Ways to Improve the Efficiency of Horizontal Wells for the Development of Oil and Gas Field

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Abstract. The effectiveness of horizontal wells is tested mainly for increase of oil withdrawal in comparison with usual vertical wells and more rarely for increase of oil recovery factor. In spite of long time application of horizontal wells in Tatarstan Republic, Russia, its efficiency is comparatively low: flow rates of horizontal wells are in 1.5-2.2 times higher than flow rates of vertical wells. The article deals with geological conditions for the effective application of horizontal wells and their limitation for the development of oil and gas fields. Particular attention is paid to the state analysis and the efficiency improvement of horizontal wells operation during field development with introduction of various water flooding systems. The highest technical and economic indicators of field development with horizontal wells are obtained by their systematic use taking into account the experience of developing oil fields with vertical wells, compliance with principles accumulated for decades of the rational field development by means of flooding.

Keywords: horizontal, multi-branched, vertical wells, geological, commercial, initial recoverable reserves, production rates, cumulative production, oil recovery factor

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operation of sites with different geological characteristics).

All this calls for a more accurate study of geological features of the object, especially in inter-well space.

Analysis of technical and economic efficiency of drilling horizontal wells in 7 plots in the second block of Kizelian deposit, Bavlnsky field, conducted by G.F. Yulmetova, showed:

1. Lack of technological effect from horizontal drilling in the development in natural mode (2 plots).
2. In areas with flooding technological indicators of horizontal wells (oil flow rates, productivity) are better than for vertical wells, but not much (1.1 to 1.5 times).

Economic indicators in comparison with vertical drilling with distance 400 m between wells (drilling of two vertical wells instead of one horizontal with horizontal branch of 400 m long, recognized the optimal in Tatarstan) are significantly worse (Table 1).

Based on the above, for the correct determination of the economic efficiency of development using horizontal wells, it is necessary to compare it with the system of vertical wells, given that horizontal drilling reduce the vertical drilling by 1-2 wells and so on.

Accumulated horizontal drilling experience suggests that in most cases, to improve efficiency of horizontal drilling, it is necessary to create a development system using horizontal wells, and not be limited by drilling the single horizontal well or multi-branched wells. In this case, we obtain a synergistic effect from horizontal drilling. However, in most cases, in the design and implementation of horizontal drilling, a non-systemic approach is marked.

The fact is that the horizontal wells and branched-horizontal wells in platform deposits with their low energy do not solve the issues of improving the efficiency of development of reserves. They are the only elements of the development system, organically fit into this system. As in the development systems using vertical wells it is necessary to comply with the balance of injection and sampling, to optimize density of well grid and the selection and discharge pressures, to provide control and regulation of the development process, and adjust the direction and shape of fluid flow in the reservoir.

The horizontal drilling has developed at the Fedorovsk oil and gas field, the largest in Western Siberia, in order to engage oil and gas difficult to recover from the formations AS4-8, the feature of which is the presence of bottom water and gas cap, and a small thickness (8-12 m) of oil rim (Fig. 1) (Muslimov, 2005).

Given the encouraging results of the first horizontal wells and the low efficiency of the vertical wells (low flow rates and high

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<table>
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<th>Value</th>
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<th>Vertical wells</th>
<th>Difference</th>
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<td>266811</td>
<td>58887</td>
</tr>
<tr>
<td>2 Oil and gas production tax, thous.rub</td>
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<td>86248</td>
<td>19035</td>
</tr>
<tr>
<td>3 Business expenses, thous.rub</td>
<td>16669</td>
<td>13655</td>
<td>3014</td>
</tr>
<tr>
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<td>6684</td>
<td>1475</td>
</tr>
<tr>
<td>5 Prime cost of commercial output, thous.rub</td>
<td>236063</td>
<td>163459</td>
<td>72604</td>
</tr>
<tr>
<td>6 Sales profit, thous.rub</td>
<td>89635</td>
<td>103352</td>
<td>-13717</td>
</tr>
<tr>
<td>7 Profit tax, thous.rub</td>
<td>21512</td>
<td>24804</td>
<td>-3292</td>
</tr>
<tr>
<td>8 Profit remained in organization, thous.rub</td>
<td>68123</td>
<td>78548</td>
<td>-10425</td>
</tr>
<tr>
<td>9 Net Present Value (NPV)</td>
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<td>58882</td>
<td>-85955</td>
</tr>
<tr>
<td>10 Profitability index</td>
<td>0.95</td>
<td>2.04</td>
<td>-1.09</td>
</tr>
<tr>
<td>11 Payback period, years</td>
<td>1.05</td>
<td>0.49</td>
<td>0.56</td>
</tr>
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</table>

Table 1. Economic indicators for the plot No.7.

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Fig. 1. Geological profile of productive deposits for the formation AS4-8 of the Fedorovsk oil and gas field.
water cut), in 1994 the Tyumen branch of SurgutNIPIneft compiled the development plan of oil and gas formation AS4-8 of the Fedorovsk field using horizontal wells.

Technological scheme provided drilling of 1931 wells, including 1175 producing wells, of which 1003 horizontal wells and 756 injection wells. Drilling of this amount of horizontal wells has no analogues in the world (Fig. 2).

Then, in the process of designing the project fund has been increased to 2511 wells, of which 1003 horizontal wells.

The horizontal drilling out provides the involvement in the development of 522.4 million tons of oil, or 86.8% of the approved reserves, additional 100.8 million tons of oil (16.8% of proved reserves). According to hydrodynamic calculations the oil recovery factor doubles. This came from the fact that the depression using the horizontal drilling is much lower compared to the vertical drilling. The quantities of impermeable layers at the gas-oil contact and water-oil contact hindering gas flow and bottom water at the well bottom are reduced, respectively, to 2 m and 1 m.

For project horizontal wells the average length of the horizontal portion of 550 m was adopted. This value is substantiated by detailed technical and economic calculations, but the authors highlight that the actual length of the horizontal part should be justified for each horizontal well under the terms of its construction. The main provisions, which guided the authors of the project document, are that the drilling of each individual horizontal well should be conducted on individual technological scheme, in which it is necessary to determine the specific geological structure of the formation along the path of horizontal well.

The technological scheme provides construction of 60-65 wells per year. Project profiles of horizontal wells are the most widely used, consisting of portions: vertical, drift angle with large and medium curvature radius and horizontal. The average displacement to the entry point into the formation is 550 m, with a spatial azimuthal curvature 65-70°.

On Fedorovsk field OJSC Surgutneftegas solved the main technical and technological issues of deposits development by horizontal wells system: construction, drilling of horizontal wells (direction of trunk and entry into formation, the profile and provision of the specified interval of horizontal portion), wellhead and downhole equipment, optimal length, horizontal section, horizontal portion, distance of the horizontal portion from the gas-oil contact and water-oil contact.

When comparing the development characteristics with vertical wells, the oil production rate is higher, water and breakthrough gas is produced less. An exception is the oil contacted with gas, where in horizontal wells in the initial stage of operation, the gas factor was higher than in vertical wells.

The stabilization of water cut started earlier. If for the plot with vertical wells water cut stabilized at 85%, then for plot with horizontal well it was at the level of 70%, that is, the share of oil in the produced fluid at the same oil recovery factor was 2 times more.

At the same degree of injection (the ratio of accumulated liquid production in situ to balance oil reserves) the current oil recovery factor is higher, the accumulated oil-water factor and gas-oil factor are lower.

<table>
<thead>
<tr>
<th></th>
<th>Horizontal well</th>
<th>Vertical well</th>
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<tbody>
<tr>
<td>Number of wells</td>
<td>215</td>
<td>93</td>
</tr>
<tr>
<td>Time in operation on 1 well, well – year</td>
<td>1,5</td>
<td>4,2</td>
</tr>
<tr>
<td>Cumulative oil production on 1 well, th. t</td>
<td>14,9</td>
<td>16,0</td>
</tr>
<tr>
<td>Average oil flow rate, t/day</td>
<td>29,8</td>
<td>10,8</td>
</tr>
<tr>
<td>Average liquid flow rate, t/day</td>
<td>103,0</td>
<td>94,0</td>
</tr>
<tr>
<td>Cumulative water-oil ratio, t/t</td>
<td>2,45</td>
<td>6,97</td>
</tr>
<tr>
<td>Productivity factor, 10 t/day, mPa</td>
<td>11,0</td>
<td>5,5</td>
</tr>
<tr>
<td>Measured depth, m</td>
<td>2800</td>
<td>2150</td>
</tr>
<tr>
<td>Horizontal length, m</td>
<td>521</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. The so-called benefits of the new scheme on reserves approval.

Analyzing the results it can be concluded that in almost all geological conditions displacement characteristics for horizontal wells are better than for vertical wells, the oil production rate is higher, water and breakthrough gas is produced less. An exception is the oil contacted with gas, where in horizontal wells in the initial stage of operation, the gas factor was higher than in vertical wells.

The stabilization of water cut started earlier. If for the plot with vertical wells water cut stabilized at 85%, then for plot with horizontal well it was at the level of 70%, that is, the share of oil in the produced fluid at the same oil recovery factor was 2 times more.

At the same degree of injection (the ratio of accumulated liquid production in situ to balance oil reserves) the current oil recovery factor is higher, the accumulated oil-water factor and gas-oil factor are lower.
Comparison of operation parameters for horizontal and vertical wells is shown in Table 2.

Comparison of operation parameters shows that almost the same oil production (13.9 thousand tons for 1 horizontal well and 16.0 thousand tons for 1 vertical well) was received for 1.5 years of work of horizontal well and 4.2 years of vertical well work. In horizontal well the water was extracted 2.8 times less than in the vertical well (horizontal well – 2.4 tons of water per 1 ton of oil, vertical well – 7.0 tons of water per 1 ton of oil).

Extraction of breakthrough gas from the gas cap for the horizontal well is greater than for the vertical well (horizontal well – 982 m³ per ton of oil, vertical well – 862 m³ per ton of oil).

Average production rates for the period of operation are as follows: oil – horizontal well – 27.8 tons/day, vertical well – 10.8 tons/day (for horizontal well 2.5 times more), liquid – horizontal well – 103.0 tons/day, vertical well – 94.0 tons/day (1.1 times greater for horizontal well). Productivity index is 2 times greater for horizontal well than for vertical well.

Actual indicators of reserves development in 2012 for horizontal well are the best for horizontal well: 59.7% of the initially recoverable reserves were extracted for horizontal wells, 9.2% – for vertical wells. Peak production for 231 horizontal wells in 4.22 times higher than vertical wells, the average production rate is of 22.7 tons/day. For 119 vertical wells the average production rate is of 10.4 tons/day (Fig. 3).

According to calculations in the deposit operation to limit water cut is of 98%, water content in accordance with the implemented system of CIN may reach 0.27 at the design value of 0.2. Pilot area indicators developed by vertical wells are as follows: oil – horizontal well – 103.0 tons/day, vertical well – 10.8 tons/day (for horizontal well 2.5 times more), liquid – horizontal well – 103.0 tons/day, vertical well – 94.0 tons/day (1.1 times greater for horizontal well), productivity index is 2 times greater for horizontal well than for vertical well.

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According to the latest Project Document of 1994 the following was adopted:
- For Kizelian horizon drilling of the combined horizontal wells (8-9 wells per year) and vertical wells with the organization of three-row flooding system, the creation in vertical wells of artificial cavern oil storage, testing of new development technology of carbonate reservoirs with injecting surface-active agents and polymer dispersed systems in the order of pilot development;
- Carrying out on all objects of development of non-stationary flooding.

Investigation of the geological structure of the carbonate productive horizon and generalization of the results of pilot development has allowed identifying the main ways to improve the development of low permeable heterogeneous reservoirs to ensure their cost-effective development.

The object is Kizelovsky deposit of Bavlinsky field, the development of part of which provides essentially horizontal wells.

The total thickness of the development object in the deposit is 21.4 m, for blocks the average values vary from 20.6 to 23.3 m. The total net pay thickness, respectively, equals to 18.6 m changing average values for blocks ranging from 16.0 m to 20.5 m. The average net pay thickness varies according to areas from 5.3 to 8.5 m and average for the deposit is 7.0 m. The proportion of reservoirs in the context of an object changes in the range of 0.268 to 0.435 unit share and averaged 0.369 unit share. The stratification of the section is low and does not exceed an average of 1.548 unit share, while in some wells according to the logging data up to 8 layers of productive reservoirs are allocated. The thickness of dense carbonate layers between reservoirs ranges from 0.4 m to 15.2 m and an average of 5.5 m (Fig. 4) (Khisamov et al., 2013).

On the deposit substantially vertical-lateral development system is applied (Zakirov et al., 2009).

Block 6 is the most drilled both with vertical and horizontal wells on Kizelian object, which accounts for 53% of horizontal wells drilled on the deposit (Fig. 5).

Oil deposit of Korobkovsky area is of massive type. Kizelian horizon of Tournaisian tier consists of limestone. Development of this area of Bavlinsky field was started in 1976.

The total thickness of Kizelian horizon averages of 21.4 m, the effective average net pay thickness of 5.8 m; stratification rate is 1.4 unit share. Oil is characterized by medium viscosity 20.8 mPa*s, density – 872.5 kg/m³ at reservoir conditions, the saturation pressure – 3.3 MPa. According to the content of sulfur oil is sour.

In 2002 the Institute TatNIPIneft in collaboration with specialists from geological survey of oil and gas production department “Bavly-Neft” proposed a new complex technology of carbonate reservoirs development (Khisamov et al, 2013; Podavalov et al, 2016.).

The technology includes areal nine-point system of wells with horizontal and system vertical trunks and injection wells in the center of the element. The distance from the injection to the horizontal production well is 450 meters; to vertical corner production well is 635 m (Fig. 5).

In the injection wells it is recommended to conduct vertical seismic profiling for fracture studies. Closure pressure of cracks is determined. Estimates are produced of the required volume of water injection from the conservation of initial reservoir pressure after the selection of the reservoir fluid. The injection wells are perforated in the bottom part of the formation. Anticipatory cyclic water injection is produced, thus preparing the formation for oil extraction. Water injection as displacing agent must be alternated.

After specification of the geological structure of drillable object, vertical and horizontal wells are drilled equidistant from injection wells. The horizontal shaft, as well as the perforations in producing wells is carried out in the top part of the productive formation. This ensures a uniform coverage of the reservoir with filtration flow from the bottom up.

Extraction of well production as water injection is carried out in a cyclic mode.
Table 3. The dynamics of flow rates, water content and the existing fund of vertical and horizontal wells.

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<tr>
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<tr>
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<tr>
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<td>7.9</td>
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<td>( P_{\text{extra}} ) mPA</td>
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<td>7.4</td>
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</table>

Since 2002, the drilling and operation of Korobkovsky area is carried out by adopted technology (Podavalov et al., 2016).

As of 01.01.2016, there are 172 producing (71 – horizontal) and 40 injection (1 – horizontal) wells are in the industrial exploitation, of which 8 are in the permanent work from the group pumping station (KNS-12), the remaining injection wells operate from the wells giving process water in a cyclic mode.

In 2015, oil production on the object in question was 293.6 thousand tons, the rate of extraction from the initial recoverable reserves – 6.9%, 343.6 thousand tons of the liquid was produced with water cut of 14.6%. In order to maintain reservoir pressure 72 thousand m3 of water was pumped.

The dynamics of flow rates, water content and the existing fund of vertical and horizontal wells is shown in Table 3 and Figure 6. The oil flow rate and water cut of the sun and the HS are shown in Figure 7 (Podavalov et al., 2016).

It draws attention to the discrepancy between the oil extraction rate and water cut of production. At the very high depletion of deposits (76.6% of the initially recovered reserves) water content is only 14.6%, which is contrary to the development experience (especially for oils with a higher viscosity (Fig. 8) (Muslimov, 2014). With such low water content the current oil recovery factor is 0.153 at the design 0.2. At the same time the pace of development is very high – 6.9% annually from initially recoverable reserves (compared to conventional deposits in carbonate formations of Tatarstan 0.5-1, at least 2% per year). Moreover, such oil recovery was achieved at an early stage of development when the reservoir did not even reached the maximum annual production.

What’s the matter? Such indicators may be either due to underestimation of balance reserves, or by understating the project oil recovery factor when applied new technology of development, or by both. Obviously on the considered deposits we are dealing with the third case. With regard to the under-balance reserves we are dealing with carbonate array, in which the current practice of determining the so-called balance reserves is not perfect. They are defined only by artificially allocated, so-called permeable interlayers. Calculated on the accepted technique share of reservoirs in this case is about 45%. But in the development the whole carbonate array participates. With this in mind, reserves are understated by half.

Recent studies of the Kazan Federal University (V.P. Morozov et al.) for the Upper Tournasian deposits of the east board of Melekess depression showed the presence of oil in almost all oil-saturated part of the section.

According to many modern concepts about the oil and gas basins (Morariu, Averyanova, 2013; Prischepa, Averyanova, 2013), the following rock types can be distinguished in them:

- Reservoir rocks (conventional);
- Source rocks (unconventional);
- Dense rock or half-reservoirs.

If the conventional reservoirs are usually localized within anticline structures, the unconventional reservoir rocks do not comply with it. Important features of oil and gas deposits in shale reservoirs and tight reservoirs that distinguish...
them from conventional deposits, are:
- Continuous type reservoir;
- Are not controlled by the structure factor;
- Controlled by stratigraphic and lithological factors.

Therefore, the prevalence of non-conventional reservoir rocks, controlled by lithological and stratigraphic factor has a very wide areal distribution. The result of work held by V.P. Morozov et al was the presence among the studied sections of tight oil-saturated carbonate rocks with potential industrial oil bearing. Thus, the study of core material sections of the Lower and Middle Carboniferous show that it is possible to distinguish carbonate rocks by the degree of oil saturation:
- Oil-bearing rocks;
- Tight with no signs of oil;
- Tight oil-bearing rocks, intermediate between them (half-reservoirs).

V.P. Morozov on an area of 8.5 thousand km² on the eastern board of Melekess depression defined in the tight layers 8.5 billion tons of oil. Thus, the geological reserves in carbonate array are substantially above the so-called balance reserves. According to our research, the so-called tight sections in carbonate and clastic reservoirs take an active part in the processes of filtration and oil displacement (Muslimov, 2014). Therefore, some experts strongly suggest to go on account of the so-called balance reserves to geological reserves (Zakirov et al, 2009; Muslimov, 2005; 2014). Then discrepancy will disappears between the large selections from the recorded reserves on the balance sheet and low water cut on Korobkovsky area. A similar pattern is observed throughout the Republic of Tatarstan.

The second aspect relates to the effectiveness of development technology in the area with the use of horizontal drilling. The calculations of oil production until the end of the development, to the water content of 98% showed the possibility of achieving oil recovery factor 0.369, i.e. initially recoverable reserves will be more on the balance sheet by 1.84 times. Given the necessary adjustment of reserves (switching to geological), this value of initially recoverable reserves should be increased at least twice. But this does not exhaust the possible effectiveness of this technology. It can be improved and further developed.

The real basis of the adopted technology is the application of horizontal wells and vertical lateral cyclical flooding. As substantiated in the publications of S.N. Zakirov (Zakirov, Zakirov, 1996) it is proved that if horizontal production well is drilled, it must be complemented by a horizontal injection well. In addition, over time, the selection of 80% or more from the actual oil reserves, which are described above, it is necessary to use such a powerful lever as a change in the direction of filtration of liquid flows in the formation, changing the location of production and injection wells, transferring on the block developing system that allows to concentrate residual oil in particular, already emerged areas and ensuring that it is selected with the use of classical schemes of non-stationary flooding. At this we estimated that oil recovery factor would amount to 0.45 to now adopted balance reserves (or 0.361 to adjusted geological reserves). The latter requires a special calculation for the methods recommended by specialists of the Kazan Federal University.

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