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Successful Application of Innovative Reaming-While-Drilling Technology in the Williston Basin Wells

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Introduction of a new reaming tool for reaming-while-drilling operations in Williston Basin laterals is described, based on more than fifty wells (over 500,000 feet of hole reamed) and 100% successful installations of swellable packers with a number of Bakken operators.

This new technology, through combined efforts of proven North Dakota operations groups, rig and service companies, has eliminated 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 is critical in these complex and demanding Williston Basin wells. Historically, best drilling practices in the Bakken wells have required a dedicated reamer run at TD to ensure successful swellable packer installation in a single run.

By working together with the operations groups, the team developed several innovative reaming-while- drilling scenarios which eliminated the need for the dedicated reamer run, with current BHA modeling predicting that their use presents no significant steerabilty issues and no loss in penetration rate, while enabling subsequent installation of multiple swellable packers.

This had never been done before anywhere in world for this application -- certainly not on this scale or implemented as quickly. Again this was a cooperative effort with a wide range of companies and personnel involved in implementing a new technology to meet the operators' application-specific needs.

The paper describes design and application of a new fixed blade reaming tool which has an active cutting element incorporating PDC cutters on the leading and trailing edges of the stabilizer, as well as TCI inserts. The design is shown to provide a cleaner, better reamed out hole, which is critical in the North Dakota wells where the application may require running as many as 40 swellable packers to bottom.

In addition to documenting reamer performance in subject wells, the paper discusses optimal BHA design incorporating both steel body and non-magnetic PDC reamer tools, as well as mud properties and operating parameters that contributed to the success and constitute best practice for typical Bakken wells.

Economic impact of this reaming-while-drilling application is also addressed, showing elimination of the dedicated reamer run at TD reduces rig time per well, saving an average 3 days or about $250k/well. Also discussed is swellpacker and production string design to further assist in successful installations.

Background

Williston Basin Geology: The Bakken Shale

The Bakken differs from other shale plays in that it is an oil reservoir, a dolomite layered between two shales, with depths ranging from around 8,000 to 10,000 ft. Oil, gas and natural gas liquids are produced.

Each succeeding member of the Bakken formation – lower shale, middle sandstone and upper shale member – is geographically larger than the one below. Both the upper and lower shales, which are the petroleum source rocks, present fairly consistent lithology, while the middle sandstone member varies in thickness, lithology and petrophysical properties.

Currently, Bakken oil wells have been completed either with uncemented liners and swellable packers, and the use of isolation tools has been extensive. The Bakken is not as naturally fractured as other shale plays and, therefore, requires more traditional fracture geometries in stimulation treatments.

Recently, the Bakken has seen an increase in activity, with the trend toward longer laterals – up to 10,000 feet for single laterals in some cases. In addition, some operators are drilling below the lower Bakken shale and fracturing upwards.

Subject 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 H2S hazards.

In a typical 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 feet true vertical depth. From there, 8 ¾-inch hole continues and builds angle to horizontal in the Bakken target formation at around 11,000 ft TVD. Once landed and horizontal a 6” lateral hole is drilled and extends laterally for up to 10000 feet.

Historically, best drilling practices in the Bakken wells have required a dedicated reamer run at TD to insure successful swellable packer installation in a single run.

Oil based mud (OBM) 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, the challenge was to eliminate the dedicated reamer run in Bakken wells through a ream- while-drilling (RWD) application.

In addition, the project allowed introduction of 5 7/8" OD PDC reamer for use in the 6-inch lateral section, using both non-magnetic and steel body tools.

The objective was to enable successful installation of multiple swellable packers – up to 40 – while providing significant time savings per well (up to 3 days rig time)

Driller-Reamer Tool Design

The PDC reaming tool is a drilling enhancement reamer equipped with PDC cutters on a beveled profile to maintain gauge of wellbore 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.

In addition to drilling, the PDC reamer enables reaming through its integral chamfered blade design. Providing 360⌈ ⌈ cutter coverage, the spiraled blades incorporate tungsten carbide insert (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.

As a result of having both PDC and TCI cutters, the PDC reamer executes a unique cutting mode of both scraping and shearing that smoothes the wellbore and is effective in delivering a high quality hole through changing formations.

The PDC reamer is ideally installed as the uppermost gauge device in the BHA to prevent sticking by back reaming/drilling the way for the rest of the BHA while pulling out of hole (POOH). While the PDC reamer typically replaces the top most stabilizer, it can be placed on top of the downhole motor in cases where unconsolidated formations or hole cleaning problems are expected.

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.

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 Guage Diameter (OD)	

5.875” Fishing Neck Length min. (FN)

18.57” Bottom Neck Length min. (BN)

21.57”

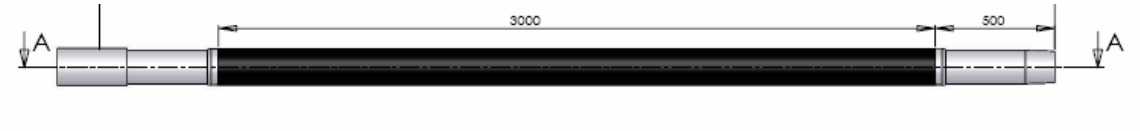
Neck Diameter (D)	4.875” and 4.75”
Tool Bore Diameter (d)	2.5” and 2.0”
Wall Contact Length (B)	11.65”

The tool executes a unique cutting mode of both scraping and shearing.

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. With the packer installed downhole, the rubber swells through absorption of hydrocarbons, 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.



Swell packers provide zonal isolation, with as many as 40 swell packers being required

Our focus with these reamers is drill a smooth well bore that is close to 6” gauge as possible. Some eccentric or bi-center tools can actually drill an over gauge hole (6 1/8” or 6 1/4” for example in a 6” hole). This actually reduces the efficiencies and sealing effectiveness of the swellable packers.

Reaming-While-Drilling Performance Recaps

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 steerability and torque performance for comparison with previous lateral BHAs, both slick and stabilized.

Sample Well #1:
Picked up 2 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.

Bottomhole Assembly

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
WEPS PDC reamer NM	5.875	2	3.02
NMDC	4.5	2.3	30.39
NMDC	4.25	2.3	30.57
WEPS PDC Reamer NM	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 begin reamed the lateral back to bottom at 19,495, 200-250'/hr, operating at a flow rate of 205 GPM, with 65 RPM surface rotary and 165 RPM at motor for 230 RPM.

Run Parameters

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

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, averaging 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.

Sample Well #2:
In this well, where the previous slick BHA achieved 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, 4-3/4-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.

Bottomhole Assembly

Type	OD (in)	ID (in)	Length (ft)
PDC Bit	6		1
Motor 7/8 3.8S 1.5 fixed	4.75		23.66
NM WEPS PDC reamer	5.875	2	5.09
UBHO	4.75	2.75	3.05
NMDC	4.75	2.63	31.24
NM WEPS 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 = 19576.2			

This assembly was run in to ream at 5000 ft 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
24.5hours, 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.

Run Parameters

Depth In	15,552	Torque	7-13K		Oil base
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

There were no issues with steerability, 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.

One of two 5 7/8-inch Non Mag PDC reamer tools after reaming 5000 feet

Sample Well #3:
Two steel PDC reaming tools were used in the lateral BHA and drilled out of the 7” shoe and proceeded to ream-while-drill the lateral.

Bottomhole Assembly

Type	OD (in)	ID (in)	Length (ft)
PDC Bit	6		1
Motor 4/5 5.4 stage 1.5 fixed	5		26.26

HOC	4.813	2.815	30.68
NMDC	4.687	2.25	30.81
X-over	4.25	2.25	4
WEPS PDC Reamer -	5.875	2.5	5.03
HWDP	4	2.56	31.27
WEPS PDC Reamer -	5.875	2.5	5.03
X-over	4.5	2.25	2.68
DP	4	2.5	10388.34

Run Parameters

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

Successfully reamed-while-drilling entire lateral of 9500’ to well TD at 19820’. No issues with torque, steerability or ROP. Successfully installed 30 swellable packers after TD – eliminated dedicated reamer run.

Observations and Results

Over the course of these Williston Basin 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 swell packer installations.

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 2 PDC reamers with 60 ft spacing caused the BHA to have dropping tendencies while in the rotary. Stacking to PDC reamers together with no spacing created a to stiff assembly and was difficult to steer / orient during slides.

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 low / manageable torque increase from 7 to 13, with up to 20 percent increase in rotary ROP, which produced a smooth well bore and greater on-bottom WOB.

The RWD BHA assembly was able to drill out 7-inch casing shoe.

Summary

Drill / ream parameters

- Multiple RWD BHA designs incorporating both non-mag steel body PDC reamer tools
- Test steerability, torque and successful installation swell packers
- Compare RWD BHA to previous lateral BHA – slick and stabilized
- Results / findings – torque increase from 7 to 13 with 20% increase in rotary ROP
- Optimal RWD BHA – 30ft spacing between PDC reamers positioned on top of lower BHA using steel body tools; 30ft spacing between PDC reamers in lower BHA using non-mag tools
- Able to drill out 7" casing shoe
- 100% successful swellable packer installations
- Able to Steer / orient
- First run for a new operator – establish a performance baseline
- No increased vibration issues ie no excess motor / mwd failures
- Increase in rotary ROP – smooth well bore, greater on bottom WOB
- Low / manageable torque
- Versatile RWD BHA using both non-mag and steel body PDC reamer tools
- Eliminated dedicated reamer run - 3 days rig time savings per well
- Reamed in excess 750,000' of hole / over 50 wells in ND / MT

Conclusions

The new PDC reamer tool design is shown to provide a cleaner, better reamed out hole in these Williston Basin wells where the application may require running as many as 40 swellable packers to bottom.

In the subject wells, utilization of this fix bladed PDC reamer resulted in no issues with steerability 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.

Contributing to the success, optimized BHA design, operating parameters and mud properties were determined, and now constitute best practice for typical Bakken wells.

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 with an average savings of 3 days.

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- This new technology, through the combined efforts of proven North Dakota operations groups, rig and service companies, has eliminated the dedicated reamer run at TD while delivering good wellbore condition that enables multiple swell packers to be run in a single, fast trip. We have worked with a number of operators, drilling contractors and service contractors – we appreciate their support in moving this project forward.
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