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Combination of Radial Drilling Technology with Acid Jetting: New Approach in Carbonate Reservoir Stimulation

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Abstract

A new solution to stimulate carbonate formations with bedding water or a gas cap was proposed. It is a combination of acid jetting and Perfobur radial drilling technology. Perfobur is a technology of a mechanical radial drilling with using of slim mud motor. The main advantages of the technology are controlled trajectory and the possibility of re-entry into the channels. After channel drilling, a jetting gun with four nozzles is run into the drilled channel. Acid is injected through these nozzles at a flow rate of 100 m/s (328 ft/s). In addition to the effect of dissolving the formation, the additional caverns, which in theory are up to one meter long, are washed out.

This technology was applied on the carbonate reservoir of Bashkirian stage, which is characterized by high heterogeneity and close location of the underlying water. Two adjacent well candidates with identical reservoir properties were selected. Acid fracturing was performed on well-A. Two channels 46 feet long each were drilled on well-B using the Perfobur technology. Then acid was injected through the jetting gun. In each channel, acid was injected at two points. In total, 48 m3 of acid were injected. The productivity index of well-A was 0.4 m3/day/atm and on well-B - 1.07 m3/day/atm. Watercut on well №1 was 28%, and on well №2 - 10%.The experience of combination Perfobur technology and acid jetting showed a number of advantages. Firstly, it is an increased acid penetration length. Secondly, controlled acid injection minimizes the risk of breakthrough into the water. Thirdly, it is high productivity of wells after the workover.

The novelty of this technology is in ability to deploy acids far out in the rock away from wellbore through the mechanically drilled holes with known depths and azimuths. Precise locations of drilled channels allow to stay away from contacting the water or gas zones. The different chemicals can be deployed through the channels to treat the wells with various challenges, for example the heave oils and others.

Reservoir Description

The field is located in central part of Russia – in Republic of Baskortostan and it is mature field. The field contains both sandstones and carbonate reservoirs. Depth of oil is from 780 m (2560 ft) to 1830 m (6000 ft). There are six reservoirs in development at the field.

Works were done in the carbonate formation of geologically age called Bashkirian stage, the substage of Earlie Pennsylvanian Epoch. This formation is highly heterogeneous with closely underlying water. Permeability of the reservoir is about 43 mDa. Reservoir pressure is 68 atm (1000 psi) when the initial pressure was 105 atm (65% of the initial pressure). Density of oil is 0.891 g\cm3.

Two adjacent well-candidates with identical reservoir properties were selected. Distance between wells is about 136 m (446 ft). Net oil thickness in well-A is 4.4 m (14.4 ft), in well-B – 3 m (9.8 ft) (fig. 1).

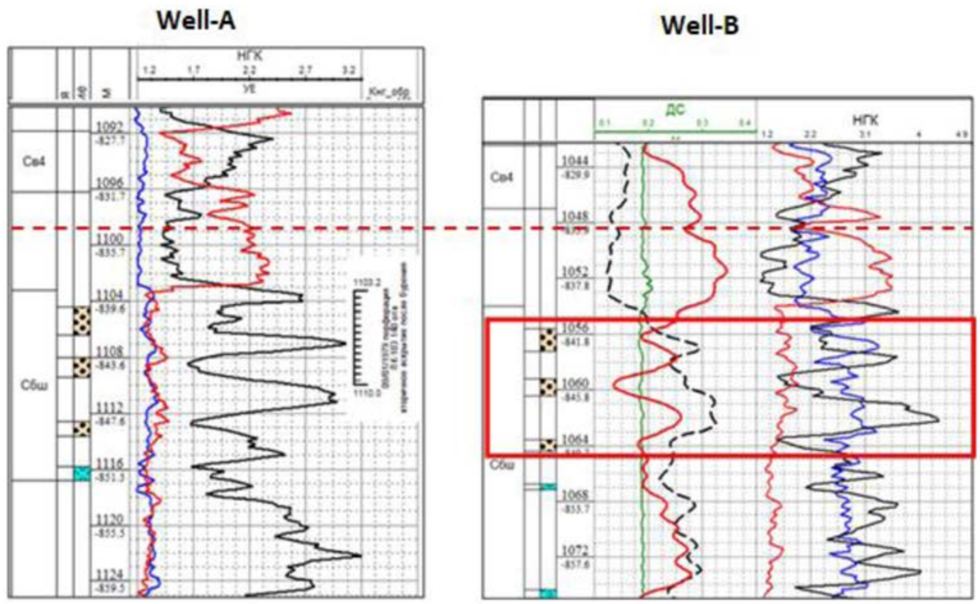

Figure 1—Geological sections of Well-A and Well-B

Perfobur Mechanical Radial Drilling Technology

Perfobur is a technology of a mechanical radial drilling with using of slim mud motor. The technology allows drilling a network of radial channels up to 15 m (49 ft) long with up to 4 channels of different trajectories on one level.

Technical system (TS) Perfobur is manufactured in a modular construction for ease of assembly at the wellhead area and increased operational efficiency. The main elements of the TS are: pipe pusher connected at the top with an overflow valve module, and at the bottom with a guiding device connected by means of a hydraulic pusher (operating in damper-oscillator modes) and a flexible pipe assembly with a small-sized (non-standard) sectional mud motor, and drilling bit (milling cutter for window cutting). A special whipstock and an anchor module with an orienting funnel are connected from below to the pipe frame (fig. 2).

Figure 2—Main elements of TS

Perfobur technology field of application:

- Alternative to hydraulic fracturing. Applicable for wells with a close location of OWC/GOC, where hydraulic fracturing is risky. Directional radial drilling of the channels will minimize the risks of a breakthrough into water-oil zone / gas cap;
- Involvement in the development of overlying formation. Drilling a network of radial channels in multizone reservoir with a high compartmentalization in order to involve several separated layers in the development.
- Combination with technologies of squeeze job on wells. Applicable for wells with behind casing flow. After conducting an aggressive squeeze job to isolate the behind casing flow — drilling channels along a predetermined trajectory to recovery of communication with the reservoir and minimize the risk of a further breakthrough of the behind casing flow;
- Combination with hydraulic fracturing. Drilling of channels will provide stress removal, which allows:
  - To conduct hydraulic fracturing in deposits with high rock stress;
  - Focus the direction of the hydraulic fracture;
- High-viscosity oils. Injection of oxidizing agents or other reagents into the drilled channels to stimulation of production;

Main elements of the TS «Perfobur» are the working bodies of the mud motor, which create the necessary torque to drive the milling cutters that cut windows in the casing string, or bits that drill the rock along the super-small radius of the channel curvature. There was developed a methodology to select the optimal variant of the working bodies of the universal high-torque slim mud motor for TS Perfobure. It allowed to construct sectional motors with the size of 43-55 mm (1.69 – 2.17 inch) with improved characteristics in comparison with serial mud motors. These were tested on the test-bench and were successfully applied in well works [1, 2].

The first stage of the technology involves the run and orientation of the anchor module. After the anchor has been run, the anchor is positioned in depth by GR and collar locator and oriented in azimuth. Then after the anchor is positioned and oriented, it is set up by pressuring up. The second stage is milling the window. The milling module is run into the well and connected to the anchor module. After window cutting the milling module is run out the well. And the third stage is drilling the channel. The drilling module is run into the well and connected to the anchor module. After drilling the channel, the drilling module is run out the well.

The main advantages of the technology are controlled trajectory of mechanical drilled channels and the possibility of re-entry into the channels. The technology can be applied both in vertical and horizontal wells.

Due to possibility of re-entry into the channels, it was proposed to combine the technology of mechanical radial drilling with acid jetting. A special jetting gun was developed for this purpose. This jetting gun has four nozzles through which acid is injected at a flow rate of 100 m/s (328 ft/s). After channel drilling, the jetting gun is run into the well and connected to the anchor module. After connecting, the jetting gun is run into the drilled channel. Acid can be injected through each meter inside the drilled channel. The treatment duration of each point is 30 minutes. In addition to the effect of dissolving the formation, the additional caverns, which in theory are up to one meter (3.3 ft) long, are washed out. The caverns are washed out with a pear-shaped, narrow cone facing the drilled channel [3, 4, 5].

Job Procedures

The task of the work was to drill on one level two radial channels, each 14 m (46 ft) long, through the milled windows in the casing column. Interval for the drilling was 1055.5-1064.5 m (3463-3494 ft) (fig. 3). Then it was decided to survey the trajectory of the drilled channels by geophysics with two different tools. After confirming the trajectory, it was planned to perform an acid jetting inside the drilled channels.

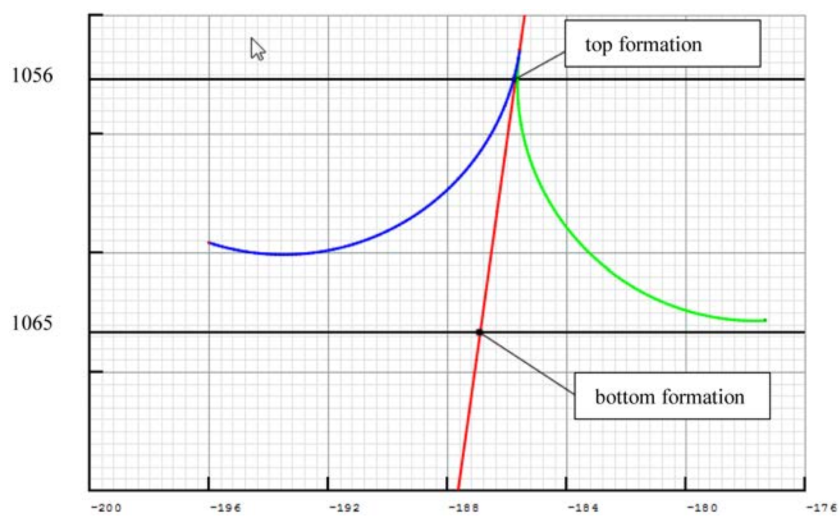

Figure 3—Design of channel trajectories

At the first stage, the anchor module was run to the depth 1056 m (3463 ft). Then it was positioned in depth by GR and collar locator and made azimuth orientation. It was then set at a pressure of 50 atm, 100 atm and 150 atm. Next, the anchor fixation was checked by unloading the tubing by 6 tn (13227 lb) above weight of tubing and keeping it steady for 5 minutes. When unloading the tubing, no weight increase was observed, which indicated a successful activation of the anchor. The detachment of the adapter connector from the anchor was done at the strainig of the tubing on 24 tn (52910 lb) above weight of tubing.

At the second stage, the milling module was run to the depth 1056 m (3463 ft). In the module there was run the mud motor (D=55 mm (2.17 inch)) and the mill with the diameter of 75.0 mm (2.9 inch). Before the connection was checked the functionality of the mud motor at a flow rate of 3.5 l/s (55.48 gpm). Standby pressure was 32 atm, which indicated the normal operation of the mud motor. After connecting the milling module to the anchor, the window milling began. The milling process of the "window" took about 10 hours at the following modes: mill load 0.5 tnf (1102 lbf), circulation rate 3-3.5 l/s (47.55-55.48 gpm), operating pressure 50 atm, mechanical milling speed was 0.07 m/h. Milling was controlled by differential pressure drop and load. Cutting chips were collected on magnetic catchers installed in the receiving tank (fig. 4). After the BHA had been moved to the starting position, the slip had been disconnected from the anchor at a tension force of 14.5 tnf (31 967 lbf) and the overflow valve had been opened by dropping the metal ball at a pressure of 102 atm. After running out the milling module from the well, it was stripped down for further revision, as a result of which no deviations were detected. The axial plays were normal. There is no wear of the mill in diameter and less than 5% wear in structure.

Figure 4—Cutting chips removal during the milling of the "window".

At the third stage, the drilling module was run to the depth 1056 m (3463 ft). In the module there was run the mud motor (D=49 mm (1.93 inch)) and the bit PDC with the diameter of 69 mm (2.71 inch). Before the connection was checked the functionality of the mud motor at a flow rate of 2.5 l/s (39.63 gpm). Standby pressure was 30 atm, which indicated the normal operation of the mud motor. After connecting the drilling module to the anchor, the channel drilling began. The channel drilling process perfomed at the following modes: bit load 0.6 tnf (1323 lbf), circulation rate 2.5 l/s, operating pressure 50 atm, mechanical drilling speed was 0.93 m/h (3.05 ft/h). Drilling process was controlled by differential pressure drop and load. The drilling time for the 14 m (46 ft) length channel was about 15 hours. After the BHA had been moved to the starting position, the slip had been disconnected from the anchor at a tension force of 16.5 tnf (36376 lbf) and the overflow valve had been opened by dropping the metal ball at a pressure of 96 atm. After running out the drilling module from the well, it was stripped down for further revision, as a result of which no deviations were detected (fig. 5). The axial plays were normal. All works were done on technical water 1,02 g/cm3.

Figure 5—Condition of the drilling module after 14 m (46 ft) long channel drilling (traces of oil on the drilling module).

The next step was to perform a gyroscopy to confirm the planned trajectory of the channel. The module with the gyro «TWIN GYRO» was run to the depth 1056 m (3463 ft). The module was connected to the anchor, with subsequent checking of the BHA's fixation by unloading and tensioning the tubing by 1 tnf. After recording the trajectory of the channel, module was run out from the well and revised at the surface. The following data were obtained by measuring the channel trajectory with the gyro:

Then a second 14 m long channel was drilled in the same sequence. The milling process of the second "window" took about 6.5 hours. The drilling process of the second 14 m (46 ft) length channel took about 12 hours. The trajectory of the second channel was measured using another tool - KVARTS-36 inclinometer. This was done to compare the measurements of two different tools. The following data were obtained by measuring the channel trajectory with the inclinometer:

As a result of data measurement with the "TWIN GYRO" and the "KVARTS-36" inclinometer, the trajectories of the drilled channels were constructed in comparison with the planned ones.

The next step was to perform an acid jetiing of the first drilled channel (fig. 10). The module with the developed jetting gun was run to the depth 1056 m (3463 ft). The module was connected to the anchor, with subsequent checking of the BHA's fixation by unloading and tensioning the tubing by 1 tnf. The hydrostatic pressure testing of line with pressure 120 atm was made before acid jetting. Then about 24 m3 of HCl-15% was pumped into the canal at a flow rate of 5-5.5 l/s at a pressure of up to 80 atm, with circulation through a receiving tank with periodic holding time for the reaction of acid with the rock. Acid was injected at two points inside the drilled channels. After the BHA had been moved to the starting position, the slip had been disconnected from the anchor at a tension force of 16.5 tnf (36376 lbf). Next, the overflow valve was activated with a pressure of 65 atm and the BHA was run out of the well. Then acid jetting of the second channel was made in the same way. A total of 48 m3 of HCl-15% were injected into two driiled channels through the developed jetting gun. The photo of the surface testing BHA for Acid treatment is shown in figure 11.

annotation	Depth, m	inclination angle, deg	angle in azimuth, deg	vertical depth, m	TVD, m	X-coordinate, m	Y-coordinate, m	Azimuth deviation, deg	wellbore deviation, m
measured in start position	1054.5	11.49	294.49	1031.18	840.79	-48.94	-185.59	255.23	191.94
	1055.5	16.29	289.54	1032.15	841.76	-48.85	-185.82	255.27	192.13
	1056.5	21.68	282.57	1033.1	842.71	-48.77	-186.13	255.32	192.41
	1057.5	27.43	277.32	1034	843.61	-48.7	-186.54	255.37	192.79
	1058.5	33.23	272.58	1034.87	844.48	-48.65	-187.04	255.42	193.26
	1059.5	39.15	268.73	1035.67	845.28	-48.65	-187.63	255.46	193.83
	1060.5	45.02	265.76	1036.42	846.03	-48.68	-188.3	255.5	194.49
	1061.5	50.3	264.09	1037.09	846.7	-48.75	-189.04	255.54	195.22
	1062.5	56.9	262.6	1037.68	847.29	-48.84	-189.83	255.57	196.02
	1063.5	62.84	260.07	1038.18	847.79	-48.97	-190.69	255.6	196.88
	1064.5	68.78	258.06	1038.59	848.2	-49.15	-191.58	255.61	197.79
	1065.5	74.3	255.63	1038.91	848.52	-49.36	-192.51	255.62	198.73
	1066.5	79.95	253.13	1039.13	848.74	-49.62	-193.45	255.61	199.71
measured depth	1067.5	84.2	251.1	1039.27	848.88	-49.93	-194.39	255.6	200.7
	1068.5	92.3	250.2	1039.3	848.91	-50.26	-195.33	255.57	201.69

Figure 6—The data obtained from the measurement channel 1 trajectoriy with the gyro

annotation	Depth, m	inclination angle, deg	angle in azimuth, deg	vertical depth, m	TVD, m	X-coordinate, m	Y-coordinate, m	Azimuth deviation, deg	wellbore deviation, m
measured in start position	1053.5	3.31	359.15	1030.2	839.81	-49	-185.39	255.2	191.75
	1054.5	3.3	94.7	1031.2	840.81	-48.97	-185.36	255.2	191.72
	1055.5	9.2	105.73	1032.19	841.8	-48.99	-185.25	255.19	191.62
	1056.5	15.2	92.91	1033.17	842.78	-49.02	-185.05	255.16	191.43
	1057.5	21.4	88	1034.12	843.73	-49.02	-184.73	255.14	191.13
	1058.5	27.2	85.3	1035.03	844.64	-49	-184.32	255.11	190.72
	1059.5	33.7	83.5	1035.89	845.5	-48.95	-183.82	255.09	190.22
	1060.5	38.8	80.9	1036.7	846.31	-48.87	-183.23	255.07	189.64
	1061.5	45.1	79.9	1037.44	847.05	-48.75	-182.57	255.05	188.97
	1062.5	50.9	79.2	1038.11	847.72	-48.62	-181.84	255.03	188.23
	1063.5	58.1	75.9	1038.69	848.3	-48.44	-181.05	255.02	187.42
	1064.5	63.4	75.1	1039.18	848.79	-48.22	-180.2	255.02	186.55
	1065.5	68.6	72.4	1039.58	849.19	-47.97	-179.33	255.02	185.63
measured depth	1066.5	73.7	71.9	1039.91	849.52	-47.68	-178.43	255.04	184.69
	1067.5	79	70	1040.14	849.75	-47.36	-177.51	255.06	183.72

Figure 7—The data obtained from the measurement channel 2 trajectoriy with the inclinometer

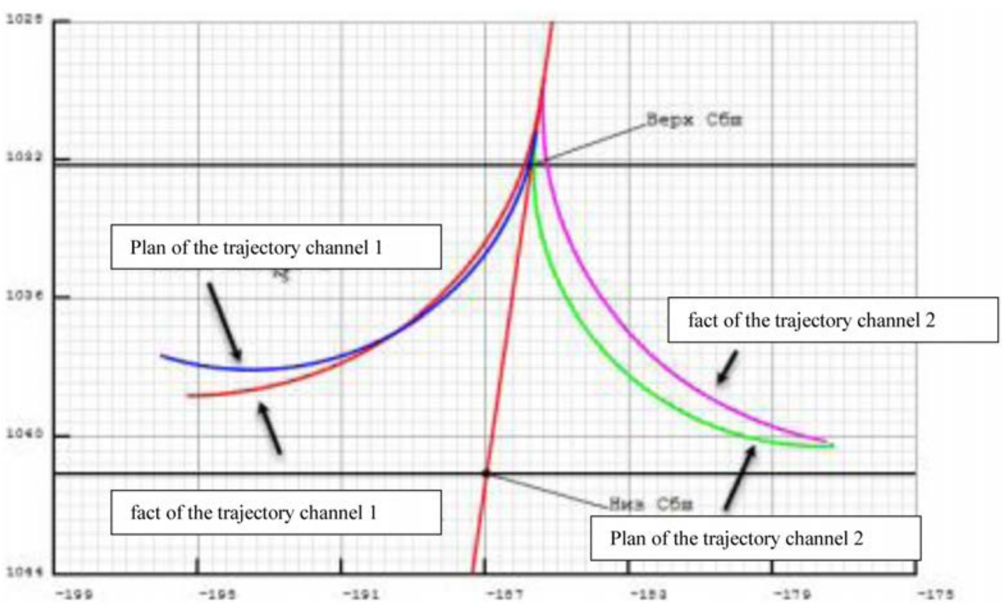

Figure 8—Trajectories of the drilled channels based on the data from the gyroscope and inclinometer (side view)

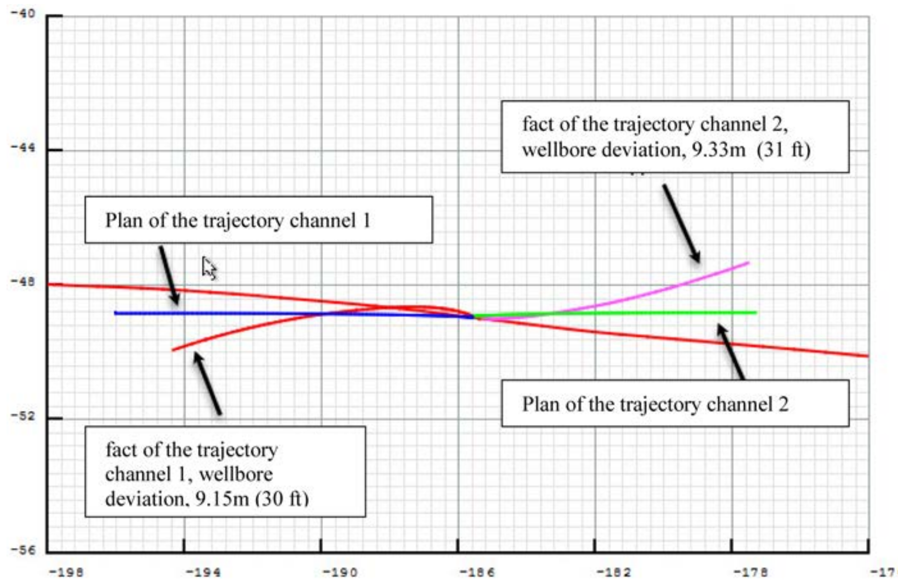

Figure 9—Trajectories of the drilled channels based on the data from the gyroscope and inclinometer (top view)

Figure 10—Acid treatment of the drilled channels

Figure 11—Surface testing BHA for Acid treatment

The acid frac was done on the Well-A. An interval of 1103-1110 m (3619-3642 ft) was perforated. The oil-saturated layer in the interval of 1112.5-1113.5 m (3650-3655 ft) was not perforated to minimize risks of breakthrough into the underlying water. 40 m3 of HCl-15% was injected during the hydraulic fracturing process. According to the model, the frac length was about 40 m (131 ft), total height was 19.6 m (64 ft) (fig. 12).

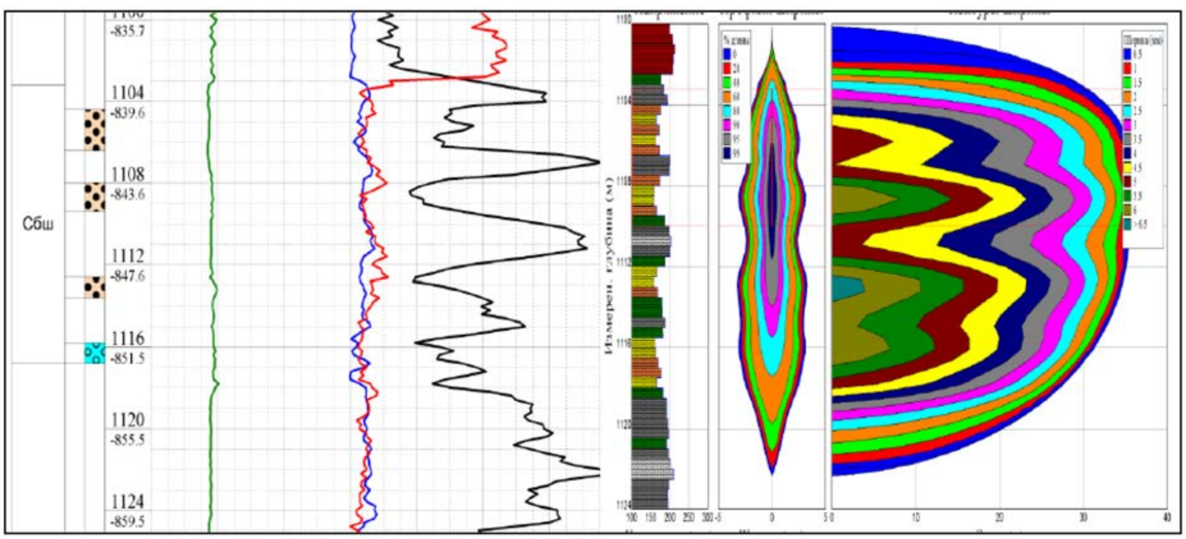

Figure 12—Geometry of fracture

Results

Well-A was put on production with liquid rate 14 m3/day, oil rate 9 tn/day and water cut 28%. These parameters are corresponding with average parameters after acid fracturing in the region. Well-B after mechanical radial drilling and acid jetting was put on production with liquid rate 51 m3/day, oil rate 41 tn/day and water cut 11%. Liquid rate after radial drilling and acid jetting is higher than after acid frac in 3.6 times. Water cut is less than after acid frac in 2.5 times, which demonstrates that during radial drilling process no breakthrough into the underlying water was achieved (fig. 12).

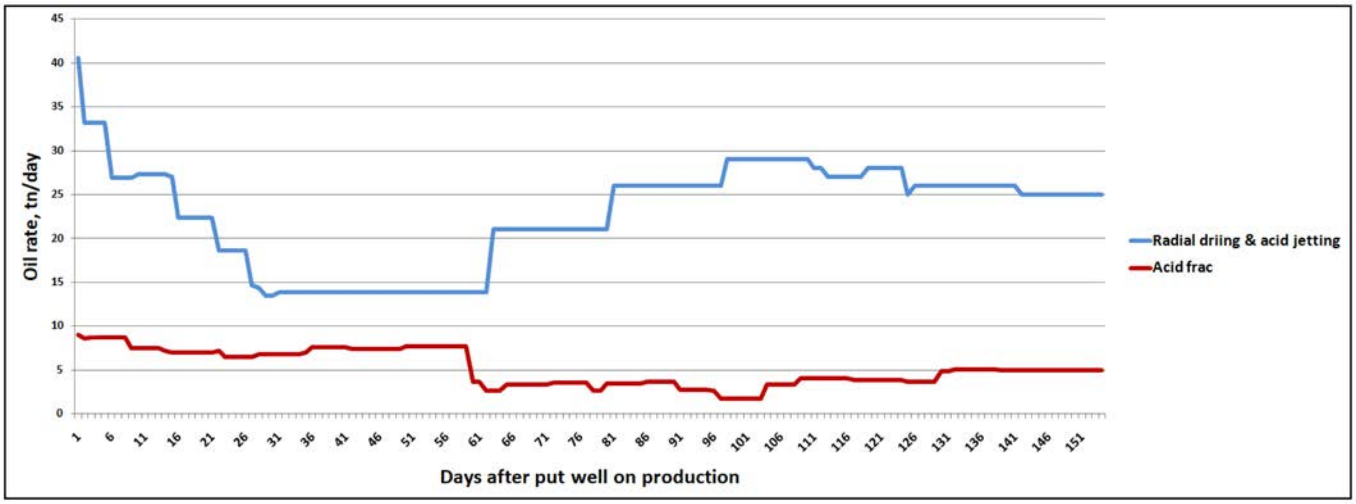

Figure 13—diagram of wells production

Conclusion

The experience of combination Perfobur technology and acid jetting showed a number of advantages. Firstly for this work, it is an increased acid penetration length. Secondly, controlled acid injection minimizes the risk of breakthrough into the water. Thirdly, it is high productivity of wells after the workover. Also, controlled trajectory of mechanical drilled channels (confirmed by directional survey), possibility of reentry into the drilled channels.

The novelty of this technology is in ability to deploy non-retarded acids far out in the rock away from wellbore through the mechanically drilled holes with known depths and azimuths. Precise locations of drilled channels allow to stay away from contacting the water or gas zones. The different chemicals can be deployed through the channels to treat the wells with various challenges, for example the heave oils and others.

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