94	2	11.1

This BHA reamed the lateral section back to bottom at 19,495 ft, at 200-250 ft/hr, operating at a flow rate of 205 GPM with 65 RPM surface rotary and 165 RPM at motor for 230 RPM. Reaming was finished after 32 hours reaming and with 9000 feet of open hole, on bottom drilling at 19,495 ft depth.

On-bottom drilling resumed at 19,895 ft depth, with an average ROP of 25 ft/hr in rotary mode and 12 ft/hr sliding. The first slide to nudge angle back up went well, but there was difficulty with the second slide in getting the required high side tool face.
The rig was limited to 4250psi differential and the Directional Driller would like to have had at least 4800psi operating parameters. After a planned, 10-20 stand short trip, and reaming the last 800 feet to TD at 20,278 ft, the BHA was POOH and 21 swell packers were successfully run. Table 3 summarizes the run parameters.

Table 3. Run Parameters Well #1

Depth In	19,495	**Torque**	8-12k		OBM
Depth Out	20,278	**RPM**	230	**MW (ppg)**	12.3
Feet	783	**Flow (gpm)**	205	**PV/YP**	26.9
Hours	30	**SSP (psi)**	4000	**Visc.**	71
ROP (ft/hr)	26.1	**WOB**	7-10k	**Solids %**	na

Sample Well #2: In this well, where the previous slick BHA achieved an ROP of 70 ft/hr rotating and 17 ft/hr sliding, the objective was to ream the lateral hole from 10,500 to 15,552 ft, then ream-while-drilling from 15,552 ft to TD at 19,576 ft depth. The BHA comprised a 6-inch PDC bit, 4 ¾-inch 7/8 fixed housing motor with 1.5° bend; the 5 7/8-inch non-mag PDC reamer, a UBHO and NMDC, followed by a second non-mag PDC reamer.

Table 4. Bottomhole Assembly Well #2

Type	OD (in)	ID (in)	Length (ft)
PDC Bit	6		1
Motor 7/8 3.8S 1.5 fixed	4.75		23.66
Non-Mag PDC reamer	5.875	2	5.09
UBHO	4.75	2.75	3.05
NMDC	4.75	2.63	31.24
Non-Mag PDC reamer	5.875	2	5.1
NMDC	4.75	2.63	31.18
X-over	5	2.56	3.97
31 Stds DP	4	3	2920
Agitator	5	1.75	11.22
Shock sub	5	1.91	11.11
79 Stds DP	4	3	7440.49
17 Stds HWDP	4	2.563	1566.09
4 DP	4	3	7523
BHA Total Length (ft) = 19576.2			

This assembly was run in at 5000 ft to ream to bottom, holding inclination from 89.4° -88.3° over 4024 feet. The BHA was used to ream-while-drilling from 15,552 ft to TD at 19,576 ft, with 5.14% sliding in 24.5 hours, and 94.86% rotating with 49.58 rotary hours. Average rotating ROP was 77 ft/hr over 3817 feet; and 9 ft/hr in sliding mode over oriented footage of 207 ft.

There were no issues with the ability to steer, and average rotary ROP increased from 70 ft/hr to 79 ft/hr. Utilization of the PDC reamer eliminated the need for a dedicated reamer run at TD, and 21 swell packers were successfully installed with no problems. Table 5 summarizes run parameters.

Table 5. Run Parameters Well #2

Depth In	15,552	**Torque**	7-13K		OBM
Depth Out	19,576	**RPM**	230	**MW (ppg)**	10.7
Feet	4,024	**Flow (gpm)**	210-228	**PV/YP**	20.9
Hours	74	**SSP (psi)**	3900	**Visc.**	52
ROP (ft/hr)	54.4	**WOB**	20-65	**Solids %**	17

Sample Well #3: Two steel PDC reaming tools with 30ft spacing were used in the lateral BHA when drilling out of the 7-inch shoe, then proceeded to ream-while-drill the lateral.
The entire lateral of 9500 feet was successfully reamed-while-drilling to well TD at 19820 ft. There were no issues with torque, steering control or ROP, and 30 swell packers were successfully installed after TD, eliminating a dedicated reamer run.

Table 6. Run Parameters Well #3

Depth In	10,320	**Torque**	7-13K		Brine
Depth Out	19,820	**RPM**	230	**MW (ppg)**	9.8
Feet	9,500	**Flow (gpm)**	230-240	**PV/YP**	1
Hours	108	**SSP (psi)**	2900	**Visc.**	52
ROP (ft/hr)	88.0	**WOB**	15-30	**Solids %**	na

Observations and Results

Over the course of these wells, the RWD BHA, using both non-mag and steel body PDC reamer tools, eliminated a dedicated reamer run and allowed for 100 percent successful installation of multiple swell packers. It was determined that the optimal RWD BHA for the application was 30-foot spacing between PDC reamers positioned on top of the lower BHA using steel body tools; and 30-foot spacing between PDC reamers in the lower BHA using non- mag tools.

We found that running two PDC reamers with 60-foot spacing caused the BHA to have dropping tendencies while in the rotary mode. Stacking two PDC reamers together with no spacing created too stiff an assembly and was difficult to steer and orient during slides.

With proper spacing, use of the PDC reamer tool had no adverse effect on steering or orientation, and compared to previous slick and stabilized lateral BHAs, resulted in a low to manageable torque increase from 7 to 13, with 20 percent increase in rotary ROP, which produced a smooth wellbore and greater on-bottom WOB. The RWD BHA assembly was able to drill out 7-inch casing shoe.

It should be noted that on several wells, BHA vibration was monitored and showed no increased levels to adversely affect the MWD system and cause premature failures. Actually, the MWD service companies prefer a stabilized lower BHA to protect and improve mean-time-between failures (MTBF).

Beyond the valuable saving in rig time realized by eliminating a reamer run, other benefits of RWD over the more than four million feet drilled to date come from detailed data on drilling T&D, wellbore spiraling, and liner T&D that now constitute best practice for Bakken wells in the Williston Basin.

Conclusions

By integrating production engineering with drilling strategies at the outset, a well program can be designed to optimize hole sizes, casing sizes, well positions, etc., to maximize long-term hydrocarbon production. By combining the requirements of both the drilling and production groups, the strategy in this case was able to successfully integrate specific objectives / technology for improving the success of landing the liner on depth and helping drill a cost-effective, smooth, in-gauge hole to enable the largest, most-effective and highest number of packers to be run.

With the type of enhanced wellbore geometry in this case, tight annular clearances of post-job swellable packers and expandable casing required more hole geometry data during pre- planning to ensure proper operations. Proven techniques using proper circulating methods, solids control in the mud system, directional control and minimal DLS across horizontal sections, were all imperative to a successful first run when casing, liners (expandable or conventional) and swellable packers are being utilized.

By working together with the operations groups, the teams developed several innovative reaming-while-drilling scenarios to meet the operators' application-specific needs. Demonstrated use of reaming tools currently used for reaming-while-drilling (RWD) operations shows you can reliably get long strings of casing with swells to bottom using the **r**eam-while-drilling approach outlined while saving rig time (and dollars). As described herein, this technique minimizes the need for a dedicated reamer run and now is "best practice" in the Williston Basin for reliably placing long casing strings at planned depth with multiple swell packers for zonal isolation, with resulting significant savings in rig time. To date we have documented over 4,000,000 feet of hole reamed and over 98 % successful installations of swellable packers on more than 400 wells with a number of Bakken operators.

Utilization of a fixed blade PDC reamer tool is shown to provide a cleaner, better-reamed out hole in Williston Basin wells where the application has required running as many as 40 swell packers to bottom. Its use resulted in no issues with steering control and an increase in average rotary ROP. The RWD application eliminated the need for a dedicated reamer run at TD and enabled successful installation of multiple swell packers with no problems.

Because operators are using various packer OD sizes in attempts to get the swell packers to TD, swell packer and production string design has been refined to further assist in successful installations. In this case, the economic impact of eliminating the dedicated reamer run at TD reduced rig time per well an average savings of three days. Such practical field experience, which has proved so valuable in the Bakken, may now be applicable to other plays.

BHA:Bottomhole assembly
DP:Drill Pipe
HWDP:Heavy Weight Drill Pipe
MTBF:Mean Time between Failures

MWD:Measurement-while-Drilling
NMDC:Non-Magnetic Drill Collar
OD:Outside Diameter
PDC:Polycrystalline Diamond Compact
POOH:Pull Out Of Hole
ROP:Rate of Penetration
RWD:Reaming-while-Drilling
T&D:Torque & Drag
TD:Total Depth
TVD:True Vertical Depth
WOB:Weight on Bit

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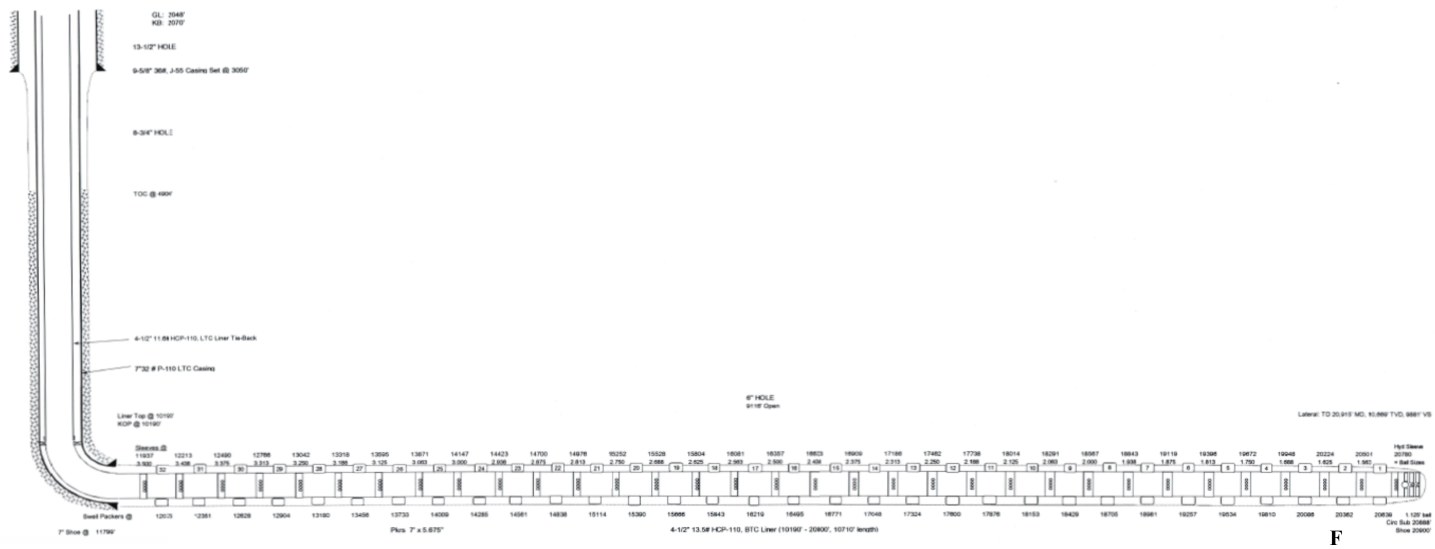

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igure 1. Typical Bakken well design

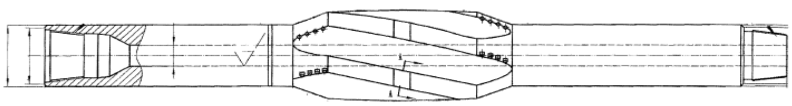

Figure 2. Latest-generation Reamer

Figure 3. Close up of TCI Stud Cutters on PDC Reamer

#	TIME IN - OUT			DEPTHs		Footage			ROP			RPM	FLOW	Incl.		Azimuth		Weight Ranges		
	Time IN	Time Out	Hrs.	IN	OUT	Rotary	Slide	Total	AVG.	Rotary	Slide		Rate	IN	OUT	IN	OUT	SO	PU	RAB
			119.67	17825.0	20578.0	2647.0	106.0	2753.0	43.04	47.9	12.1	40-50	225-277	.0	.0	.0	.0	160-180	215-250	190-190
					Hours>	55.22	8.75	63.97												

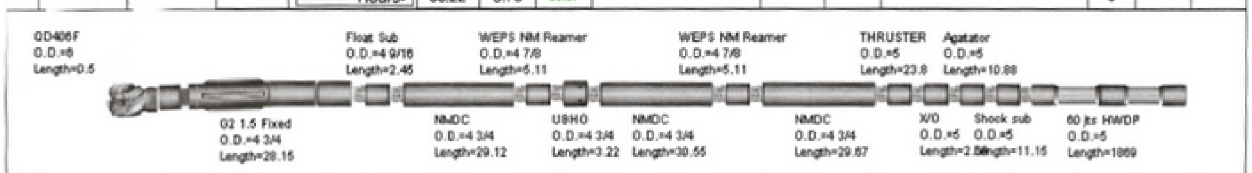

Figure 4.Typical North Dakota RWD Conventional Motor Drilling Assembly

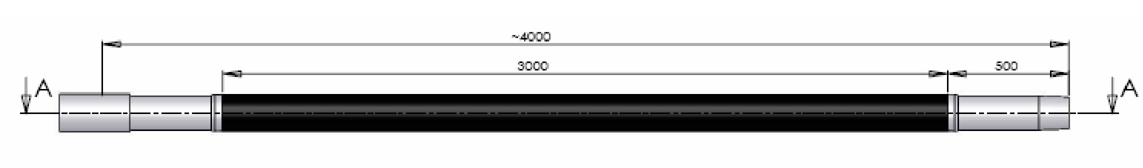

Figure 5. Design of Swell Packer for Zonal Isolation

T&D Analysis **Illustration of a Conventional VR RSS Table**

Illustrations relating to Hole Spiraling