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The Method of Deep-Penetrating Acid Treatment in Radial Channels for Stimulation of Carbonate Reservoirs

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Abstract

Many carbonate reservoirs require production stimulation. Reservoir heterogeneity, large lateral permeability differences along the reservoir, the proximity of water-saturated layers, as well as the technical condition of wells are common stimulation complications. In such conditions hydraulic fracturing has the risk of an accident and/or watered production. This greatly complicates efficient exploitation of fields and it is necessary to identify new methods to increase oil recovery.

Deep-penetrating acid treatments in radially drilled channels are applied to provide stimulation in carbonate reservoirs. Maximum four 69 mm (2-3/4″) diameter channels of up to 25m (82 ft.) are drilled along a pre-set trajectory. A special bottomhole assembly on jointed-pipes is deployed using a workover hoist. The technology allows re-entry of the drilled channels and acid treatment through the jet nozzle. The jetting nozzle has four 4.2 mm (11/64″) perpendicular nozzles, and the acid outflow rate is approximately 100 m/s. In addition to rock dissolution, wormholes are washed into the formation at exactly the most effective location.

A 3 well case-history is described where drilled radial channels with deep-penetrating acid treatments were applied through a jet nozzle in carbonate reservoir. Several 69 mm (2-3/4″) channels with a length of up to 14 m (45 ft.) were drilled a pre-set trajectory using a double-bend motor. The trajectories were analyzed with a memory directional survey. Acid treatment was performed using a jet nozzle in each channel. Well#1 included oil-saturated interlayers in the channels that were stimulated by targeted jet treatments using 15% HCl opposite each interlayer. The precisely located acid treatment removed the need for additional diverting treatments. In Well#2 the well damage challenge was solved by shutting-off cross flow near water-saturated interlayers behind the casing where standard bottom-hole treatments aren't effective. The horizontal channels from the mother-bore, together with the acid treatment, allowed successful stimulation of the reservoir while avoiding crossflow effected zones behind the casing. In Well#3, the laterals were successfully drilled and treated with acid. Many non-target upper perforation intervals were managed in addition to crossflows behind casing from below the reservoir. On average, oil increment increases at the wells amounted to a very successful 179% (2.8x production increase).

The first example of directional radially drilled channels with deep-penetrating acid treatment through a jet nozzle on carbonate reservoirs. The technology proved its effectiveness and the planned significant oil increment targets were achieved. This method is very promising due to the very common occurrence of carbonate reservoirs in need of effective stimulation. The introduction of technology into the regular production program can now be considered and is supported by the results of the described project.

Introduction

The analyzed field is carbonate reservoir of Bashkirian and Devonian deposits, located on the territory of the Samara region. In total three field were analyzed, two of which are confined to the Devonian carbonate deposits.

Bashkir and Devonian deposits are dense gray and light gray limestone deposits characterized by wide distribution of bioherms. Studied organogenic carbonates usually do not contain any clay materials. The reservoir properties are characterized by significant variability both in area and in a cross-section.

All analyzed fields have a number of problems engineers faced with during the field development. One of the main problems is a significant decrease in hydrocarbon production due to reservoir damage. The main reason of it is wellbore fluid invasion into the near wellbore zone of the reservoir.

Goal and tasks

The goal of this paper is stimulation of oil production in carbonate reservoir by drilling radial channels.

The main tasks of this paper are:

- stimulation after workovers of behind-the-casing crossflow;
- directional radial drilling as an alternative to hydraulic fracturing in the wells where this is impossible due to geological or technical reasons;
- stimulation of oil production after reservoir damage.

Methods and technologies of operation

Directional radial drilling is a new type of workover intervention aimed at oil production enhancement.

Implementation of highly effective directional radial drilling is possible through the use of Perfobore technology. This technology allows obtaining a system of extended (up to 25 meters) radial channels, and radial channels with 4 different trajectories can be created simultaneously within one depth, and there may be several such depth.

The key elements of directional radial drilling technology are shown on Fig. 1, its are: a pipe to push the tool, connected to the bypass valve and liner at the top, and to a guide device at the bottom. It is connected by a hydraulic drive to the pipe of a given rigidity to a small-sized (non-standard) sectional downhole drilling motor and a drill bit (or a rotary tool for cutting a window in a casing). A special whipstock and an anchor module with an orienting funnel are connected to the bottom of the modular guide [1–3].

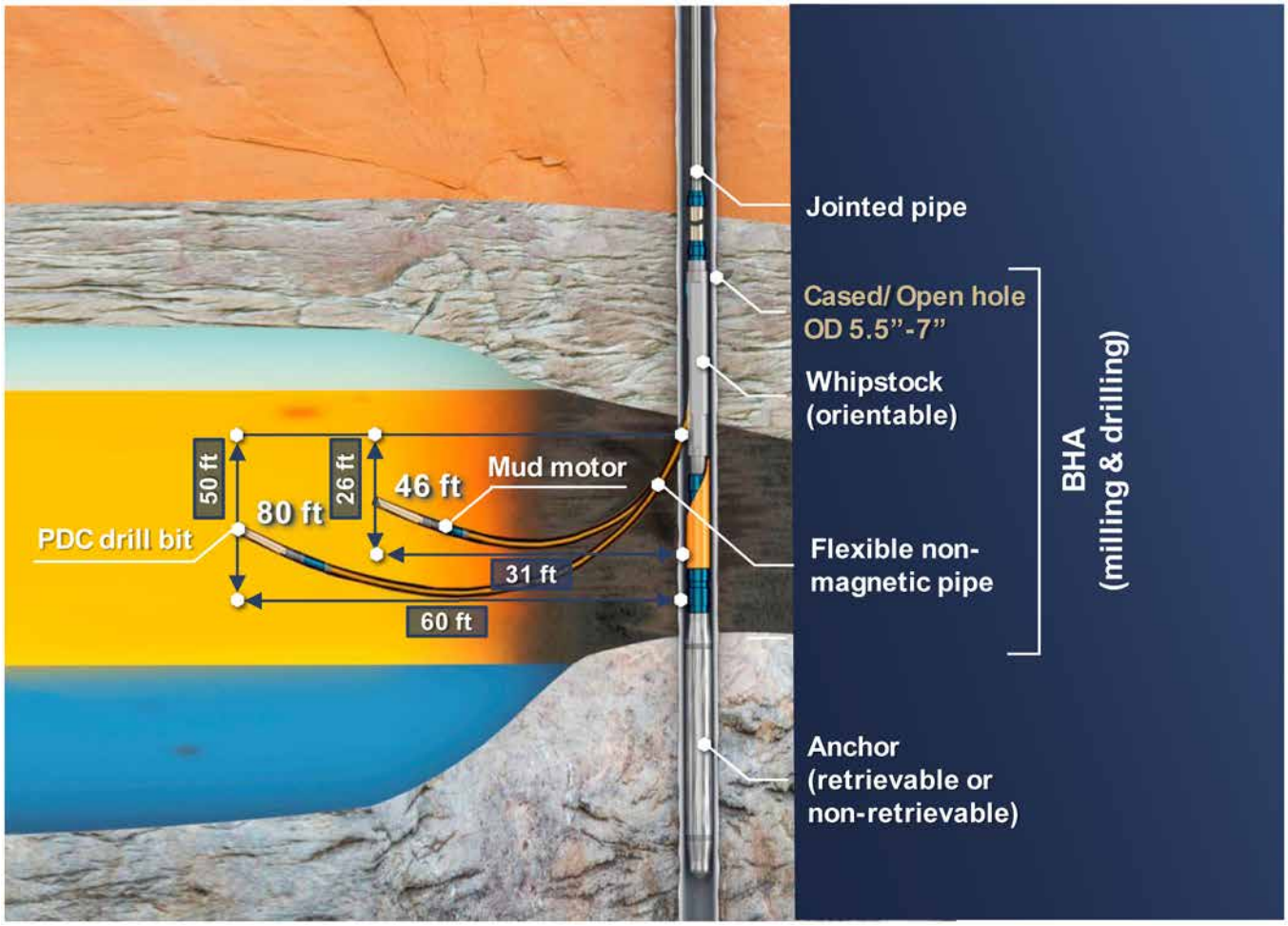


Figure 1—Main elements of Perfobore technology

There are 3 main stages of Perfobore's directional radial drilling:

1. The first stage is carrying out orientation of the anchor module in the borehole. The tool is fixed on the target layer depth by means of gamma-ray logging and collar locator and directional logging for orientation.
2. The next step is slot cutting. To accomplish this, the cutting module is lowered into the borehole and connected to the anchor module for further radial drilling. At the end of the second stage the curing module is taken out of the borehole.
3. The final step is the channel drilling. The drilling tool is lowered into the hole and connected to the anchor module and the drilling process begins, once the radial channel is drilled the module is lifted out of the hole.

The Perfobore technology has a number of advantages over other sidetracking methods. First, the technique allows full control over the path of the channels created during the drilling by dynamically orienting the drilling tool in space, which also allows reentry into channels already drilled. Another striking feature of this technology is its applicability in any type of well, whether it is a vertical well or a horizontal one.

A distinctive feature of the Perfobore technology is the ability to control the radial channel trajectory. Figure 2 illustrates an example of an electrical micro-imager and cross-dipole acoustic log interpretation result.

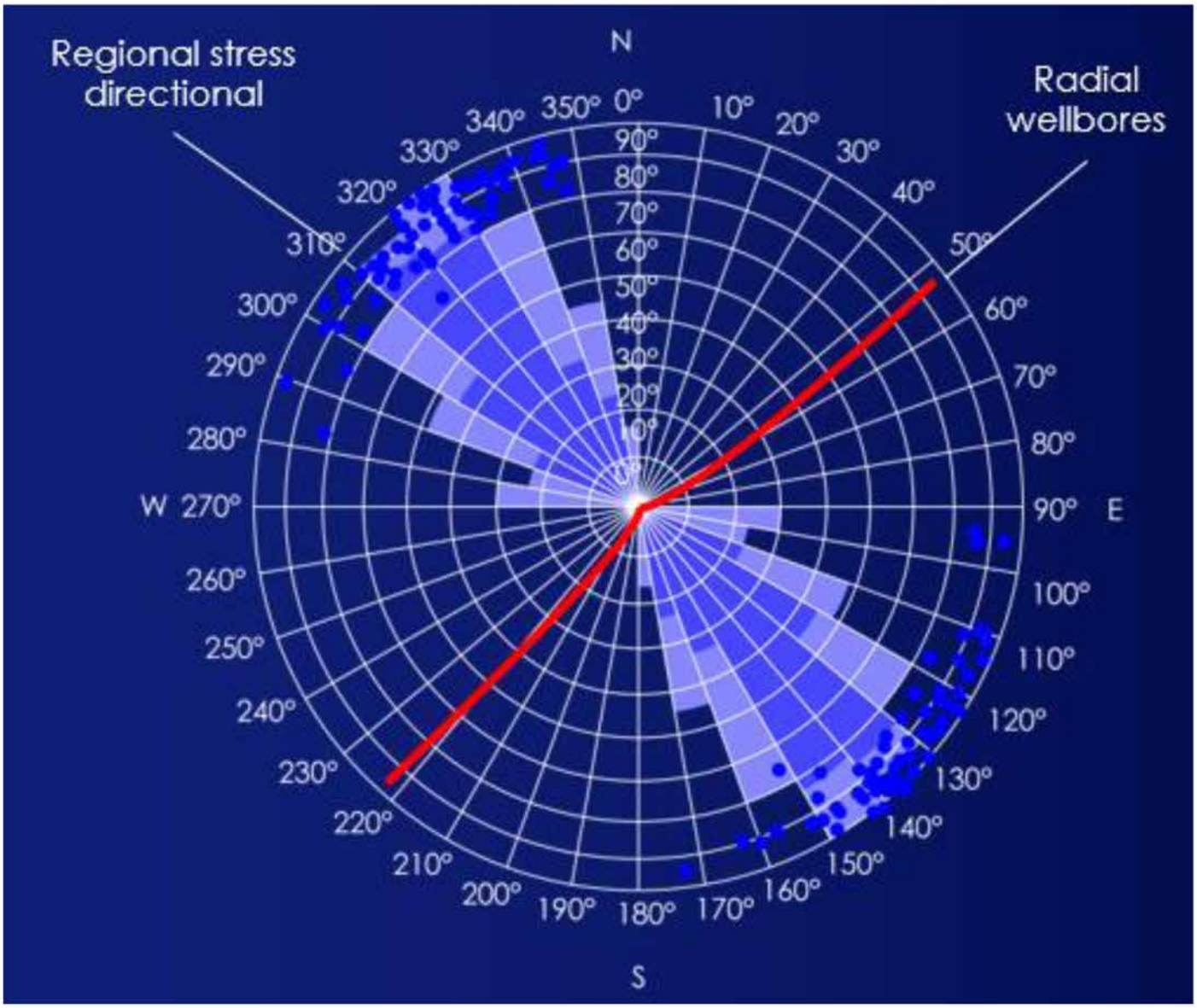
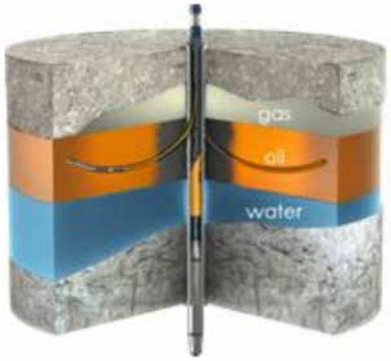
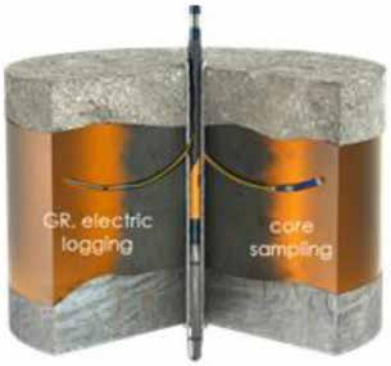


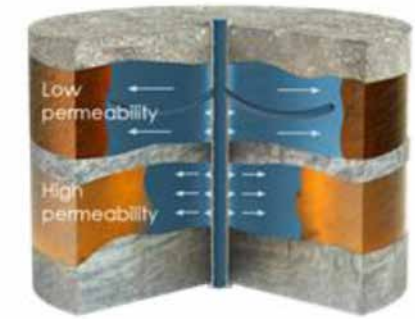
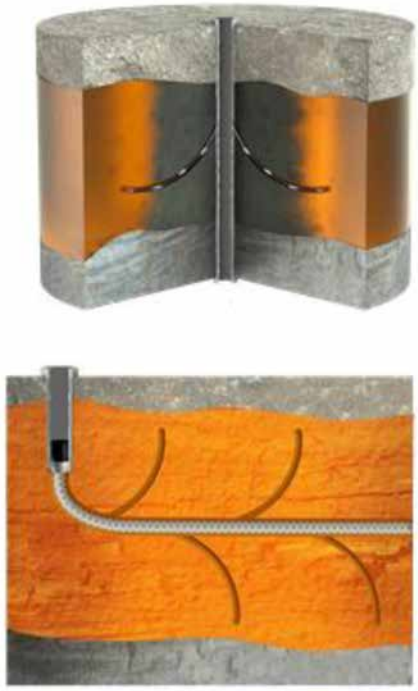
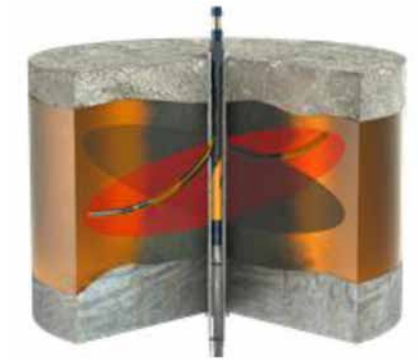
Figure 2—Azimuthal orientation of the channels

This feature makes it possible to drill channels in specified azimuthal directions, for example, perpendicular to the regional stress. 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.

Table 1 shows the applications where directional radial drilling can be used effectively.

Table 1—Application area for Perfobore radial drilling technology

Application area	Schematic	Capabilities
Well stimulation		• Stimulation of oil rim • Stimulation of bottom water-drive reservoirs • Carbonate reservoirs development
Drilling method		• It is used after the workover • Non-damaging completion • Horizontal displacement up to 10 m from the well
Reservoirs production testing		• Testing of new reservoirs at exploration wells • Possibility of coring in cased wells (2023)
Alternative to horizontal sidetracking		• In the presence of blow out equipment • No reasons to extract emergency equipment • Cutting a window in the cased well above the reservoir (up to 15 m higher from formation top)

Application area	Schematic	Capabilities
Stimulation of injection wells		• Heterogenetic deposits with different permeabilities • Conformance control for water injectors in low-permeable reservoirs without hydraulic fracturing
Well completion		• Channel drilling in open hole well before deploying of uncemented liner • Channel drilling in cased well (instead of jet perforation while low quality of cementation) • Opportunity of drilling channels in both vertical and horizontal wells
Combination with hydraulic fracturing		• Capability of hydraulic fracturing • Orientation of hydraulic fracturing • Capability of swellable packer setting

Combination of directional radial drilling with acid treatment

For more successful development of a carbonate reservoir, directional radial drilling technology is often used in conjunction with acid treatment. Radial drilling allows for spot treatment opposite each target reservoir, which multiplies the efficiency of acid treatment by several times (Fig. 3). In addition, there is no necessary to use deflecting compositions, because the acid composition is injected 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 or higher than from hydraulic fracturing

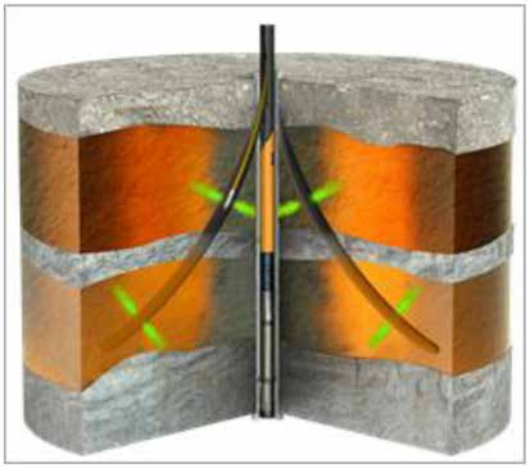


Figure 3—Stimulation of carbonate reservoir

Fig.4 shows the dependence of the skin factor from drilled radial channels length. It is noted that a larger length of the drilled channel has a more negative skin factor.

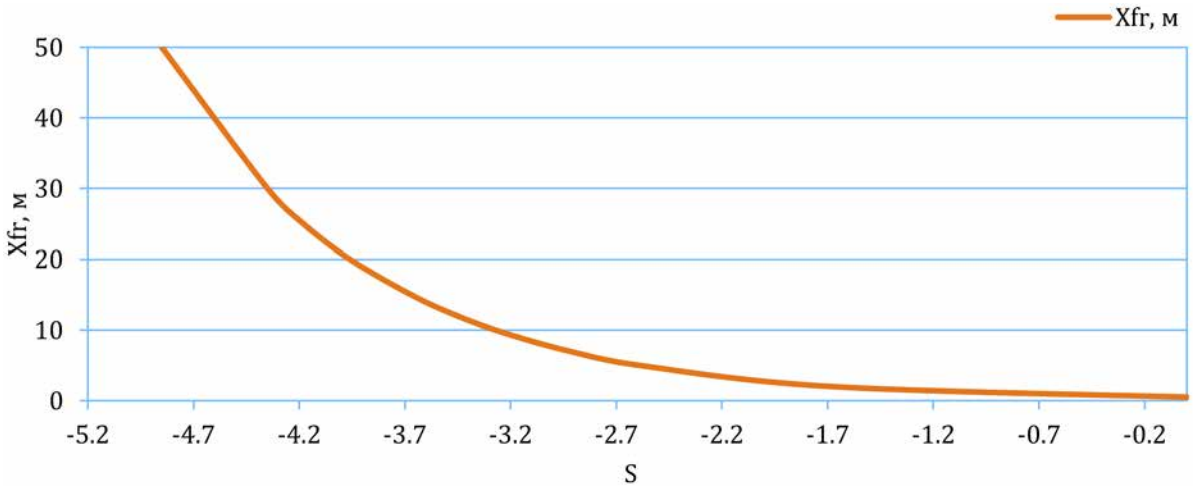


Figure 4—Radial channel length Vs skin factor

The skin factor value predicted for radial drilling is calculated using formulas analogous to the half-length of hydraulic fracture:

$$S = \ln(2\frac{r_w}{L_{fr}})$$

$$S = \ln(\frac{(2+3.21F_{cD}-1.07)r_w}{L_{fr}})$$

There is an experience of similar operations in 4 wells (Table 2). Well skin after radial drilling can be calculated by pressure transient analysis during well build-up test or well drawdown test [4–6].

Table 2—Well testing results after radial drilling in complex with acid treatment

Well	Reservoir	S plan	S actual	Results, %
A	SKZ+ SChR	-3,2	-3,2	100%
B	SKZ+ SChR	-3,2	-4,9	153%
C	C1s-3+C1s-4	-3,2	-6,9	217%
D	XVI	-3.2	-4.8	150%

Estimated time of production increase after radial drilling is 3 years. At the same time, the first radial drilling operations were performed in 2019, and the effect of oil rate increase after radial drilling still continues.

Table 2 summarizes the acid treatment results after radial drilling, as well as the well testing. The predicted skin factor for all 4 wells was −3.2. However, only in one well A, the predicted skin factor coincided with the actual one based on the results of the well test. In the other 3 wells, the actual skin factor has more negative values, respectively, the actual growth rate more than predicted reaches more than 2 times in some wells.

Experience of directional radial drilling in the Samara region fields

In order to increase the effect of oil production stimulation in 2021 it was applied the technology of deep penetrating acid treatment in the carbonate reservoirs of Samara region. For this goal radial channels (diameter is 69 mm and length is 14 m) were drilled following the preliminary planned trajectory. Radial drilling was carried out with a special downhole tubing string assembly from a standard hoist for the workover operations. The use of Perfobore technology made it possible to re-enter already-drilled radial channels and make acid treatment through the jet pump module. The jet pump module has four nozzles, each with a diameter of 4.2 mm, which are positioned perpendicularly to the drilled hole. Powerful jets of hydrochloric acid solution are injected through the nozzles, the speed of which reaches 100 m/s, thus providing the effect of dissolving carbonate components in the rocks, as well as flushing wormholes and cleaning reservoir damage due to wellbore fluids invasion to the near wellbore zone of the reservoir while well drilling and downhole pump installation.

Stimulation operations by drilling of radial channels and conducting acid treatment inside of them were executed at the analyzed field.

All wells were located on different fields with individual geological parameters. However, each reservoir was referred to carbonate rocks.

The first field's reservoir is Bashkirian formation of Samara region (well A). In the considered well there is a significant oil rate decrease after workover. The main problem in this well was that re-perforation and workovers did not allow to increase oil rate (Fig. 5).

According to the history of workowers (Fig.5), there is a significant effect of radial drilling in complex with acid treatment. Two channels of 13 m each were drilled and acid treatment 24 m3 of 12 %HCl was carried out. As a result an oil rate increase Q_{oil} of 24 t/day it's gained, at the same time well PI is increased 6 times, from 0.2 to 1.2 m3/day/atm.

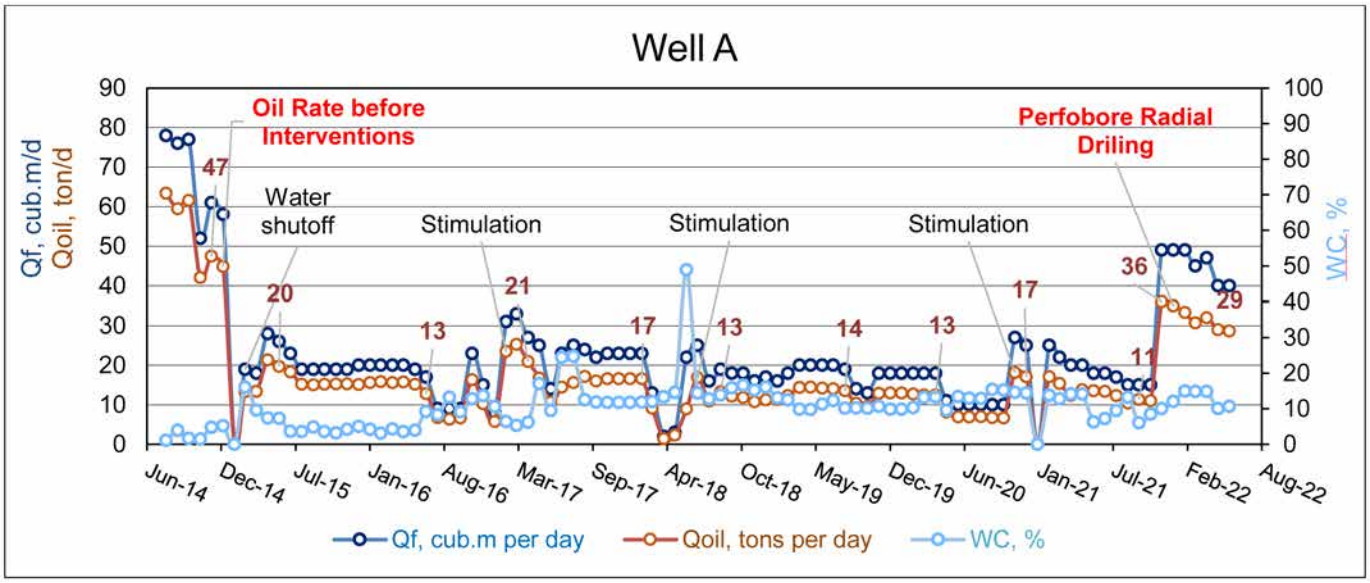


Figure 5—Production history of Well A

Fig.6 shows well logging plot with indication of radial channels intervals, as well as with indication of points of acid injection.

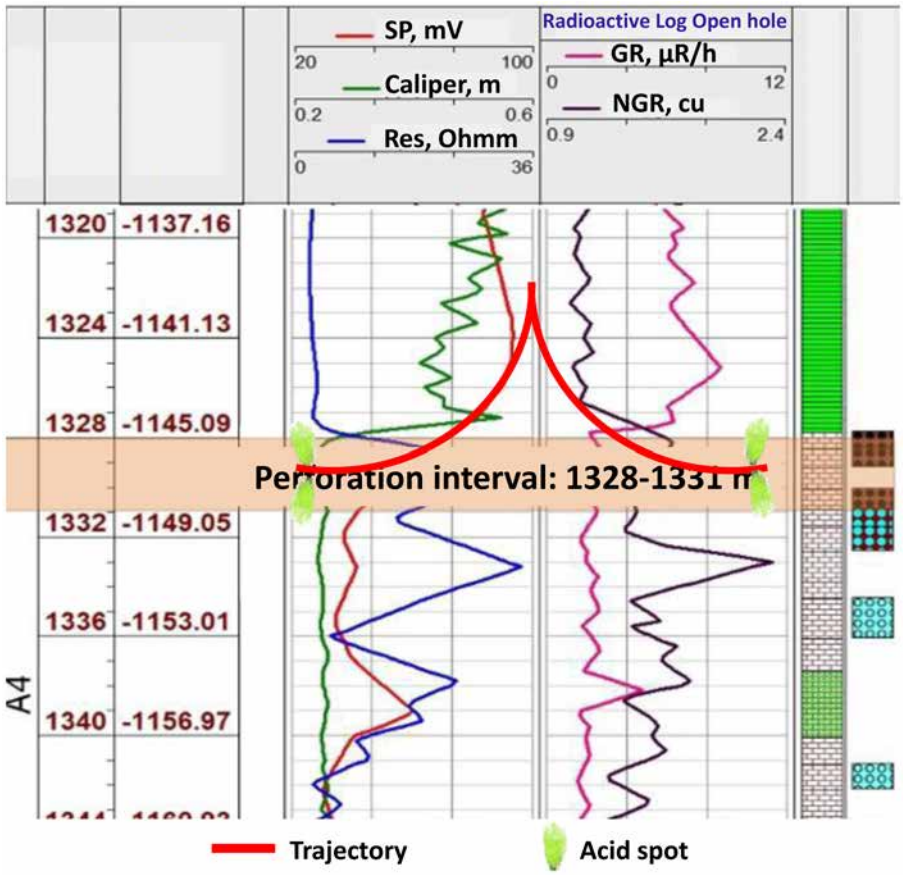


Figure 6—Well logging plot (well A)

It can be seen that each of the drilled radial channels shape is fixed.

The distance between the of the toe of each radial channel and main wellbore is 9 meters, despite the length of each of the channel from window in a casing to the channel toe is 13 meters. The toe of each radial channel is at −1447 m of true vertical depth.

Table 3 shows predicted and actual parameters for fluid and oil flow rates. You can see that the start-up flow rate after the geological and engineering operations is 285% of the current flow rate. If we compare with the parameters for 2022, the oil production rate remains 246% per day higher than it was before the radial drilling in complex with acid treatment.

Table 3—Production parameters of well A

Pre-job			Planned			Startup (Dec 2021)			Increment	Current(May 2022)		
Qliq, m3/day	Qoil t/day	WC, %	Qliq, m3/day	Qoil t/day	WC, %	Qliq, m3/day	Qoil t/day	WC, %	Qoil t/day	Qliq, m3/day	Qoil t/day	WC, %
15	13	4	31	25	10	52	37.0	11	24	47	32.0	15

The second reservoir is the Devonian one located in the Samara region (well X) (Fig. 7). In the considered well there are technical limitations for hydraulic fracturing, namely the technology of radial drilling acted as an alternative technology for stimulation of production. In addition, there is a crossflow at the bottom of hole and the presence of open perforations interval above the target reservoir.

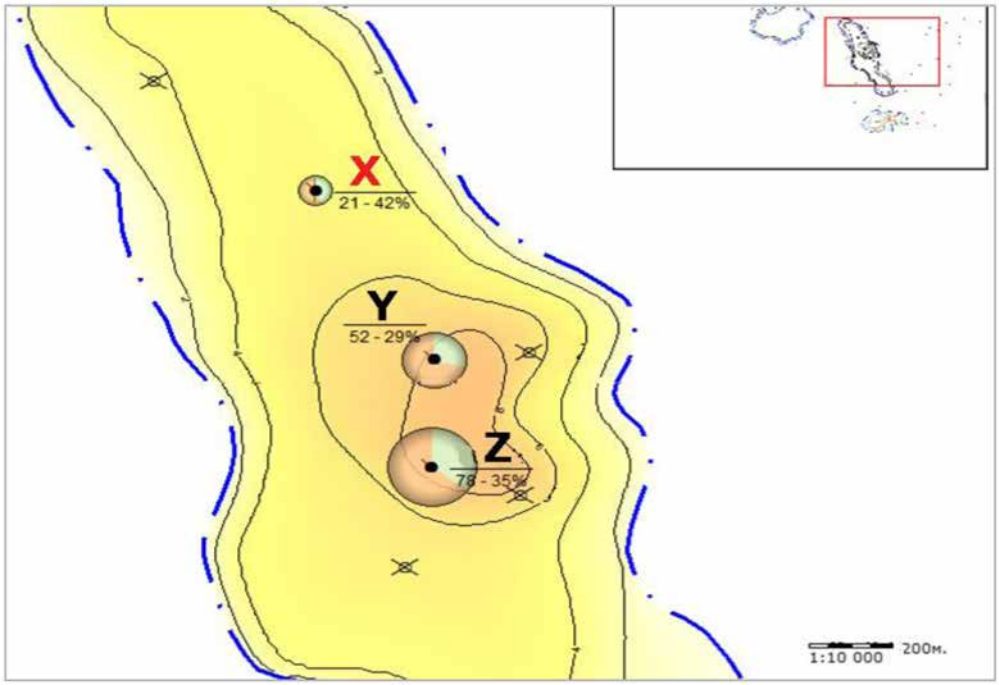


Figure 7—Map of well X location

Drilled two channels of 13 m each and carried out acid tretmant 48 m3 12% HCl. As a result, an increase of oil rate Q_{oil} on 22 t/day was achieved, with a 3 times increase of well PI.

Fig.8 shows well logging plot with indication of radial channels intervals, and also with indication of points of acid injection.

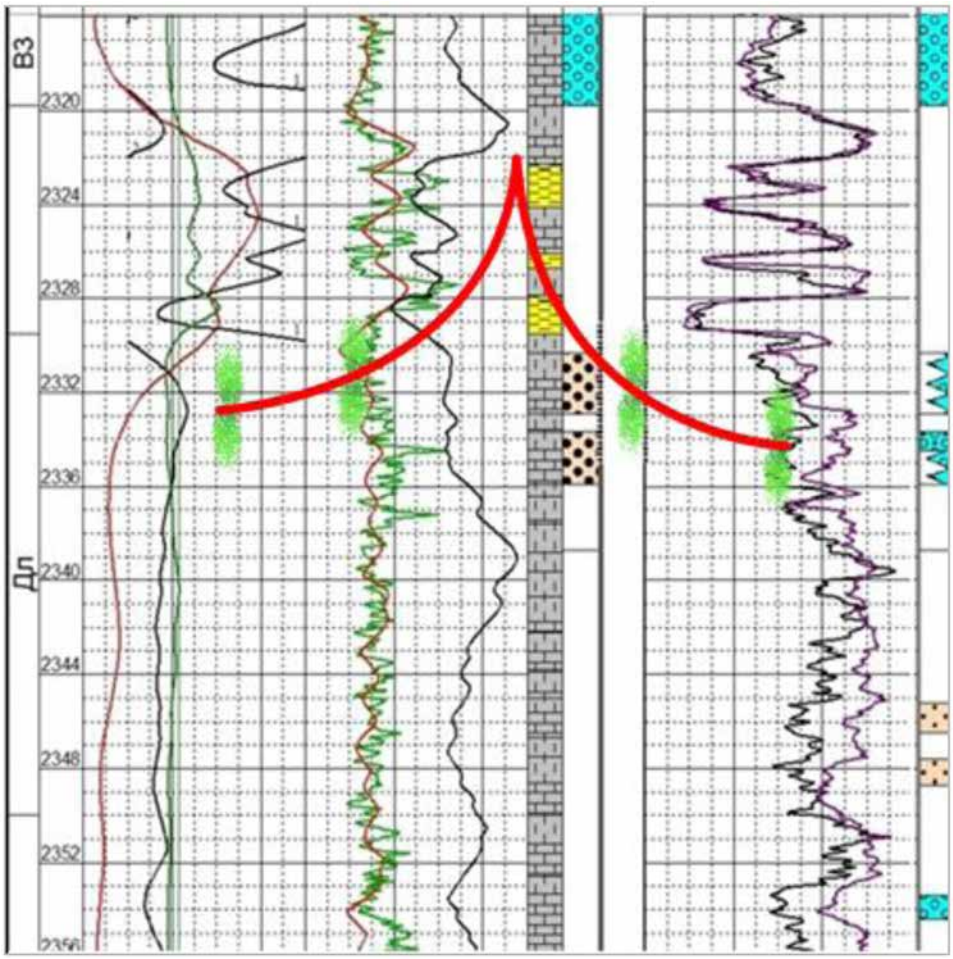


Figure 8—Well logging plot (X)

It can be seen that each of the drilled radial channels shape is fixed.

The distance between the of the toe of each radial channel and main wellbore is 9 meters, despite the length of each of the channel from window in a casing to the channel toe is 13 meters. The toe of one radial channel is at 2333 m (measured depth) and the toe of the second radial channel is at 2334 m (measured depth).

Table 4 shows predicted and actual parameters for fluid and oil flow rates. It can be seen that the start-up flow rate after the geological and engineering operations is 379% of the current flow rate. If we compare with the parameters for 2022, the oil production rate remains 266% per day higher than it was before the radial drilling in complex with acid treatment.

Table 4—Production parameters for well X

Pre-job			Planned			Startup (Jan 2022)			Increment	Current(May 2022)		
Qliq, m3/day	Qoil t/day	WC, %	Qliq, m3/day	Qoil t/day	WC, %	Qliq, m3/day	Qoil t/day	WC, %	Qoil t/day	Qliq, m3/day	Qoil t/day	WC, %
15	7.9	38	38	20.4	38	50	30.0	30	22.1	43	21.0	43

The third reservoir is the Devonian one located in the Samara region (well U). In this field, the reservoir is heterogeneous with high cleavage, which complicates the development. Also, acid hydraulic fracturing was performed in the analyzed well, but later the near borehole zone was plugged. Radial drilling was the technology of production enhancement after near wellbore zone of the reservoir damage.

Two channels of 13 m each were drilled and 48 m3 of 15% HCl were injected. As a result, an increase of oil rate Q_{oil} = 21.4 t/day was achieved, with a 2 times increase of well PI. The well logging plot introduce on the Fig.9 The radial channels intervals are indicated, as well as the points of acid injection.

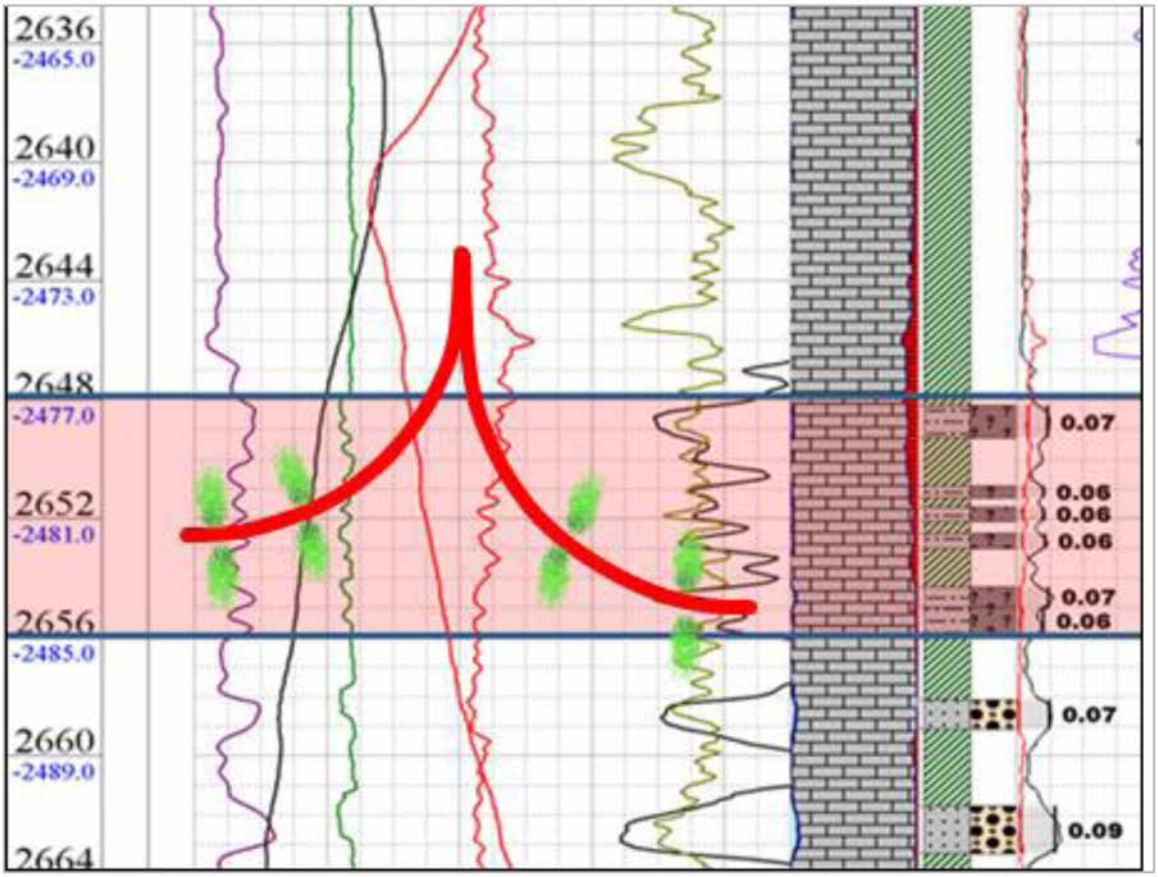


Figure 9—Well logging plot (Y)

Table 5 shows predicted and actual parameters for fluid and oil flow rates. It can be noted that the start-up flow rate after well interventions is 270% of the current flow rate.

Table 5—Production parameters for well Y

Pre-job			Planned			Startup (Jan 2022)			Increment
Qliq, m3/day	Qoil t/day	WC, %	Qliq, m3/day	Qoil t/day	WC, %	Qliq, m3/day	Qoil t/day	WC, %	Qoil, t/day
15	12.6	3.8	29.7	25.1	4	40	34.0	3	21.4

Conclusion

Efficiency of production stimulation technologies was compared at the analyzed fields (Fig. 10). It was found that the effect of radial drilling is 2 times higher than that of hydraulic fracturing and 4.5 times higher than that of reservoir stimulation by acidizing. Besides, production decline rate is 25% lower than after hydraulic fracturing.

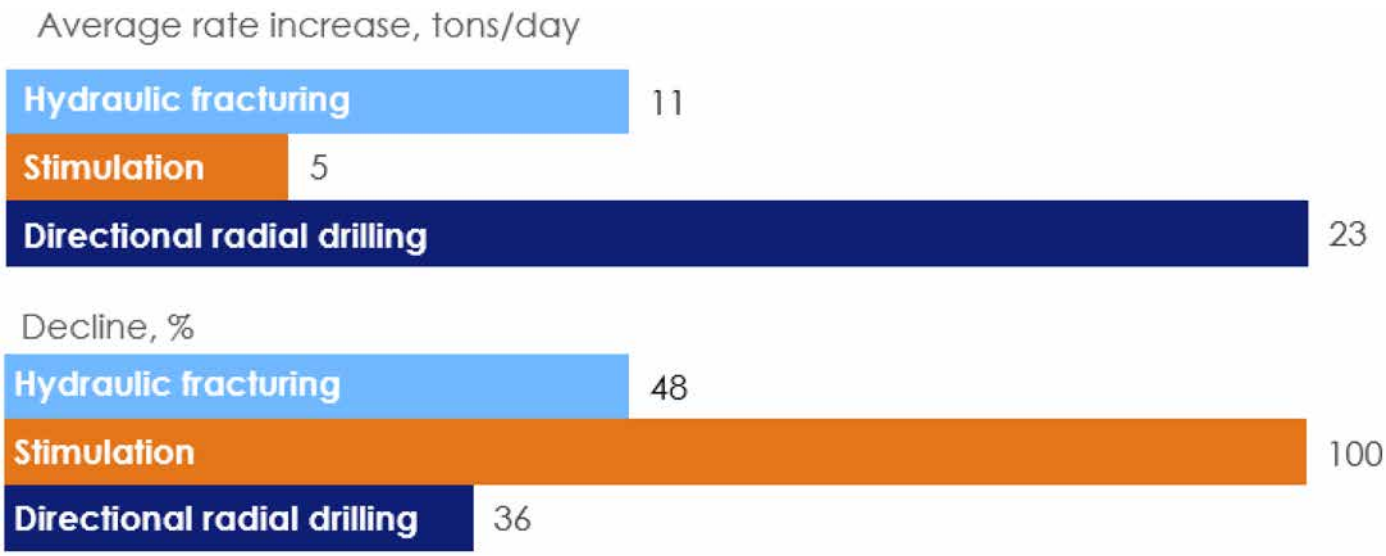


Figure 10—Comparison of technology efficiency in Samara region fields (carbonate)

At the analyzed fields the actual total oil rate Q_{oil} = 67.5 t/day was achieved with a plan of 37.5 t/day.

Recommendations

It is recommended to scale up the technology of directional radial drilling on the fields with complex geology when traditional approaches of production enhancement are not applicable, because the effect of the operations is comparable or higher than the effect of hydraulic fracturing.

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