

25-YEAR FORMATION EXPERIENCE OF DRILLING WELLS WITH HORIZONTAL END IN THE REPUBLIC OF TATARSTAN

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Abstract. The emerging problems of the long-term sustainability of the Russian oil industry, including Tatneft, in conditions of low world oil prices must be solved through more efficient use of costs, especially capital investments in the construction of new production wells. Along with various methods of increasing the oil recovery factor and intensification of oil production, one of the main ways to improve the profitability of wells is the construction of wells with horizontal end. Greater prospects for the use of horizontal wells are expected in the Timanian deposits of the Romashkino field. The use of a controlled valve (curtain) to open/close the inflow from the section of the horizontal trunk will significantly reduce the water cut of well and, accordingly, increase the share of oil per ton of produced liquid.

Keywords: horizontal wells, wells with horizontal end, oil flow rate, Tatneft

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The emerging problems of the long-term sustainability of the Russian oil industry, including Tatneft, in conditions of low world oil prices must be solved through more efficient use of costs, especially capital investments in the construction of new production wells. Along with various methods of increasing the oil recovery factor and intensification of oil production, one of the main ways to improve the profitability of wells is the construction of wells with horizontal end. Greater prospects for the use of horizontal wells are expected in the Timanian deposits of the Romashkino field. The use of a controlled valve (curtain) to open/close the inflow from the section of the horizontal trunk will significantly reduce the water cut of well and, accordingly, increase the share of oil per ton of produced liquid.

The current stage in the development of oil industry in Tatarstan is characterized by the introduction of active development of oilfields that are at different stages of development, characterized by high layer and zone heterogeneity, where effective production of oil reserves will be made using horizontal technology and advanced methods of enhancing the oil recovery factor. To achieve the predicted oil recovery coefficients, the most urgent for today, along with the use of hydrodynamic methods, is the use of horizontal technology. The use of horizontal technology will reduce the number of project vertical well stock, while not decreasing, but increasing the coverage factor for the production of oil reserves due to the spatial architecture of reservoirs drainage, which

means raising the oil recovery factor and saving on infrastructure (Idiyatullina, 2015).

By the 1970s, more than 30 wells with a horizontal end were constructed under the leadership of A.M. Grigoryan in 13 regions of the former USSR (Tatarstan, Bashkortostan, Samara and Perm Regions, Western Ukraine, the Krasnodar Territory, etc.), including hundreds of curved branches, as well as a large number of wells with a single nominally horizontal trunk. Thus, the technology of drilling wells with horizontal end, having proved its high efficiency in various mining and geological conditions, was brought to the industrial level of application.

However, the discovery of highly productive fields in Western Siberia prompted the Ministry of Oil and Gas of the USSR to focus on the development of only these fields, and thus the interest in the development and improvement of horizontal drilling decreased. The drilling of wells with horizontal end was terminated for a period of more than 20 years before the implementation of the integrated branch program "Horizon".

The company Tatneft much earlier than many oil companies has embarked on the industrial development of the horizontal technology. The development of horizontal technology in Tatneft PJSC began in 1977 with the drilling of three wells with horizontal end No. 1918, 1947 at the West-Sirenevsky site of the Sirenevsky field of the Oil and Gas Production Department Yamashneft proved to be the most productive, the accumulated oil production for them amounted to 68.7 thousand tons and 71.2 thousand tons at current average production rates of about 2.5-4.5 tons per day, which is 2-2.5 times higher than the average production

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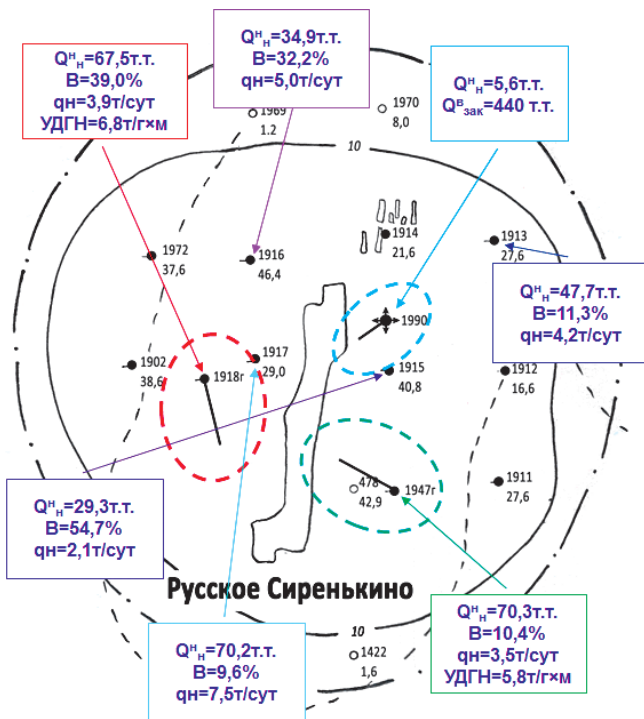


Fig. 1. Extract from the thickness map of the Zapadno-Sirenevsky section of the Sirenevsky oil field

rates of neighboring producing vertical wells. These wells are still in operation (Fig. 1).

Since 1978, the drilling of wells with horizontal end has been suspended and resumed only in 1992, which is still used instead of vertical drilling. As of January 1, 2017, 940 wells with horizontal end were drilled; the accumulated oil production for the whole period of exploitation was more than 6.5 million tons. The dynamics of drilling wells with horizontal end by years is shown in Fig. 2. Since 1990, the TatNIPIneft industry institute has compiled more than 80 design documents for the development of deposits using horizontal wells,

according to which several thousand horizontal wells were to be drilled. Depths of occurrence of productive layers, penetrated by horizontal wells are from 800 to 2400 m.

Tatneft PJSC has been steadily increasing the number of wells with horizontal end, especially in the last 4 years. If from 1977 to 2012 the average number of horizontal wells drilled was 24 per year, from 2013 to 2016, on average, about 103 wells per year were drilled. In total, as of January 1, 2017, 940 horizontal wells were drilled in Tatneft PJSC. In addition, the company actively uses horizontal technology on deposits of super viscous oil. A striking example of using horizontal wells for the development of heavy oil objects is the Ashalchinsky field, where as of 01.01.2017 313 wells with horizontal end have been drilled (including 51 steam cycling and 138 production ones).

In general, according to oil fields of Tatneft PJSC, it is possible to distinguish five main objects that are developed using horizontal technologies (bottom-up):

- Timanian-Pashchian;
- Tournaisian;
- Tulian-Bobrikovian;
- Bashkirian-Protvinian;
- heavy oil deposits (Sheshminian horizon of the Ashalchinsky field).

The predominant part of wells with horizontal end was drilled to low-productivity carbonate deposits of the Tournaisian (36.8%) and Bashkirian-Serpukhovian (27.0%) stages of small deposits. 22.0% were drilled on the Tulian-Bobrikovian formations, 13.7% on the terrigenous Devonian and 0.5% of the wells on the carbonate Devonian (Fig. 3).

Geological and physical characteristics of reservoirs are given in Table 1.

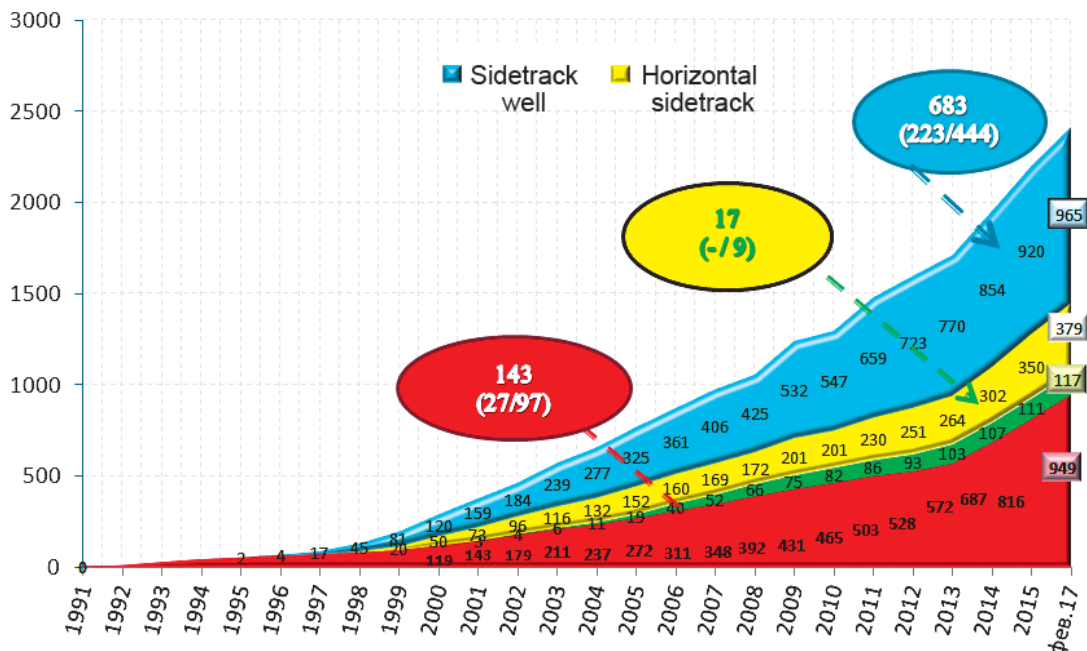


Fig. 2. The dynamics of drilling wells with horizontal end by Tatneft PJSC

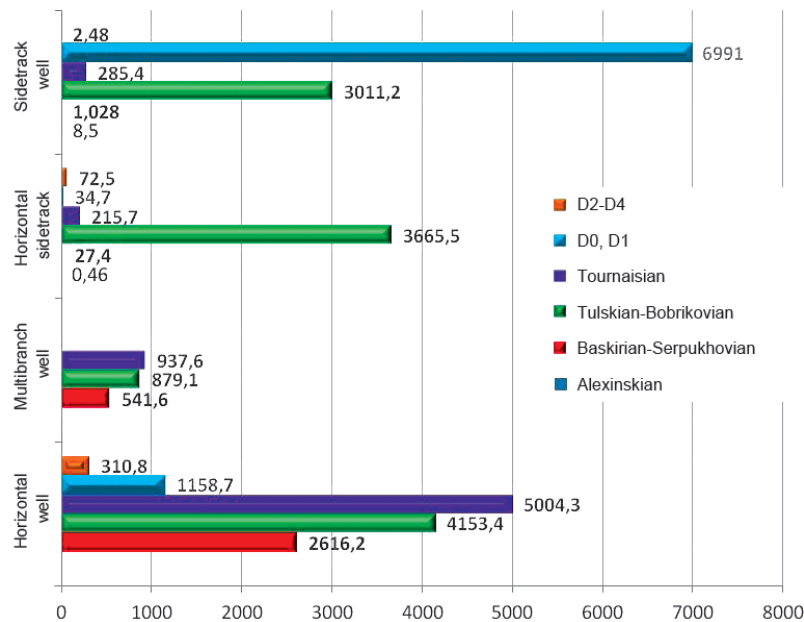


Fig. 3. Distribution of accumulated oil production by types of wells and development objects

Since 1990, the TatNIPIneft branch institute has compiled more than 80 design documents for the development of fields with the use of wells with horizontal end, according to which several thousand wells were to be drilled.

In connection with the increasing volume of directional drilling, the problem of monitoring the direction of the horizontal well trunk during its drilling becomes very relevant, therefore, since the end of 2010, the navigation systems “near-bit module of the measure while drilling” have become widely used in Tatneft PJSC, which allowed increasing annual oil production.

Greater prospects for the use of wells with horizontal end are expected in the Timanian deposits of the Romashkino field. The oil of the Timanian object differs little from the oil of the Pashian object (the viscosity of the oil is also 5-7 mPa·s), but the inhomogeneity of the productive formation D0, its lenticular-mosaic structure, does not allow the active development of the Timanian deposits. Drilling horizontal wells on the deposits of the Timanian age will allow the development of the full amount of oil reserves in lenses, water-oil zones and inaccessible areas under sanitary protection

zones, populated areas, forests, floodplains and springs. The use of horizontal technology contributes to a more even production of reserves and, ultimately, an increase in the oil recovery factor. In addition, the use of wells with horizontal end is due to the geological structure of the Timanian reservoir, clamped from the roof and the bottom by thick intercalations of clays, which for a long time did not allow the Timanian site to be actively developed.

The mosaic spread of different lithotypes of rocks in the D0 reservoir does not allow uniform production of reserves. The solution of the problem also lies in the application of horizontal technology with the exit from one lithotype to another and by hydraulic fracturing with the connection to the development of far zone of the reservoir. In this regard, it is important to drill long trunks that replace the drilling of 3-4 wells and conduct multi-zone fracturing on them. Such a technology would allow a multiple reduction in the number of drilled wells and significantly reduce the mosaic effect on well productivity. Moreover, with long operation of wells with extended nominal horizontal trunks (350 ÷ 450 m and more), there are significant advantages.

Characteristic	Vereiskian-Bashkirian	Bobrikovian	Tournaisian	Dankovian-Lebedyanian	Pashian-Kynovian	D _{II} -D _{III} -D _{IV}
Average occurrence depth, m	911÷943	до 1099	1164	1466	1720	1773÷1811
Average net oil thickness, m	0,5÷25	0,8÷20	0,8÷45	1,8÷8,1	3,7÷16,6	2,3÷2,7
Permeability, μm^2	49	1,261	0,042	0,03	0,527	0,13÷0,258
Porosity, %	15	22,4	11,8	7,00	19,8	16,8÷18,7
Initial formation pressure, MPa	9,11	11,0	11,26	14,6	17,2	17,2
Viscosity mPa·s	15,5÷288	11,4÷220	6÷172	8,4÷46	1,9÷4,5	2,92÷7,55
Oil density, t/m ³	0,90	0,875	0,88	0,91	0,77÷0,82	0,79÷0,823
Gas-oil ratio, kg/m ³	2,34	11,37	17,66	12,40	46÷74,2	25,7÷54,5

Table 1. Geological and physical characteristics of objects

Such wells work stably with a lower rate of decline in productivity (Petrov et al., 2016). For example, well No. 4712G of the Bavlinsky field, which has the longest nominal horizontal trunk (637 m), is one of the most productive. The debit of oil in it in the first year of operation (2001) was 16-17 tons/day, for 2016 – 15.3 tons/day.

The carbonate layers of the Dankovian-Lebedyanian horizon and the Zavolzhskian horizon overlap up the section. As of 01.01.2017, 6 wells with horizontal end were drilled on the sediments of the Dankovian-Lebedyanian horizon, and 3 wells with horizontal end in the Zavolzhskian horizon. All the wells with horizontal end on the Dankovian-Lebedyanian horizon were drilled into 665 deposits of the Romashkino field. The average initial production rate for the wells with horizontal end for the Dankovian-Lebedyanian horizon was 2 tons/day (water cut 14.3 %), current – 6.9 tons/day (water cut 34.2 %). In total, since the beginning of the development of wells with horizontal end, 91.4 thousand tons were extracted from the deposits of the Dankovian-Lebedyanian horizon, with an additional production of 24.1 thousand tons.

3 wells with horizontal end on the Chegoday sky field were drilled on the sediments of the Zavolzhskian horizon. The initial oil production rate was 18 tons per day, the current production rate was 1.5 tons per day. In total, since the beginning of the development, 19.7 thousand tons of oil was extracted from the deposits of the Zavolzhskian horizon as of 01.01.2017 (Petrov et al., 2016).

At present, in the Republic of Tatarstan the development of oil deposits, represented by carbonate reservoirs, enters the open phase. Horizontal technologies are particularly important in the development of carbonate reservoirs. Basically, this is due to the need to increase the productivity of wells and reduce their payback periods. As practice shows, wells with horizontal end are most effective for developing reserves in weakly drained areas, in low-permeability and cavernous-fractured reservoirs. Horizontal wells provide much greater opportunities for different methods of stimulating oil production than vertical or controlled directional wells.

The main share of wells with horizontal end in Tatneft PJSC was drilled on carbonate sediments of the Tournaisian stage. Korobkovsky area (6 block) of the Bavlinsky field (Fig. 4) is one of the most representative sites for the development of carbonate reservoirs by horizontal wells (Khakimzyanov, 2012).

Beginning in 2010, the amount of horizontal wells in the Korobkovsky area is about 40% of the total production stock, while providing 60% of the annual production of oil. The average debit for horizontal wells for the last three years was 7.1 tons/day with a

water cut of 5.3%, for comparison, the performance of the controlled directional wells for the same period was 3 tons per day and 16.6 %, respectively.

In total, according to the Tatneft PJSC, 5377.5 thousand tons of oil were extracted from the sediments of the Tournaisian stage by horizontal wells as of 01.01.2017. The additional production from the beginning of the development of Tournaisian object by horizontal wells is 1758.3 thousand tons. The average initial production rate at the Tournaisian object by horizontal wells was about 3.4 tons/day (water cut 22%), current 4.8 tons/day (water cut 28%).

Terrigenous deposits of the Bobrikovian and Tulian horizons of the lower section of the Carboniferous system lie above the section. In general, the average initial production rate for the Tulian-Bobrikovian deposits in the Tatneft PJSC amounted to 7.5 tons per day with water cut of 50 %, the current one – 10.7 with water cut 59 %. Accumulated oil production as of 01.01.2017 was 4319.4 thousand tons (including 2739.2 thousand tons of additional production).

Tatsuksinsky field discovered in 2014 by exploration well No. 300 is an example for the efficiency of drilling horizontal wells on the terrigenous reservoirs of the Lower Carboniferous. As of the first half of 2017, 12 wells with horizontal end were drilled at the Tatsuksinsky field, one well with a horizontal profile is in drilling process. The average initial oil production rate was 40 tons per day with an average water cut of 8.2 percent, the current – 49 tons per day and 13 %, respectively (Petrov et al., 2016).

The next (upstream) development target, where horizontal wells are actively used, is the Protvinsky horizon of the Lower Carboniferous and the Bashkirian stage, the Vereiskian horizon of the middle section of the

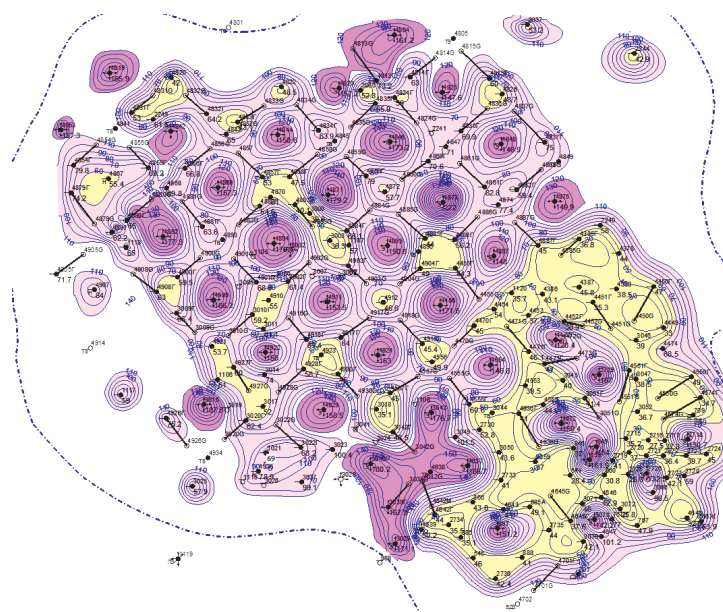


Fig. 4. Extract from the development map of the Korobkovsky area (6 block) of the Bavlinsky oil field, January 1, 2017

Lower Carboniferous. Accumulated oil production as of January 1, 2017 for this development project amounted to 2584.4 thousand tons (including 1366.6 thousand tons of additional production). The average initial production rate for horizontal well was 2.5 tons per day with 47% water cut, current – 3.2 tons per day with 86.5 % water cut.

About half of the residual recoverable oil reserves of Tatneft PJSC are concentrated in carbonate reservoirs, a significant part of which is located in the Vereiskian horizon. The traditional well production rate here is 1 to 4 tons per day (Khakimzyanov, 2012).

An example of the successful application of horizontal technologies in the sediments of the Vereiskian horizon is well No. 4777G. A multi-stage hydraulic fracturing (5-stage) was produced in well No. 4777G of the Sokolkinsky field of Oil and Gas Production Department Elkhovneft in a horizontal wellbore of a small diameter that consists of five intervals (Fig. 5). The oil production

rate was 40 tons per day. The experience of using a 5-stage acid fracturing in a horizontal borehole of a small diameter on the Vereiskian horizon of the Sokolkinsky oil field of Oil and Gas Production Department Elkhovneft is proposed to be distributed to other Oil and Gas Production Departments of Tatneft PJSC.

The highest development target, where oil production is carried out by horizontal wells, is the Sheshminskian horizon. As of January 1, 2017, 1 million 781 thousand tons of oil were extracted from the sediments of the Sheshminskian horizon of the Ashalchinsky field. The average initial oil production rate by horizontal wells was 9.8 t / day, the current one – 32.7 t/day.

It should be noted that the rate of annual production by horizontal wells has a tendency to increase – for example, in 2008 in horizontal well No. 2320 a total of 6.8 thousand tons of oil was produced per year (oil production rate oil was 19.4 tons /day), and in 2016 – already 23.1 thousand tons (oil production rate – 63.4 tons/day).

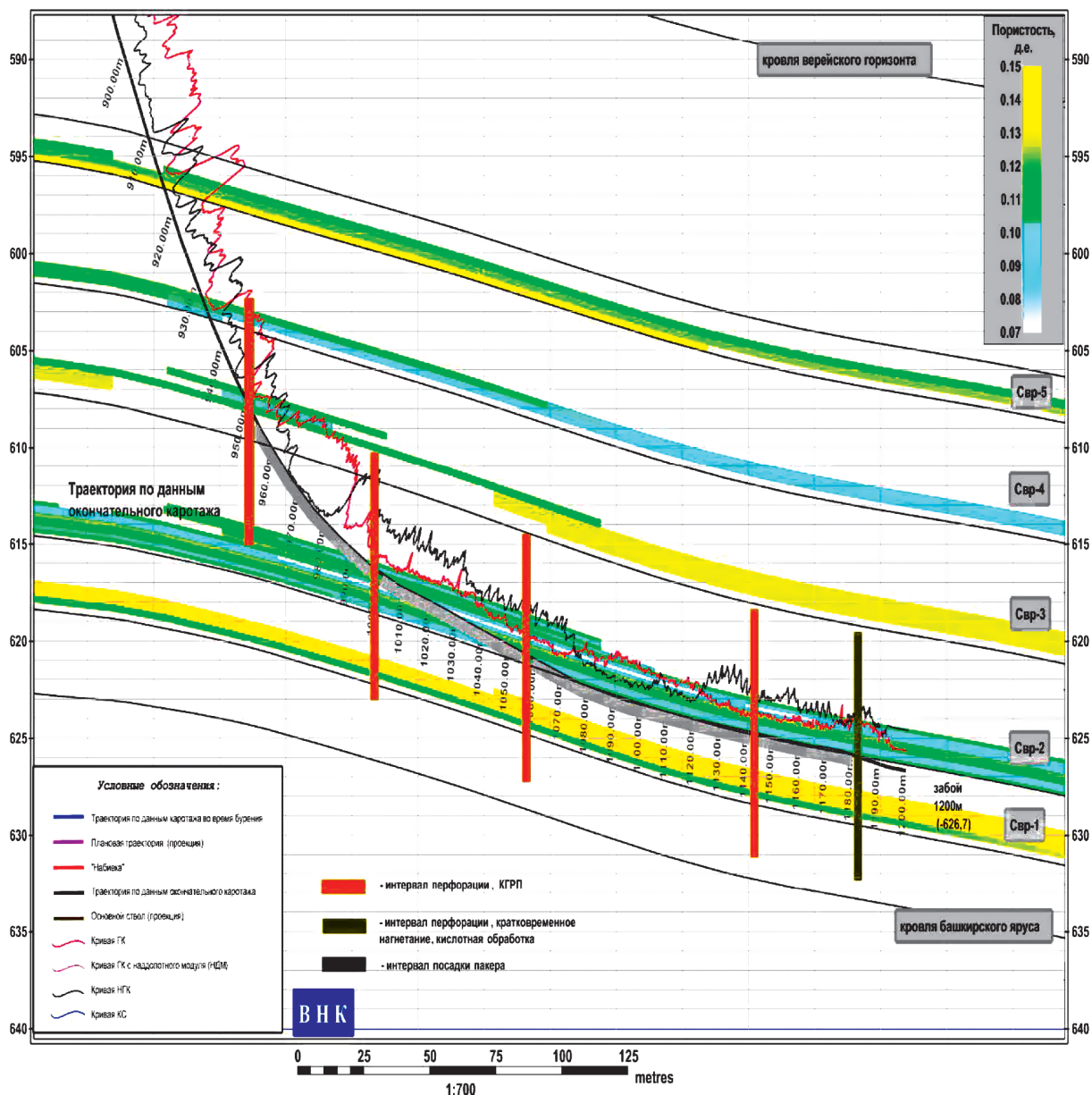


Fig. 5. The profile along the conditional-horizontal wellbore No. 8385G in the section on the porosity parameter

The same can be said for horizontal wells No. 232 and 240, which were put into operation in 2006 and 2008, respectively.

Beginning in 2010, Oil and Gas Production Department of Tatneft PJSC pays a lot of attention to the problem of geological justification for the selection of objects for drilling horizontal wells in carbonate and terrigenous reservoirs located at different stages of development. Oil deposits that are developed using horizontal technology require a detailed approach to the selection of points for drilling, operation objects and orientation of additional trunks.

Since 2012, the creation of sectoral geological and hydrodynamic models to justify the rational placement of horizontal wells has begun, which increased the efficiency and accuracy of installing conditional-horizontal trunks.

TatNIPIneft has developed a controllable valve (curtain) for opening/closing the inflow from the horizontal trunk section (Fig. 6). Increasing the effectiveness of dividing the horizontal trunk into sections is supposed to be realized by applying in the horizontal trunk downhole flow regulation valves, which allow limiting the volume of water during extraction from the sections. The

curtains are installed on 5 wells of deposit No. 303 of the Romashkino field of Oil and Gas Production Department Leninogorskneft, in which the horizontal trunk is divided into 3 sections (Yartiev et al., 2016).

Figure 7 shows the scheme for completing the horizontal well using electro-controlled borehole valves (well No. 41502g of Oil and Gas Production Department Djalilneft).

Well No. 41502g has a horizontal trunk in the Bobrikovian-Radaevskian sediments of the deposit No. 12 of Romashkino field, and for the first time in Tatneft PJSC valves are installed that controlled from the surface by cable without stopping the operation of the well. With the operation of both sections of the trunk, the oil production rate was 12 tons per day with a water cut of 50 %, the production rate of the trunk sock was 21 tons per day with a water cut of 10 %, the production rate of the trunk sock was 7.5 tons per day, with a water cut of 65 %. Thus, by controlling the valves, the extraction from the well No. 41502g was optimized by reducing the water cut of production without stopping the exploitation of the well. Well No. 41502g has been in operation since 2012; the experimental equipment works reliably (Takhautdinov et al., 2013).

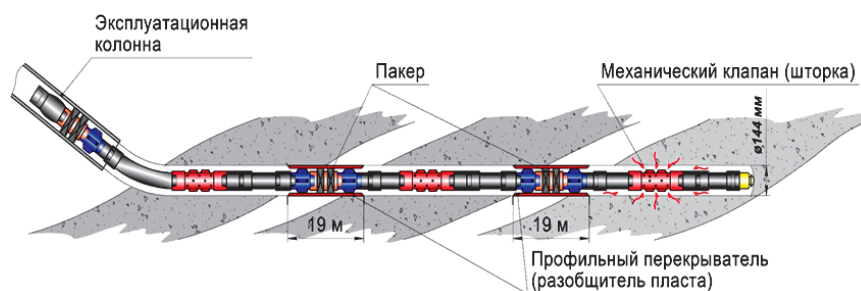


Fig. 6. Separation of the conditional-horizontal trunks into sections with the use of expandable pipes and mechanical valves (shutters)

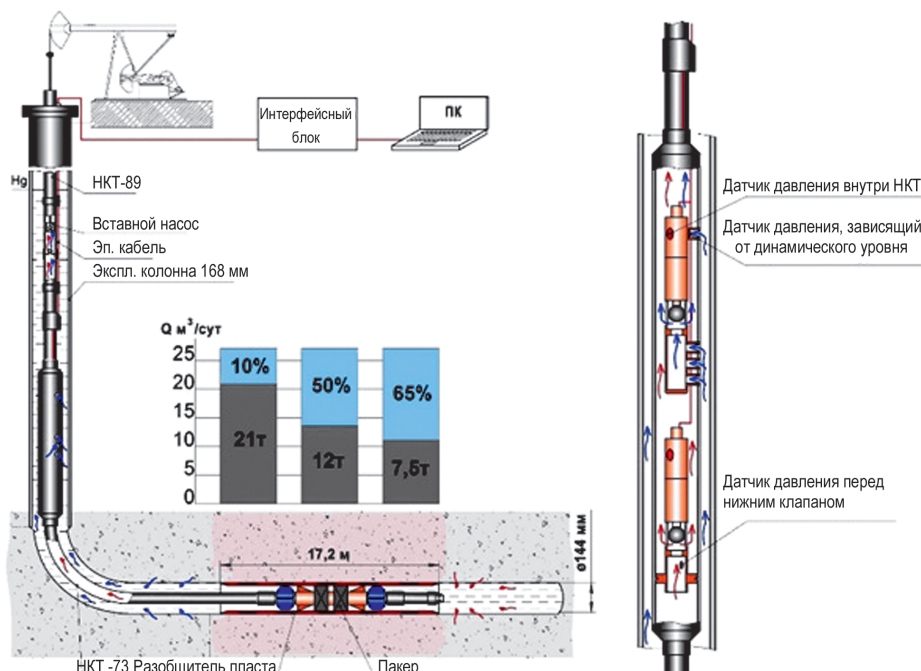


Fig. 7. Completion of the wells with horizontal end using electro-controlled borehole valves (well No. 41502g of Oil and Gas Production Department Djalilneft)

The effect from the use of horizontal technologies is particularly evident in the case of high lateral heterogeneity of reservoir rocks, which is more common for limestone. The horizontal wellbore increases the probability of penetrating sections with increased permeability of the reservoir, which has a high degree of heterogeneity both over the lateral and along the cut. In addition, due to the horizontal section, the area of contact between the well and the target reservoir increases, as a result, a more voluminous and complex drainage geometry arises as compared to the controlled directional wells. In general, the development of the Korobkovsky section by a system of horizontal wells is considered to be justified. With the current water cut, such a development system allows maintaining high rates of oil withdrawal from the initial recoverable reserves (6.8%).

In general, the efficiency of drilling horizontal wells in Tatneft PJSC was repeatedly confirmed in practice. However, the use of horizontal technologies does not always give the expected effect. The well-known factors of unsatisfactory efficiency of the use of wells with horizontal end in the fields of Tatneft PJSC are as follows (Idiyatullina et al., 2015; Khakimzyanov, 2012; Fazlyev, Mironova, 2005; Guidance document for the geological and technological feasibility ..., 2013):

- excessively high heterogeneity of the deposit section;
- probability of “swelling” and shedding of clay interlayers in the process of drilling and operation of wells;
- probability of crossing aquifers or layers in the inter-spacing interval because of the lack of information on the geological structure and saturation of the inter-wellbore interval;
- a rapid drop in oil production over time, caused by a pressure drop in the in the reservoir zone due to high heterogeneity and a difficult connection with the boundary zone.

Therefore, to ensure the maximum effect from the use of horizontal technologies, it is necessary to thoroughly study all stages of the horizontal wells design – from the idea to its implementation:

- when choosing the location of horizontal wells, it is necessary to apply a comprehensive approach – the study and analysis of seismic survey data (including the forecasting of reservoir properties), the construction of hydrodynamic models to justify the optimality of the horizontal well location and the calculation of technical and economic development indicators, studying the “best practices” of applying horizontal technologies both in Tatneft PJSC and in other companies;
- when drilling wells, constant monitoring of the curvature data (correspondence of the project placement of the trunk to the actual one), lithology and saturation

of the formations in real time with the help of a near-bit module of the measure while drilling system;

- in the development of fields by horizontal wells, monitoring of the level of reservoir pressure and its maintenance at a sufficient level to ensure efficient development of the field.

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