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EXPERIENCE OF OILFIELD DEVELOPMENT IN PERM KRAI USING HORIZONTAL WELLS

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ОПЫТ РАЗРАБОТКИ МЕСТОРОЖДЕНИЙ ПЕРМСКОГО КРАЯ ГОРИЗОНТАЛЬНЫМИ СКВАЖИНАМИ

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Hydrocarbon reservoir engineering has a top priority to achieve the highest possible value of the cost-effective oil recovery factor. Structural deterioration of residual oil reserves and inevitable development of hard-to-recover reserves require new effective technologies and engineering solutions. Today, there is a tendency to replace the standard size well drilling technologies (including vertical, directional, horizontal, multilateral wells) and standard size dual completion equipment usage by slim-hole drilling technologies. In Perm Krai fields, more than 385 horizontal wells have been drilled, while 3.4 % of them, i.e. 13 wells, have a small diameter. The conducted well operation analysis shows that the effectiveness of the horizontal well operations in a number of instances is significantly lower than the potential one. This leads to a deteriorated economic performance of reservoir developments, and, eventually, to asset value reductions. Perhaps, the main reason of low effectiveness of the horizontal well operations lies is an insufficient understanding of geological and physical conditions of their successful operations. It has become obvious that drilling horizontal wells in reservoirs with high compartmentalization, low net oil thickness, and decreased hydrodynamic connectivity to the edge water zone offer a low level of performance. Productivity tends to decrease to average output values of directional wells. Therefore, the problem of choosing a well design and its direction in specific geological and physical conditions is highly relevant.

Ключевые слова:
геолого-физическая характеристика, карбонатный коллектор, терригенный коллектор, запасы, залежь, месторождение, разработка, бурение, горизонтальные скважины, наклонно-направленные скважины, малый диаметр, дебит нефти, эксплуатация, добыча, ценность актива.

В настоящее время при проектировании разработки месторождений углеводородного сырья приоритетом является достижение максимально возможного и экономически рентабельного коэффициента извлечения нефти. Ухудшение структуры остаточных запасов нефти, необходимость вовлечения трудноизвлекаемых запасов в разработку привели к поиску новых эффективных технологических решений в проектировании. На сегодняшний день осуществляется поэтапный переход (замена) технологии бурения вертикальных, наклонно направленных (в том числе горизонтальных, многозабойных) скважин, применения оборудования одновременно раздельной эксплуатации скважин в стандартном диаметре на малый диаметр.
На месторождениях Пермского края пробурено более 385 горизонтальных скважин, из которых 3,4 % (13 скважин) составляют скважины малого диаметра. Проведенный анализ эксплуатации скважин показывает, что эффективность использования горизонтальных скважин в ряде случаев оказывается существенно ниже потенциальной и, ухудшая экономические показатели разработки объекта, в конечном счете приводит к снижению ценности актива. Возможно, главной причиной низкой эффективности использования горизонтальных скважин является недостаточное понимание геолого-физических условий для их эксплуатации. Накопленный опыт бурения горизонтальных скважин в коллекторах с высокой расчлененностью, малыми значениями эффективных нефтенасыщенных толщин, ухудшенной гидродинамической связью с законтурной областью показал их низкую успешность: отмечается динамика снижения продуктивности до средних значений дебитов наклонно направленных скважин. В связи с этим актуальным становится вопрос выбора конструкции скважины и ее направленности в конкретных геолого-физических условиях.

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Introduction

Development of oilfields in Perm Krai started in 1929. Oil production peak in 1976 was followed by a sharp decrease (almost by three times) to the minimum level in 1994. A gradual growth of annual recoveries (starting from 1995) resulted in a two-fold increase of oil production by 2019. Factor analysis of growth shows that the basic production relative to the year of the historic minimum as of January 1st, 2020 amounts to only one-fourth of the entire oil production. Bringing into service deposits of produced fields and discovery of new ones would help stabilize oil production at the level of the historic minimum. Use of state-of-the art production drilling technologies in combination with extensive replications of new geological and technical activities based on the results of successful pilot production works (PPW) helped ensure the output growth in the old oil producing region almost by 40 % (Fig. 1).

As of January 1st, 2020, the majority of producing fields in Perm Krai with high and medium porosity and permeability (P&P) had high recovery rates of oil reserves [1].

In the current structure of residual recoverable reserves (RRR) in Perm Krai oilfields, ineffective reserves constitute 61 % (Fig. 2). This category includes oil deposits with low permeability (less than 0.05 μm^2), high viscosity (more than 30 mPa·s) and low net oil thicknesses (less than 2 m).

It is obvious that over time, the structure of residual recoverable oil reserves deteriorates, necessitating the need for search, testing and implementation of new technologies for involvement of hard-to-recover reserves into production operations. If we consider structures of cumulative oil production since 1994, it is obvious that the major share of oil production (88 %) is associated with the old assets, i.e. mature fields. Many of Perm Krai fields are at the third stage of development (66.1 %) and have the largest residual recoverable reserves.

It became possible to increase oil production volumes in the conditions of annually deteriorating geological conditions due to activities in the following areas [2–7]:

– cost reduction due to the use of lightweight structure of wells, use of dual completion systems for several strata, side tracking

– implementation of new technologies for oil production stimulation (formation hydraulic fracture, self-diverting acid compounds, radial drilling, etc.)

– discovery of new oil deposits, additional exploration of fields (seismic exploration works using 3D method, exploration and prospecting drilling).

Lightweight well structures in Perm Krai oilfields have been used since 2010. At that time, cost reduction from a standard diameter directional well (DW) amounted to 8 % [8–11]. In 2012–2013, this technology started to be commercially implemented, followed by the small-bore drilling technology to horizontal and multibranch wells. Empirical knowledge, as well as experience of Tatneft PJSC (2018–2019) through the use of reduced casing string diameters, use of a drilling rig with a smaller lifting capacity and implementation of a series of technical and technological solutions make it possible to reduce well construction costs up to 50 % (upper development reservoirs), compared to standard diameter wells (168 mm) [12–17].

Horizontal Wells in Perm Krai Oilfields

Presently, great experience has been gathered concerning construction and operation of horizontal wells in both standard and small diameter categories [18–22]. Initial outputs of horizontal wells are usually times larger than outputs of vertical (directional) wells in the same geological and physical conditions [23, 24]. In Perm Krai fields, more than 385 horizontal wells have been drilled. The most intense growth of production drilling (PD) of horizontal wells is observed since 2010. The majority of horizontal wells (82 %) are drilled in carbonate reservoirs (Fig. 3).

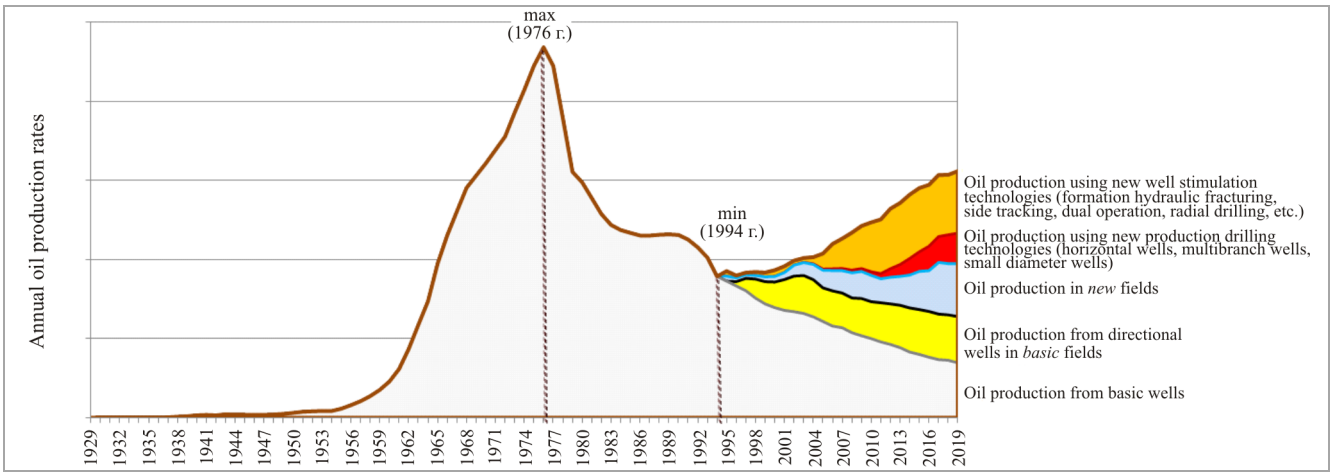

Fig. 1. Oil production dynamics in Perm Krai

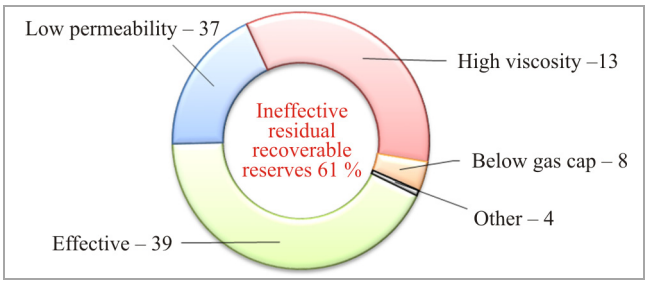

Fig. 2. Structure of residual recoverable reserves in Perm Krai oilfields, %

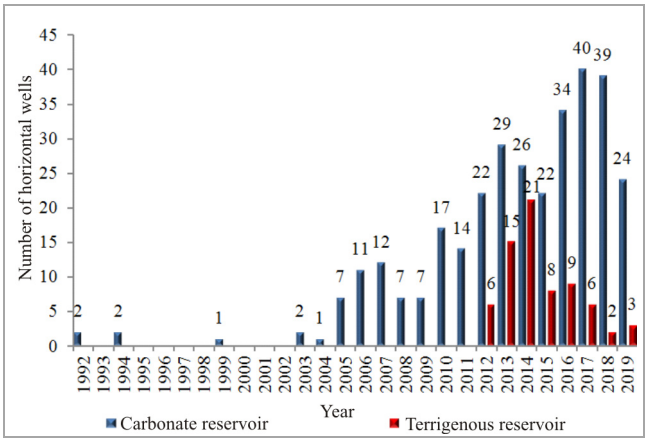

Fig. 3. Horizontal well drilling dynamics in Perm Krai oilfields

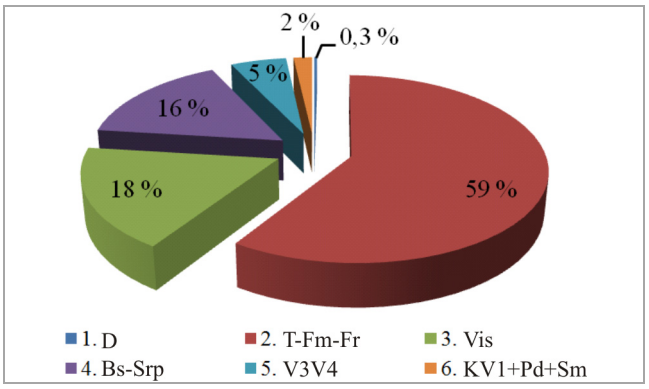

Fig. 4. Distribution of horizontal wells by development reservoirs. D shows Devonian deposits; T-Fm-Fr – Tournaisian – Famennian – Frasnian deposits; V shows Visean deposits; Bs-Srp – Baskirian-Serpukhovian deposits; V3V4 – Vereiskian deposits; KV1+Pd+Sm – Kashirskian-Vereiskian + Podolskian + Sakmarian deposits

Extensive drilling of horizontal wells for development of upper reservoirs (Bs, Srp, V_3V_4, KV_1) started since 2012. As of January 1st, 2020, upper development reservoirs accounted for 23 % of the total amount of drilled horizontal wells. In less than ten years (2011–2020), the slim-hole drilling technology started to be used in Perm Krai fields, in Baskirian and Vereiskian development reservoirs with various types of completion (directional, including horizontal and

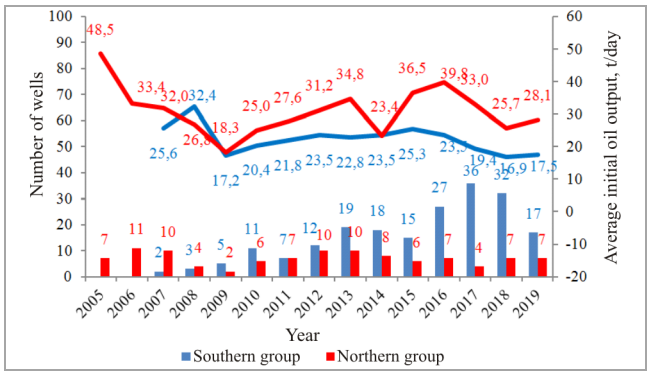

Fig. 5. Dynamics of average initial outputs of wells produced from the new horizontal wells in the carbonate reservoir ranged by territory

multibranch wells). Distribution of the horizontal wells across the development reservoirs is shown in Fig. 4.

Effectiveness of HW use is often far below the potential one, which has a negative impact on economic performance indicators of the reservoir development and, eventually, leads to an asset value reduction. The conducted analysis of HW drilling shows that the main reason of their low effectiveness is an insufficient understanding of geological and physical operation conditions [25–35].

Studies [36–46] outline that the success of HW drilling and operation is determined by cost-effectiveness of the development method and a correct reservoir selection, a comprehensive study of formation geological and physical characteristics. It is also notable that HWs often fail to reach their intended performance: the actual output is below the plan, the produced fluid watercut grows rapidly, the share of producing intervals decreases, etc. Therefore, the problem of choosing a well direction profile in specific geological and physical conditions is highly relevant.

In terms of territory, Perm Krai oilfields can be provisionally divided into two groups: *northern* and *southern*. These groups of fields have different geological and physical characteristics and, as a consequence, well production capacities. Productivity of wells drilled in the reservoirs belonging to the *northern* group of oilfields is usually higher than that of the *southern* group. Dynamics of average initial oil outputs from HWs in carbonate reservoirs and ranging by territory for the period of 2005–2019 (80 % of all the drilled HWs were commissioned for production) are shown in Fig. 5, whereas the main geological and physical parameters of these deposits are provided in the table.

The experience of drilling wells with various types of completion in the *southern* group of fields to upper development reservoirs helped adjust certain project solutions for a number of such reservoirs, since they contain the major part of residual recoverable reserves,

Geological and physical characteristics of carbonate reservoirs in Perm Krai oilfields

Parameter	T-Fm reservoir		Bs reservoir		V_3V_4 reservoir	
	Southern	Northern	Southern	Northern	Southern	Northern
Permeability, mD	1–1420	2–647	22–698	9–123	17–605	–
Porosity, %	7–15	8–17	14–16	9–14	12–20	–
Average net oil thickness, m	2.0–13.4	4.5–30.2	2.4–7.4	4.4–15.9	1–3.9	–
Compartmentalization	3.0–19.0	6.0–41.4	3.5–17.7	5.4–29.9	1.0–9.3	–
Sandiness	0.007–0.74	0.08–0.45	0.22–0.40	0.15–0.62	0.2–0.3	–

and pose the highest risk for the asset, because a wrong choice of a well design can significantly reduce its asset value. For instance, in Batyrbayskoye field, the experience of HW drilling in reservoirs belonging to Bs and KV_1 in the inferior geological and physical conditions (high compartmentalization, low permeability and oil mobility) demonstrated their low effectiveness and helped adjust the production drilling program by changing well profile in its own reservoirs and their analogues.

HW Drilling Experience in Batyrbayskoye Field

In 2017–2018, in the scope of pilot production works (PPW) at Bs reservoir in the western part of Asulskoye uplift (Fig. 6), three producing horizontal wells (Nos. 1203, 1207, 1206) and one directional well (No. 1205) were drilled. Production drilling was performed in the previously uninvaded part of the deposit, with net oil thicknesses exceeding 4 m. Initial outputs varied from 8.3 to 12.2 t/day for oil and 11 to 18.2 m^3/day for liquid. Despite the start of injection (well No. 1205) simultaneously with commissioning of the producing wells, productivity reduction was observed during operation in all wells. As of today, oil outputs range within 2.2–7.7 t/day for oil and 5–10 m^3/day for liquid. An average water intake of the injection well No. 1205 amounted to 25 m^3/day. Most probably, the well output reduction is related to the inferior hydrodynamic connectivity between the recovery and injection zones caused by geological and physical properties of the reservoir (high compartmentalization, low permeability and mobility).

Reduction of productivity may also be related to a high initial recovery from the wells, which is not typical for this development reservoir: nearly all producing wells have low outputs, 70 % is operated with oil outputs up to 2 t/day. As an instance, Fig. 7 shows the basic indicators descriptive of operation of production well No. 1203.

Based on the actual well operation in deposits with similar geological and physical characteristics (GPC), in the course of preparation of a project technology document for Baklanovskoye field in 2018, a

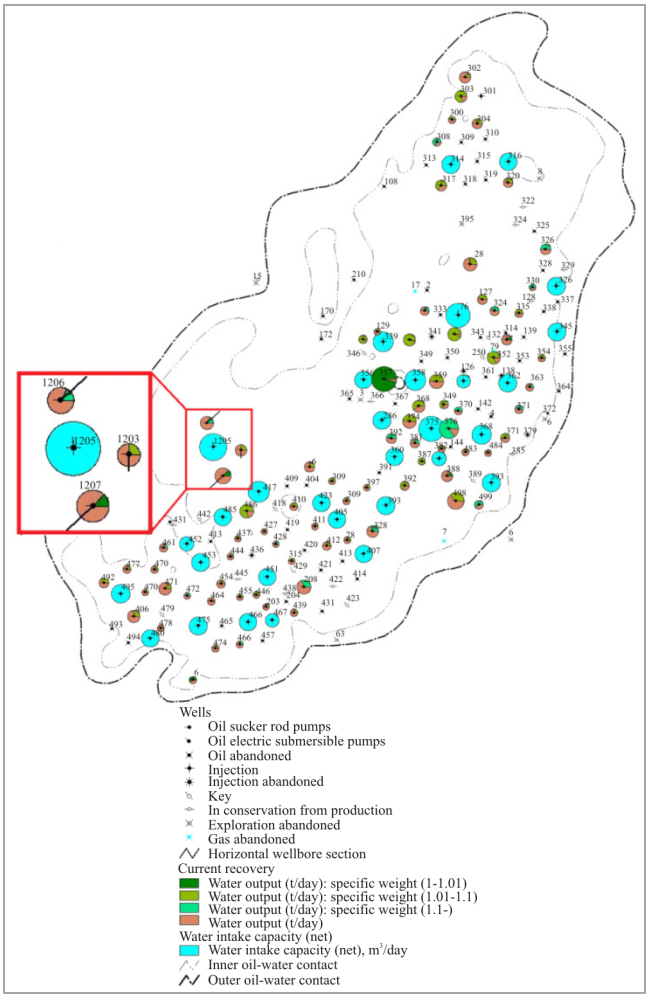

Fig. 6. Current recovery map from Bs reservoir of Asulskoye uplift of Batyrbayskoe field with PPW focus

justification was made to change the well profile from horizontal to directional. The previous project document dating back to 2008 envisaged involvement of large deposit areas in Bs and V_3V_4 reservoirs by drilling horizontal wells with a standard diameter, a three-row well arrangement, and 350×350 m grid. Since the project solutions did not meet the company profitability criteria, production drilling was not performed. In 2107, after test drilling of small diameter horizontal wells in Perm Krai fields in the course of industry development program preparation for Baklanovskoye field, the standard size

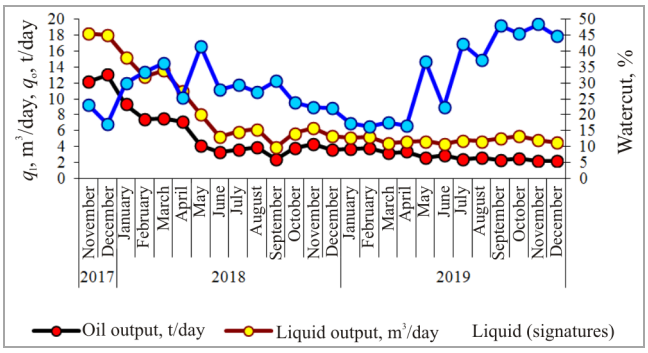

Fig. 7. Main operating indicators of horizontal well No. 1203 in Batyrbayskoye field (Bs reservoir)

well drilling technology was eventually substituted with the slim-hole drilling technology. Consequently, during project document preparation in 2018, scenarios with different well designs were considered. The slim-hole directional drilling technology has shown an increase of NPV up to 30 % versus the the slim-hole horizontal drilling technology. According to the approved scenario, more than 30 wells were actually drilled at the field, 17 producing wells were commissioned, with oil outputs from 6.2 to 13.6 t/day.

Conclusion

During the last 26 years, implementation of new production drilling technologies and oil production stimulation methods helped increase annual oil production outputs in the old oil producing region by almost 40 %.

For the horizontal wells drilled in the reservoirs with high compartmentalization and low net oil thicknesses, the productivity reduction dynamics is more pronounced. The productivity reduction to average values of the directional well outputs in the same reservoirs has been identified.

The experience of well drilling with various structures and directional profiles in identical geological and physical conditions requires determining the selection criteria of a certain method of well completion, which has a significant impact on the asset value.

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