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Application of Hyper-Short Radius Mechanical Radial Drilling for the Enhanced Production of Heavy Oil in a Carbonate Reservoir in Egypt

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Abstract

Developing heavy oil in complex carbonate reservoirs requires the application of effective and customized stimulation techniques. Currently in the Issaran field in Egypt heavy oil (<14 API, 1000 – 3000 cP) carbonate reservoirs are being developed by acid treatment with subsequent cyclic steam injection. Although steam injection has proven itself at the initial stage of development, poor vertical steam conformance in the complex geological conditions in the wells reduce the effectiveness of steam injection in later cycles. This requires novel methods to reach the parts of the reservoir that remain untouched by acid and steam.

The technology of Hyper-short Radius Mechanical Radial Drilling was piloted on three wells in an onshore carbonate field with heavy oil in the Eastern desert of Egypt. The technology utilises a method of mechanical radial drilling using small-sized mud motors. This approach allows the accurate drilling of multiple radially directed production channels which are ultra-short radius with a dogleg severity of 200 deg/100ft and which extend up to 80 ft long and are 2.75″ in diameter. This approach bypasses any damage zones, targets very specific intervals in the well, can be applied to any formation, and allows the re-entering of each channel to perform selective jetting of acid, survey the trajectory and for reservoir evaluation. In the Egyptian project the radial channels benefits both the acid injection and steam injection effectiveness, in addition to improved production flow, thereby resulting in the significantly increased production rates compared to the wells' historical performance.

A three-well pilot project was executed. After drilling the channels, recording survey data in order to confirm the trajectories, and acid treatment through a special jet sub, each well was put under a cyclic steam injection. On the first well four channels were drilled, followed by jetting 210 bbl. of acid in each channel. Two target layers stratigraphically 220 ft apart were stimulated. After the radial drilling and acidizing, 23,000 bbl. of steam was injected in the well. In the second well, four channels were drilled using only a single anchor. On the second well a unique small-diameter unique GR/SP/Resistivity tool was deployed for logging the drilled channel. After jetting acid, using a special jetting gun to target specific depths, the well intervention was completed with the steam injection cycle. The third well was stimulated by four radial channels and after surveying, acid jetting, steam injection was performed. Initial results indicated

a significant enhancement for the effective permeability based on steam injectivity data with very good indications of significantly improved production.

For the first time in the industry the new Mechanical Radial Drilling technique has been successfully applied to a heavy oil carbonate reservoir. The key achievements were:

- directional radial channels were drilled to stimulate viscous oil deposits,
- logging inside of channels has been performed,
- radial drilling was performed in conditions of total fluid loss.

Due to the vertical variability in the carbonate reservoir, it is difficult to develop it by conventional means. Upon receiving significant improvements in the oil production from the pilot wells, the radial drilling technology is now being planned for a significant number of follow-up candidate wells.

Introduction

The Radial Drilling pilot project was performed in the Arab Republic of Egypt. The Issaran field is composed of fractured carbonate reservoir (Upper Dolomite formation) (Figure 1) of Miocene age.

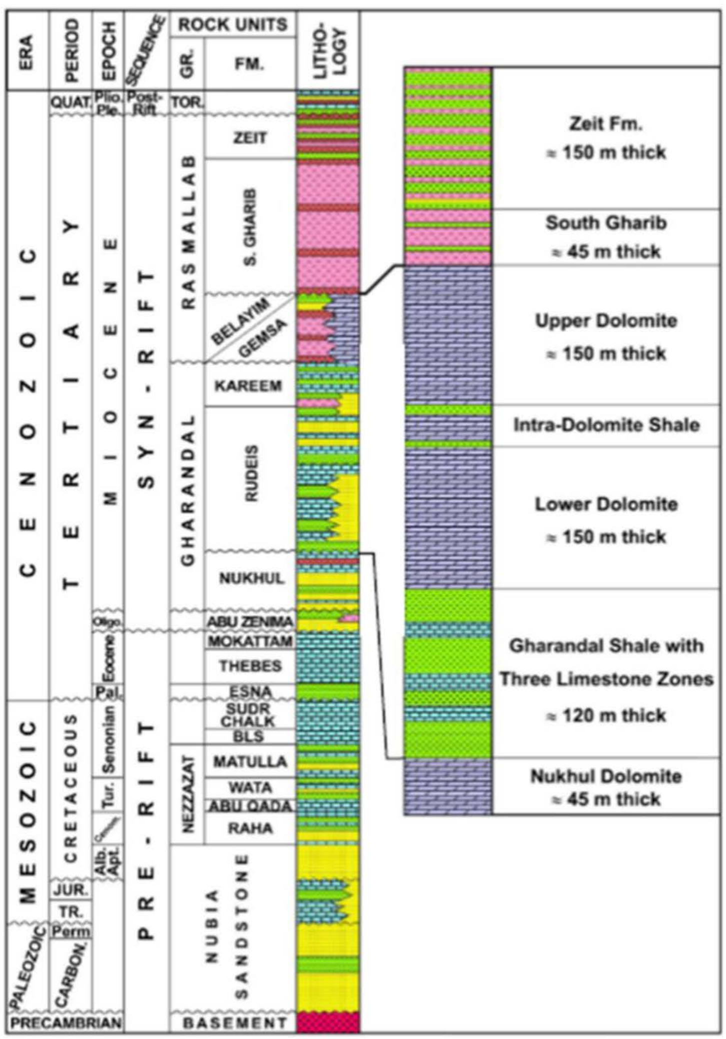

Figure 1—The stratigraphic column of the field

Complex geological conditions such as high reservoir compartmentalization, heterogeneity of the carbonate reservoir, fracturing, large lateral variability of permeability, high oil viscosity, the presence of washed-out zones, and the existence of wormholes due to prior treatment with HCL acid followed by steam injection, provide development challenges. Geological and physical characteristics are presented in Table 1. The method of cyclic steam injection into the production wells is used for effective development of the field.

Table 1—Geological and physical characteristics

Formation	Upper Dolomite
Type	fractured carbonate
MD, ft	350 - 450
Net pay, ft.	45 - 100
Porosity	20-22%
Oil viscosity, cP	1,000 - 3000
Temperature, deg C	44
Current reservoir pressure, bar (psi)	200
GOR, scf/bbl.	23
Oil density, API	12-14

Objectives

The pilot project objective was to evaluate the stimulation of oil production in a carbonate reservoir by drilling radial channels from the main wellbore, combined with acid treatment and cyclic steam injection.

The main factors to evaluate whether:

– directional radial drilling increases the well exposure to the reservoir and can provide targeted stimulation of the reservoir matrix.
– the radial channels benefit the both the acid injection and steam injection.
– the radial channels overcome the lack of steam conformance.

Methods and Technology

Mechanical Radial Drilling is a unique but established new technology that has been described in the literature, (Lyagov et Al, 2021; Lyagov et Al, 2014,; Lyagov et Al, 2022; Lyagov, 2013) and has been successfully utilized on conventional Oil and Gas wells since 2019 (Galas et Al, 2022; Bashirov et Al, 2020; Basyrov et Al, 2021; Galas et Al 2022).

System Novelty. The Mechanical Radial Drilling technology is unique and novel. It uses a small-sized mud motor and conventional bits/mills. The technology allows radial penetration of the reservoir with high accuracy, while providing a significant horizontal displacement from the main wellbore. The technology bypasses any near-wellbore damage zone with multiple large bore production channels that connect directly to the motherbore/production tubing for unrestricted flow. All channels can be re-entered after drilling for treatments or measurements. The large production radius has a distributed pressure-drop that prevents, delays, and/or reduces water or gas breakthrough due to traditional "coning" at the perforations. Production decline rates after stimulation are proven to be much lower than traditional stimulation techniques.

The main assembly (Fig. 2) includes an integral whipstock and a multi-section positive displacement motor (PDM) with a specific geometry between the motor sections to allow the drilling of long 2.75″ diameter channels along a planned trajectory of 45 ft to 80 ft long (depending on the equipment selected).

Due to the ultra-small radius of curvature (>100 to >200 deg/100ft), predictability of the channel trajectory, as well as several unique solutions applied in the technical design, it became possible to accurately mill a window in the casing with subsequent drilling of the channel within the targeted interval. The technique allows reliable delivery of the channel trajectory during drilling by the fixed geometric design of the bottom hole assembly. The same principle also allows re-entering the already drilled channels which is unique to the system. A whipstock is integral to BHA and an anchor tool with an orienting shoe are attached to the pipe string (Fig 3). The average actual deviation values of the trajectory are not more than +/− 3 ft. vertically.

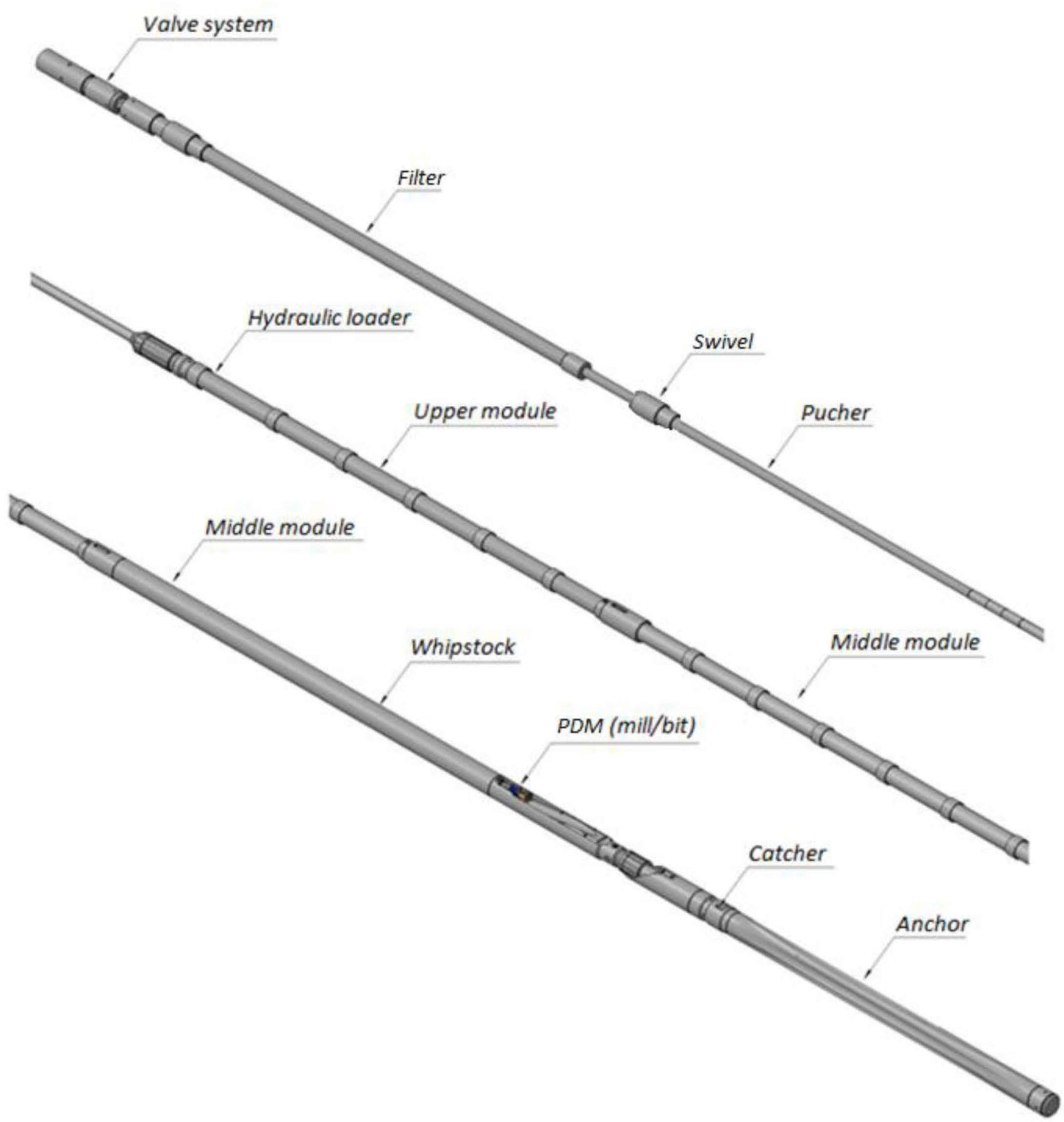

Figure 2—Parts of the Mechanical Radial Drilling technical system

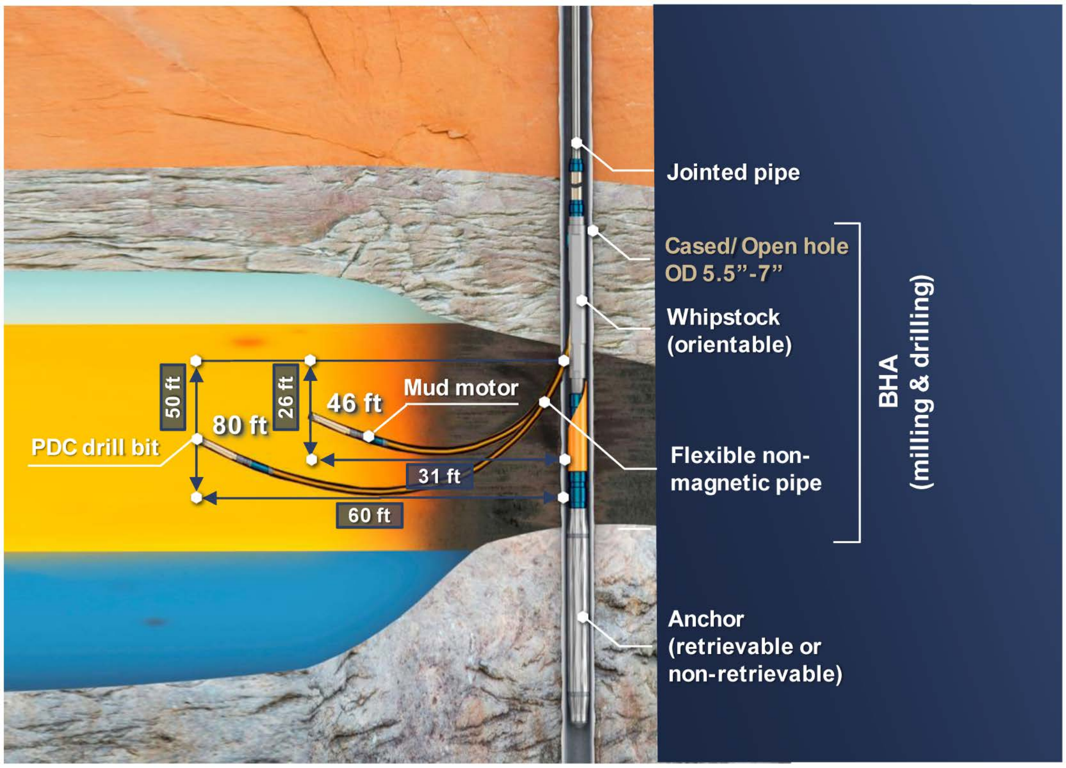

Figure 3—Main elements of the technology

The new Mechanical Radial Drilling System combines technology for window milling, channel drilling and channel re-entry that provides for the following advantages:

- significantly increases the drainage radius of production/injection wells, optimizing the field development without drilling additional wells between existing wells.
- is applicable in carbonate and terrigenous formations.
- bypasses the damaged bottomhole "near perforation" zone including deposits of paraffin and asphaltene which can significantly impact a wells production performance.
- works in "thin" limited thickness formations/reservoirs (<10 ft.),
- can be used in formations with close aquifers or nearby gas-oil contact.
- provides an opportunity to perform formation evaluation and record the actual trajectory of the drilled channels.
- up to 4 radial channels can be drilled at one TVD with different curvature and length of channels,
- provides the possibility of multiple re-entries into the drilled channel,
- it is possible to combine the Mechanical Radial Drilling technology with focused acid and/or chemical treatments,
- possibility to work in vertical, inclined, and horizontal wells,
- can be applied in cased or open hole.

The world-wide technical success rate of the technology is more than 90%. There is proven compatibility to both terrigenous/clastic and carbonate formations with various well types (vertical and inclined, oil or gas, cased or open hole), with depths from 1,000 to 15,000 ft.

Combination of Mechanical Radial Drilling with Directional Acid Treatment. Directional Mechanical Radial Drilling technology is often used in conjunction with acid treatment in carbonate reservoirs. A distinctive feature of the technology is control of the radial wellbore trajectory. Fig. 4 illustrates an example of an electrical micro-imager and cross-dipole acoustic log interpretation result.

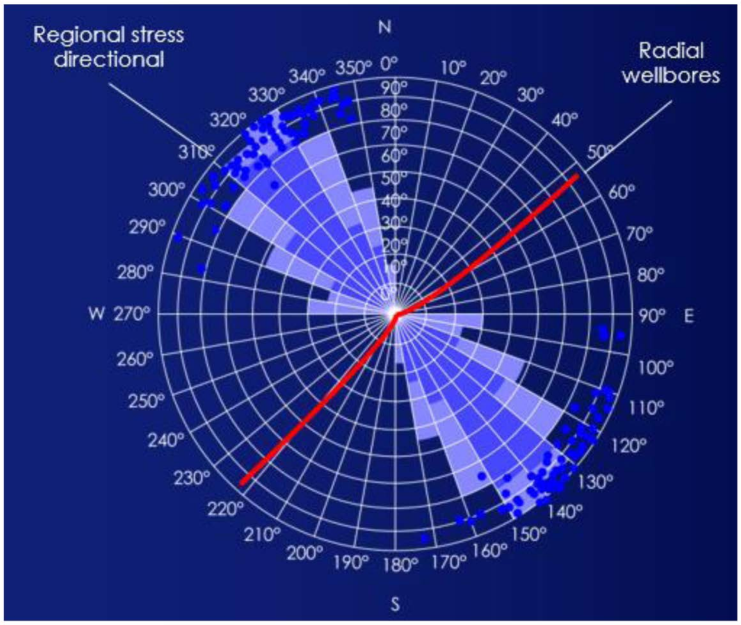

Figure 4—Azimuthal orientation of the wellbores

This feature makes it possible to drill wellbores in specified azimuthal directions, for example, perpendicular to the regional stress. The interpretation of logging data makes it possible to identify and assess the orientation of any natural fractures in rocks. Based on this information, the radial channel is oriented so that it crosses the maximum number of natural fractures. This feature is widely used in naturally fractured carbonate reservoirs to increase well production by penetrating the largest possible number of fractures around the well.

Radial drilling allows for spot treatment in each target reservoir, which multiplies the efficiency of acid treatment by several times (Fig. 5). In addition, it is not necessary to use diverter compositions because the acid composition is injected directly into the target reservoir. The injecting speed of acid composition is 100 m/s. The combination of the two technologies makes it possible to inject the mixture of acids in every meter, thus the results are comparable to, and frequently superior to acid fracturing.

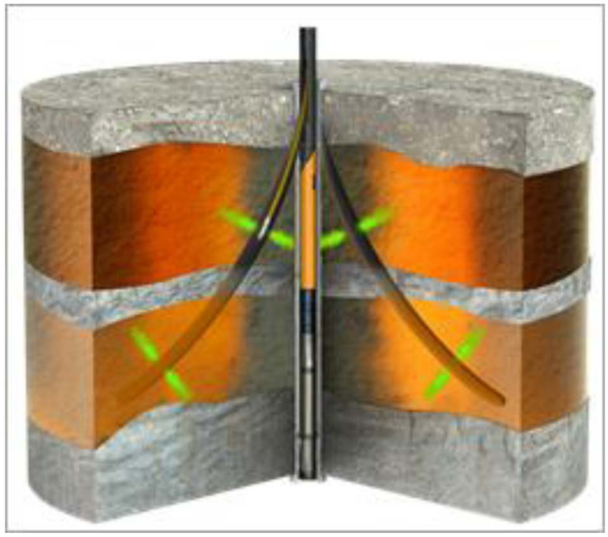

Figure 5—Stimulation of carbonate reservoir

Experience of Mechanical Radial Drilling in Egypt

A three-well pilot project was executed. After drilling the channels and recording survey data, in order to confirm the trajectories, acid treatment was performed through a special jet sub, and each well was put under cyclic steam injection before initiating production.

The Upper Dolomite reservoir was formed in a lagoonal environment, characterized by the presence of diverse grains such as ooids, peloids, algae and reworked bioclasts, accompanied by anhydrite nodules. The geological consequence of this setting is the occurrence of intense diagenetic processes, including dolomitization, dissolution, and cementation. The original reservoir fabric has been significantly altered by these diagenetic activities, leading to a change in the reservoir's characteristics and an increase in its overall heterogeneity.

Approximately 97% of the oil in the fractured carbonate reservoirs of Upper Dolomite is located within the reservoir matrix. Only a small portion, between 1 and 3 percent, is located within the fracture system. Relatively low rates of fluid production can be attributed to the low permeability matrix found in the Upper Dolomite. However, fracturation, karstification, and dissolution-enhanced fractures within the reservoir allow for efficient oil production and quick inter-well communication.

To enhance the ultimate recovery from the matrix, a crucial strategy involves improving the flow from the matrix to the wellbore. Mechanical Radial Drilling offers a viable solution for enhancing the flow from the matrix. By implementing Mechanical Radial Drilling techniques, it becomes possible to optimize the extraction of oil from the matrix, thereby contributing to an overall improvement in ultimate recovery from fractured carbonate reservoirs.

The Mechanical Radial Drilling technology selection criteria involved targeting matrix-dominated wells with moderate to low fracture intensity, assessing post-treatment performance, favoring low water cut and sustained gross rates. In order to ensure a methodical evaluation of the technology's efficiency across a variety of formations, other criteria include sufficient well spacing, good cement integrity, and avoidance of steam and acid thief zones, ensuring a systematic approach to assess the technology's success across diverse formations.

In August 2023 the Mechanical Radial Drilling technology was applied to well A of the Issaran field utilizing a 350 HP workover rig. After the well preparation which includes scraping and drifting the well, the anchor was installed at the target depth. In total, two anchors were used to drill 4 channels as two pay zones were separated by 200 ft. The design of the channels with acid points indicated is represented in Fig. 6.

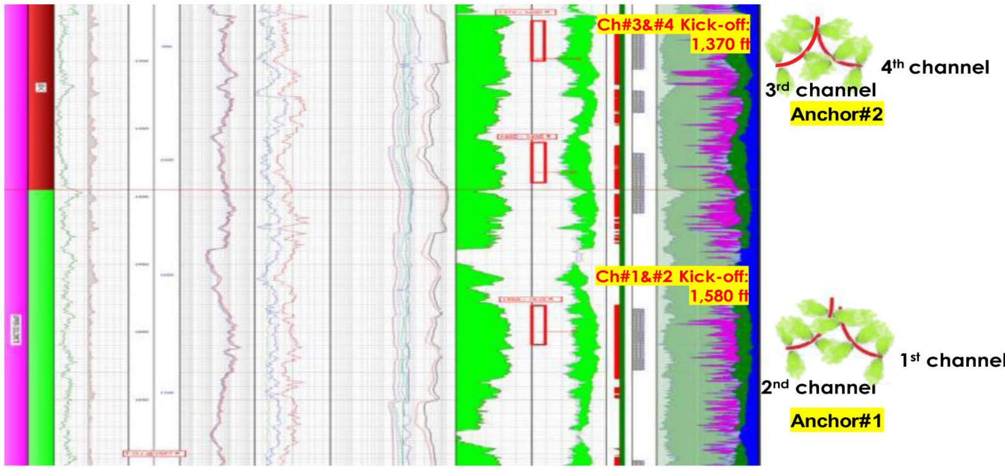

Figure 6—Design of Mechanical Radial Drilling channels in Well A

To ensure the accuracy of the anchor depth installation, a wireline logging operation was performed. Four "windows" were milled in the casing and four radial channels with a length of 45 ft. were drilled with the BHA's showing visual oil when returning to surface (Fig.7). After completing the drilling operation, a surveying tool was deployed to confirm the trajectory. The last operation prior to retrieving the anchor was a targeted multipoint acid stimulation which was performed by deploying a special acid jetting sub.

Figure 7—Mechanical Radial Drilling BHA after POOH

Acid treatment was carried out inside each drilled channel at three points. The volume of the acid was 210 barrels in each channel.

After acid treatment, 23,000 barrels of steam were injected into the well (the same volume as was injected during the previous cycle). It should be noted that when steam was injected after Mechanical Radial Drilling, there was an increase in injectivity by 1.4 times (from 800 to 1100 bbl/d at similar injection pressures). The results of the completed Mechanical Radial Drilling, acid treatment and steam injection are presented in Table 2 and Fig. 8.

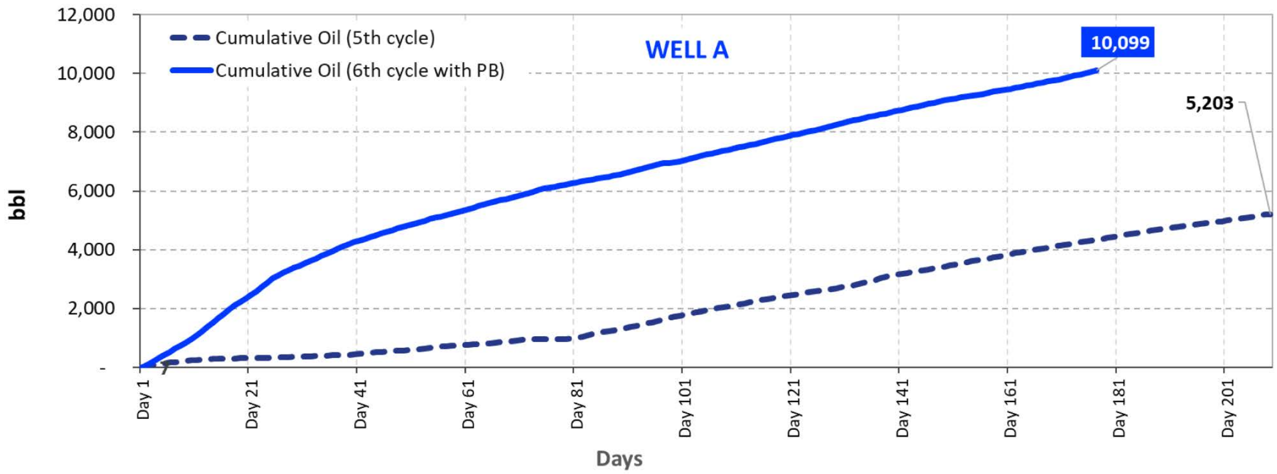

Figure 8—Comparison between two steam cycles in Well A – before and after Mechanical Radial Drilling

Table 2—Production parameters of well A

Well	Pre-job			Planned			Startup (Sep 2023)			Increment
A	Qfluid, BFPD	Qoil BOPD	WC, %	Qfluid, BFPD	Qoil BOPD	WC, %	Qfluid, BFPD	Qoil BOPD	WC, %	Qoil BOPD
	78	31	60	308	113.6	62	527	144	72	113

Results and Discussion

The utilization of Mechanical Radial Drilling made it possible to achieve same amount of cumulative oil production as for previous cycle more than 4 times quicker (Fig 8). Also, Mechanical Radial Drilling technology provided an increased steam-oil-ratio (SOR) from 3.8 (for 5th cycle before) to 3.2 (6th cycle).

In the second Well B, another four radial channels were drilled, but from a single anchor location, with survey data recorded. The next stage was the deployment of a Gamma-Ray and Resistivity logging tool for the first time in history (Fig. 9–11). These petrophysical methods using extremely small diameter tools, upon completion of drilling radial channels, make it possible to prove that drilling was carried out in the target reservoir.

Figure 9—GR tool

Figure 10—Resistivity tool

Figure 11—String of logging tools made-up at a rig site

The data from the logging tools provided objective information about the formation and reservoir. Qualitative determination of oil saturation as an additional method provides for more efficient field development. Performing logging in the channel up to 45 ft. from the main wellbore eliminates the distortion of parameters close to the production casing or cement bond. The results obtained are shown in Figure 12.

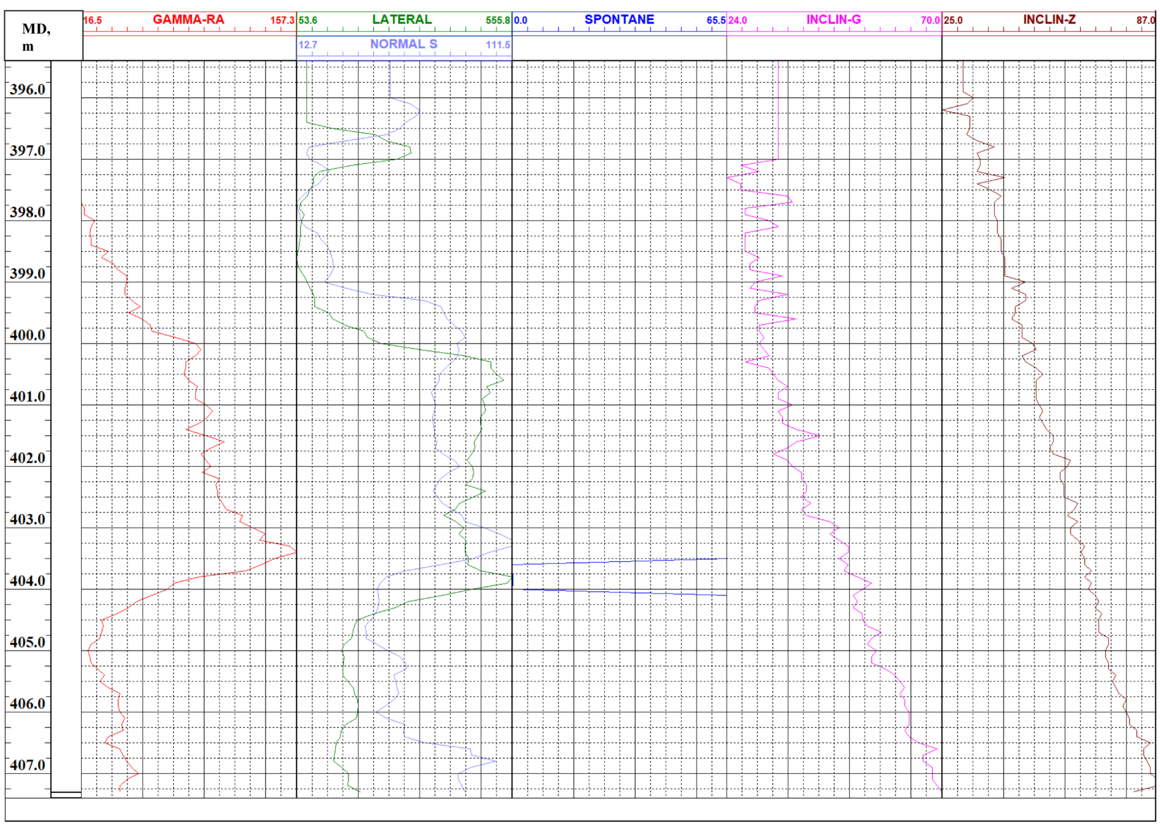

Figure 12—Record of GR and Resistivity logging tools

After conducting logging, acid treatment was performed. The volume of the acid pumped was 210 barrels in each channel. The design of channels with acid spots is shown in Figure 13.

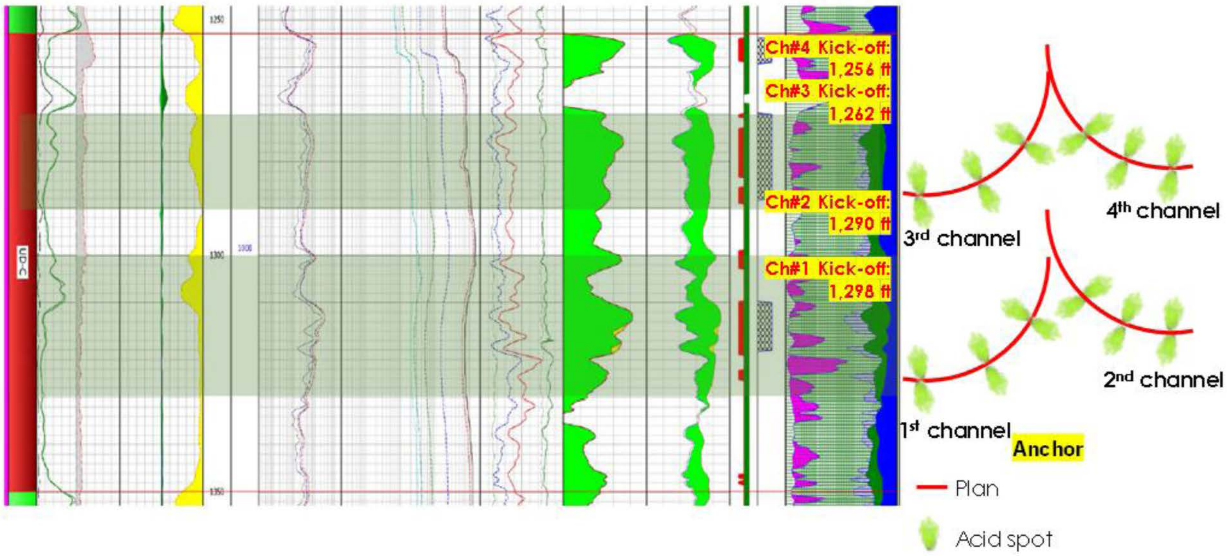

Figure 13—Design of Mechanical Radial Drilling channels in Well B

After acid treatment, 20,000 barrels of steam were injected. The Mechanical Radial Drilling channels increased steam injectivity by 1.3 times (from 830 to 1054 bbl/d with a 10% pressure reduction). The results after Mechanical Radial Drilling, acid treatment and steam injection are in Table 3 and Fig. 14.

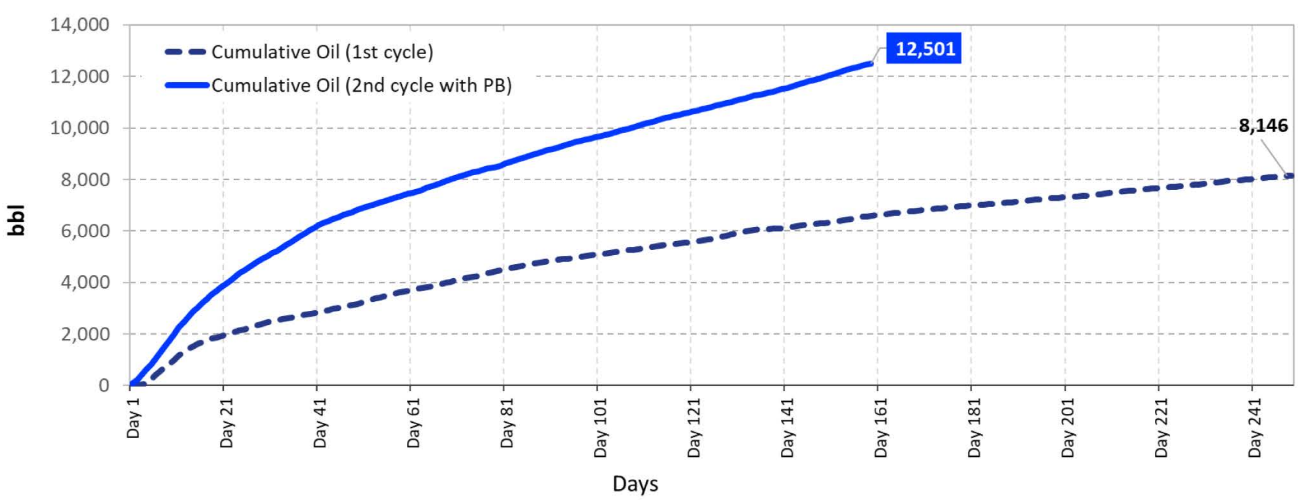

Figure 14—Comparison between two steam cycles in Well B – before and after Mechanical Radial Drilling

Table 3—Production parameters of well B

Well	Pre-job			Planned			Startup (Sep-Oct 2023)			Increment
A	Qfluid, BFPD	Qoil BOPD	WC, %	Qfluid, BFPD	Qoil BOPD	WC, %	Qfluid, BFPD	Qoil BOPD	WC, %	Qoil BOPD
	20	17	12	325	113	65	506	210	58	193

On well B the technology was applied before second steam cycle which offered an opportunity to assess the potential of the technology application in newly drilled wells. Figure 14 indicates that Mechanical Radial Drilling delivered the same amount of cumulative oil production as for the previous (1st) cycle more than 4 times quicker. The Mechanical Radial Drilling technology provided an improved SOR from 2.5 (for 1st cycle before) to 2.3 (2nd cycle after Mechanical Radial Drilling).

The third Well C also drilled four channels with survey, GR and resistivity logging, where acid treatment and subsequent steam injection were performed. Taking into consideration the natural fracture propagation orientation, the radial channels were drilled in one direction (80-90 deg in azimuth).

After acid treatment, 23,000 bbls of steam were injected into the well. Mechanical Radial Drilling channels have increased steam injectivity by 1.3 times (from 909 to 1,388 bbl/d). The results of the completed Mechanical Radial Drilling, acid treatment and steam injection are shown in Table 4 and Fig. 16.

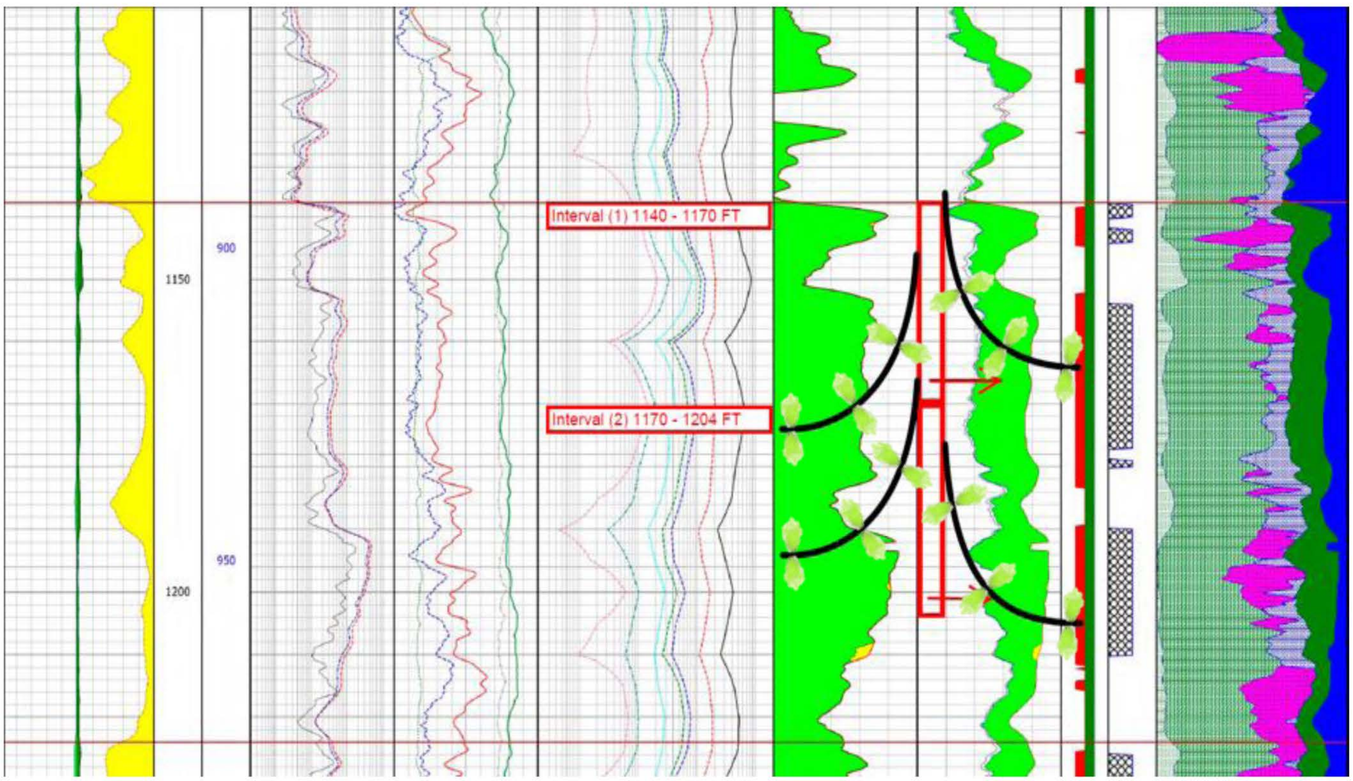

Figure 15—Design of Mechanical Radial Drilling channels in Well C

Table 4—Production parameters of well C

Well	Pre-job			Planned			Startup (Oct 2023)			Increment
A	Qfluid, BFPD	Qoil BOPD	WC, %	Qfluid, BFPD	Qoil BOPD	WC, %	Qfluid, BFPD	Qoil BOPD	WC, %	Qoil BOPD
	57	8	86	176	68	60	456	82,6	82	74,6

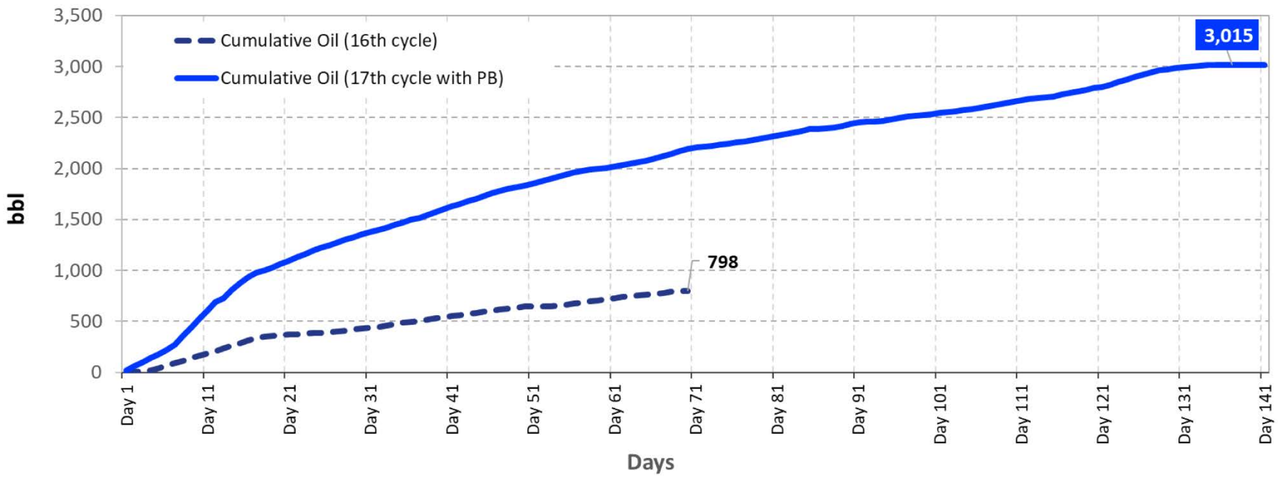

Figure 16—Comparison between two steam cycles in Well C – before and after Mechanical Radial Drilling

In comparison to wells A and B, well C had a much longer previous period of production with 16 cycles of steam injection prior to the Mechanical Radial Drilling application. Nevertheless, the chart in Figure 16 shows that Mechanical Radial Drilling achieved 3 times more production for the same period of time as the previous cycle. Also, Mechanical Radial Drilling technology provided an improved SOR from 12.5 (for 16th cycle before) to 10 (17th cycle with Mechanical Radial Drilling).

The Mechanical Radial Drilling technique is unique in the industry. No other technology allows for the drilling and re-entry of as many as 4 channels from the same depth and allow chemical treatments. The verification of the channel locations using survey, and the Gamma Ray, Resistivity and Spontaneous Potential measurement tool is unique and not available anywhere else.

Summary and Conclusions

The Pilot Project of Mechanical Radial Drilling technology in heavy oil deposits with complex geological conditions delivered excellent results.

- The combination of radial channels with steam cycles provides more efficient distribution of steam in comparison to conventional steam injection and significantly improved oil production.
- The Mechanical Radial Drilling delivered an increased oil production over the first 30 days of: -
  - 144 bbl/day on well A, vs 31 bbl. day before the operation.
  - 210 bbl/day on well B, vs 17 bbl. day before the operation.
  - 82.6 bbl/day on well C. vs 8 bbl. day before the operation.
- The combination of Mechanical Radial Drilling technology with multi-point acid injection demonstrates significant increases in oil production when compared to regular acid treatment with subsequent steam injection.
- Mechanical Radial Drilling technology allows to shorten the duration of the steam injection cycle.
- Possible to manage the inflow profile by the selective penetration and simultaneous stimulation of target formations.
- Radial channels have a significant advantage in medium and highly permeable reservoirs compared to other stimulation methods.
- The 2.75″ drilled channel is a production path of almost infinite conductivity when compared to proppant fracturing where on average fractures with width not more than 0.4-0.6″ are created.

Recommendations

Longer term analysis of effectiveness in the pilot wells will continue with measuring the frequency and performance of any subsequent steam cycles. This knowledge will be used to mature the scope of future candidate wells and for a larger scale field development program. Additionally, the evaluation of using the longer (25m) channels is planned in the future.

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