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Improving the efficiency of the Pavlovskoye field development through the reconstruction of wells by drilling sidetracks (on the example of object T)

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Повышение эффективности разработки Павловского месторождения за счет реконструкции скважин методом бурения боковых стволов (на примере объекта Т)

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Keywords:
sidetrack, sidetracks with a horizontal ending, complex reservoir, dual porosity, fracture opening, pressure drop, production schedule.

The study was aimed at a comparative analysis of the exploitation efficiency of the Tournaisian reservoir by sidetracks and sidetracks with a horizontal ending in the Pavlovskoye field.
One of the most effective technologies that allows to achieve an increase in the level of oil production in old fields (late stage of operation) and increase the oil recovery factor from the reservoirs, to return to operation oil wells that could not be returned to the existing fund by other methods is sidetracking. By drilling sidetracks, previously unused sections of the reservoir are introduced into development, as well as unconventional oil reserves, the extraction of which was not previously possible. The advantage of drilling sidetracks is that there is no need to build new communications. This reduces the cost of equipment and materials, reduces the negative impact on the environment. In addition, restoring an inactive well stock is 1.5–2.5 times cheaper than drilling new wells.
The article analyzed the construction and operation of 54 sidetracks drilled for the Tournaisian object, 6 of them with a horizontal ending. The following issues of with sidetracks and sidetracks with a horizontal ending were considered: comparison of technological aspects of well construction; comparison of the well operation indicators dynamics; comparison of the initial filtration parameters of productive formations and analysis of their changes during the operation of wells.
The result of the work was the conclusions on a comparative analysis of the exploitation of the Tournaisian reservoir by sidetracks and sidetracks with a horizontal ending. The results of the work were of practical importance and could be used in the production activities of oil and gas companies.

Ключевые слова:
боковой ствол, боковой ствол с горизонтальным окончанием, сложный коллектор, двойная пористость, раскрытость трещин, снижение давления, график эксплуатации

Проведенное исследование направлено на сравнительный анализ эффективности эксплуатации турнейской залежи боковыми стволами и боковыми стволами с горизонтальным окончанием на Павловском месторождении.
Одной из наиболее эффективных технологий, которая позволяет добиться повышения уровня добычи нефти на старых месторождениях (поздняя стадия эксплуатации) и увеличения коэффициента извлечения нефти из пластов, вернуть в эксплуатацию нефтяные скважины, которые не могли быть возвращены в действующий фонд другими методами, является зарезка боковых стволов. Путем бурения боковых стволов в разработку вводятся ранее не задействованные участки пласта, а также трудноизвлекаемые запасы нефти, добыча которых ранее не представлялась возможной. Преимущество бурения боковых стволов заключается в отсутствии необходимости строительства новых коммуникаций. При этом сокращаются затраты на оборудование и материалы, снижается негативное воздействие на окружающую среду. Кроме того, восстановление бездействующего фонда в 1,5–2,5 раза дешевле бурения новых скважин.
В статье проведен анализ строительства и эксплуатации 54 боковых стволов, пробуренных на турнейский объект, из них 6 с горизонтальным окончанием. Рассматриваются следующие вопросы: сравнение технологических аспектов строительства скважин бурением боковых стволов и боковых стволов с горизонтальным окончанием; сравнение динамики показателей эксплуатации скважин с применением этих технологий; сопоставление начальных фильтрационных параметров продуктивных пластов и анализ их изменения в процессе эксплуатации скважин.
Итогом работы стали выводы по сравнительному анализу эксплуатации турнейской залежи боковыми стволами и боковыми стволами с горизонтальным окончанием. Результаты работы имеют практическую значимость и могут быть использованы в производственной деятельности нефтегазодобывающих обществ.

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Introduction

Today, most fields developed by LUKOIL-PERM LLC are at the final stage of exploitation.

All current project documents for field development include sidetracking options. By drilling sidetracks, previously unused sections of the formation are brought into development, as well as hard-to-recover oil reserves, previously considered impossible. Experience has shown that this technology is one of the most effective geological and technical measures (GTM) that can extend the operational life of mature fields and increase the economic value of these assets [1, 2].

Analysis of production levels and their distribution over the geological and technical measures

In the period from 2006 to 2012, the development at Tournaisian productive formation of the Pavlovskoye field was carried out with a significant increase over the projected oil production levels (by 33–78 %) due to significant number of sidetracks drilling in undrained zones, as well as using methods of oil well stimulation and enhanced oil recovery in the existing production fund (see Fig. 1).

The distribution of additional oil production from well interventions at the Pavlovskoye field (productive formation C_1t (T)) is as follows: sidetracking 562 thousand tons (37 %), hydraulic fracturing 240 thousand tons (16 %), radial drilling 215 thousand tons (14 %), perforation methods 205 thousand tons (14 %), remedial cementing methods 90 thousand tons (6 %), bottomhole zone treatment (BZT) 183 thousand tons (12 %), conversion 11 thousand tons (1 %).

The analysis showed that the existing reservoir development system requires an adjustment. In this situation, the planned production volumes can only be achieved by regulating the system. The priority areas for regulation should include:

1) optimization of the reservoir pressure maintenance system;

2) increasing the productivity of the existing production fund to enhance oil recovery.

Comparative analysis of inclined directional sidetracks and horizontal sidetracks technologies

Taking into account the technical condition of the wells and their high water content, drilling sidetracks should be considered as the priority direction for enhanced production [3]. This method has already practical use at Pavlovskoye and neighboring fields. A characteristic feature of the Pavlovskoye field is the drilling sidetracks practice of various designs, including those with a horizontal end of the wellbore.

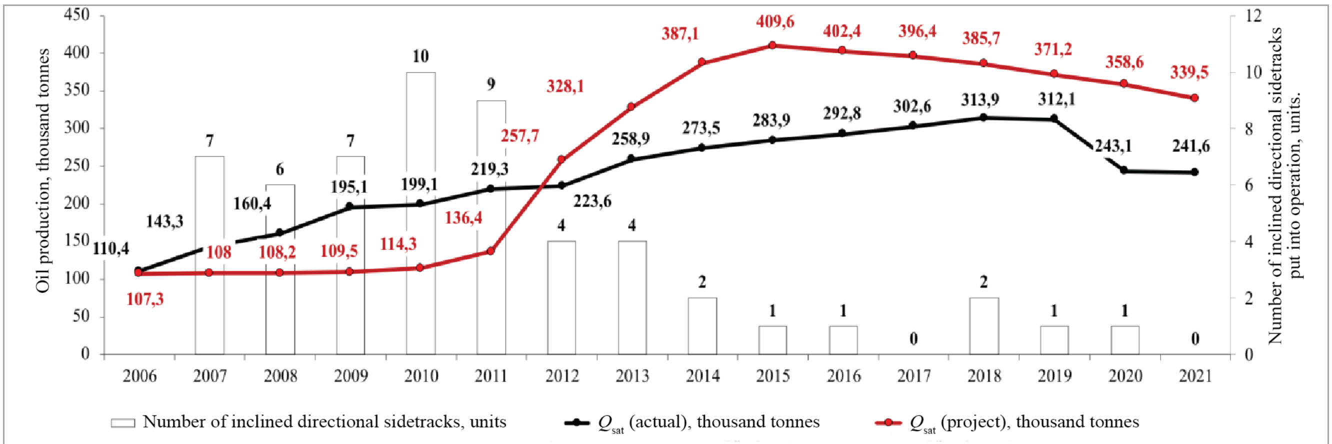
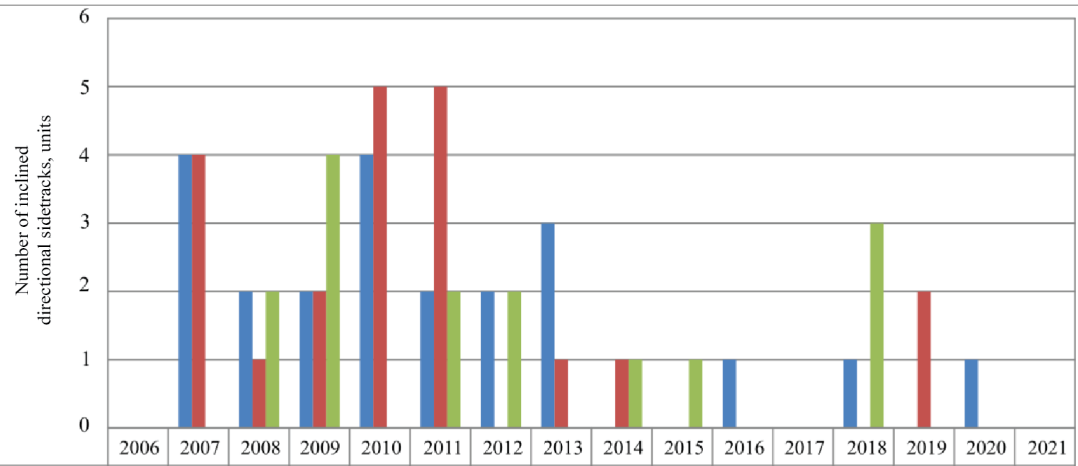


Fig. 1. Dynamics of oil production levels in the period from 2006 to 2021 (Pavlovskoye field, productive formation T)



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
From 0 to 49	0	4	2	2	4	2	2	3	0	0	1	0	1	0	1	0
From 50 to 65	0	4	1	2	5	5	0	1	1	0	0	0	0	2	0	0
From 66 to 90	0	0	2	4	0	2	2	0	1	1	0	0	3	0	0	0

Fig. 2. The fund of sidetracks (Pavlovskoye field, productive formation T)

It is believed that the technology for constructing conditionally vertical or inclined directional sidetracks is simpler and less expensive than the technology for horizontal sidetrack. However, wells with horizontal sidetrack are characterized by greater productivity due to a higher coverage of the formation. Additionally, the technology of drilling horizontal wells in the edge of carbonate reservoirs helps to solve the problem of early flooding, thereby increasing the efficiency of field development [4].

All sidetracks drilled in the Tournaisian deposit of the Pavlovskoye field can be divided into three groups:

1. Sidetracks with a zenith angle of 0–49° (using water-based fluid NCDM-SKP-MH).
2. Sidetracks with a zenith angle of 50–65° (using water-based solution TCDM-PMH).
3. Sidetracks and horizontal endings – zenith angle of 66–90° (using hydrocarbon-based solution of IEF).

Fig. 2 shows the drilled sidetracks distribution among these groups.

From the conducted analysis, it follows that the first two groups can be combined and considered as one, since the capital investments and the cost per meter of drilling are approximately the same. Sidetracks with a zenith angle of 66–77° differ from the first two groups only in terms of capital investment, as a hydrocarbon-based mud is used during drilling, which significantly increases construction costs. The group should be compared with the last group, as their capital costs will be approximately the same.

Drilling of sidetracks with horizontal completion was carried out in a relatively long time ago, when drilling technologies were not sufficiently developed. The data obtained during the construction of a sidetrack in the present time may differ significantly from previously obtained results (drilling with LWD, the use of PDC bits and hydrocarbon-based fluids, etc.). Available technologies for drilling wells with horizontal completion have enhanced the economic viability of well construction and ensured more efficient reserves production by opening the oil-bearing part of the deposit with maximum oil saturation [5–23].

Comparative characteristics of construction technologies are given in Table 1.

The comparative analysis of sidetracks showed that with an increase in the zenith angle, their lengths increase without significant capital costs. The use of hydrocarbon-based fluids has a significant effect on the sidetrack construction cost, which is confirmed by the cost of a meter of drilling and capital investments [23–33].

The technology of drilling sidetracks with horizontal completion in terms of capital investment does not differ much from that using sidetracks drilling as water-based fluids were used. Additionally, the listed horizontal sidetracks were drilled between 2008 and 2011, a period when expensive methods of horizontal well drilling, such as the LWD system and hydrocarbon-based fluids, were not used.

The comparison of previously used operations with improved technologies showed that current well construction technologies allow for a significant drilling time reduction and sidetracking completions, as well as avoid complications with borehole wall stability [33–53].

The next stage of the work involved comparing the operational performance parameters of sidetracks and horizontal sidetracks.

Since the main task of any well operation is to ensure oil production, this section presents a comparative analysis of production performance parameters for wells with sidetracks and horizontal sidetracks, their initial values, as well as the cumulative values and the dynamics over the past operating period.

To analyze the flow rates dynamics after the wells were put into operation, exploitation graphs are constructed. Fig. 3 shows typical graphs for wells with sidetracks and horizontal sidetracks.

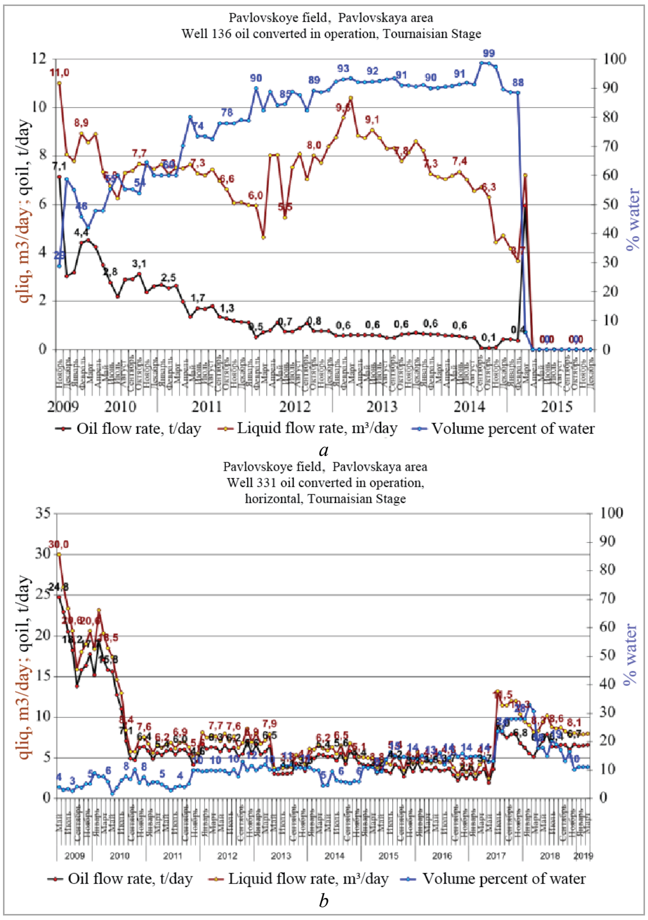


Fig. 3. Well operation schedule: *a* – No. 136_2 (Sidetracks, Pavlovskoye uplift); *b* – No. 331_2 (Horizontal sidetracks, Ulykskoye uplift)

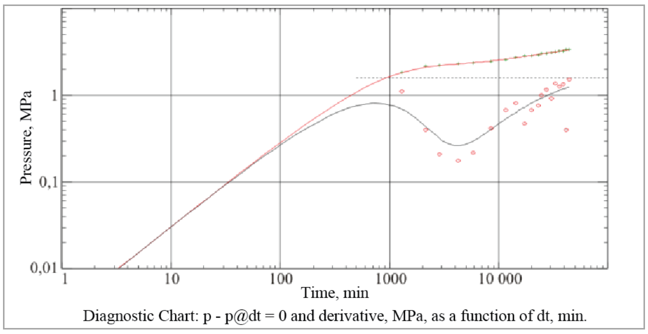


Fig. 4. Pressure recovery curve for well No. 331 as of January 15, 2010 in SAPHIR software coordinates

As can be seen from the graphs analysis, the initial flow rate of wells with sidetracks is lower than that of wells with lateral horizontal wellbore. However, subsequently, the flow rates of the wells with horizontal sidetracks decrease more sharply than those of the wells using sidetracks. This pattern is observed for all analyzed wells.

In this regard, it seems appropriate to analyze and compare both the initial and cumulative production parameters for wells with sidetracks and horizontal sidetracks. It has been accomplished in the present work and is shown in Table 2.

As follows from Table 2, wells with horizontal sidetracks are characterized, on average, by higher initial flow rates.

For a reasonable comparison of accumulated parameters considering different operating time, Table 2 presents such a parameter as ratio of accumulated oil production to the operating time.

Table 1

Comparative characteristics of construction technologies

№	Parameter	Average value for sidetracks				Average value for horizontal sidetracks
		ZA (up to 49°)*	ZA (50–65°)**	ZA (66–77°)	(ZA 77°)***	
1	Length, m	495.1/506.1	574.5/581.9	612.0	974.5	670.3
2	Construction duration, days	25.16/25.58	27.69/28.03	29.71	34.1	54.3
3	Commercial speed, m/rig-month	626.4/634.1	761.12/768.6	709.27	927.74	408.1
4	Capital investments, rub.	26 831 182.41/ 26 166 454.98	25 594 672.46/ 25 565 100.23	31.606.748.57	51 458 244.95	28 328 624.96
5	Cost of 1 meter of drilling, RUB.	57 965.05/ 54 582.82	46 295.24/ 45 542.46	59214.0	52 897.39	42.677.94

Note:
* – the numerator includes the values considering the sidetracks with core sampling (No. 81, 2075), the denominator excludes them;
** – the numerator includes the values considering the sidetracks with core sampling (No. 150), the denominator excludes them;
*** – activities carried out in 2018–2019 (improved technology).

Table 2

Assessment of the initial operating sidetracks parameters and their changes over the operation period

Parameter		Values for sidetracks					Values for horizontal sidetracks			
		Baranovskoe	Pavlovskoe	Ulykskoe	South Pavlovskoye	Average value	Baranovskoe	Pavlovskoe	Ulykskoe	Average value
Number of sidetracks		1	23	13	12	49	2	3	1	6
Q_{oil} (initial), t/day		12.1	11.6	10.3	10.2	10.8	14	14.1	24.8	15.8
Q_{liq} (initial), t/day		16.7	14.2	13.1	12.7	13.4	43.5	18.6	26	28.1
Water content of production, %		22.4	19.4	15.3	15.3	17.5	51.5	16.8	4	26.2
Q_{oil} (average for the operation period), t/day		9.2	4.4	5.2	3.5	4.5	3.1	4.7	6.4	4.4
Q_{liq} (average for the operation period), t/day		19.7	7.6	7.7	5.6	7.3	8.9	6.3	7.4	7.3
Dynamic Level	cumulative oil production (ΣQ_{oil}). T	31799.8	13393.6	16005.8	10618.1	13782.6	7886.4	18813.8	27404.4	16603.1
	period of work (t). month	114.9	106.6	101.6	104.3	104.9	86.0	135.7	146.1	120.9
	$\Sigma Q_{oil/t}$. t/month	276.7	125.6	157.5	101.8	131.4	91.7	138.6	187.6	137.4

Table 3

Reservoirs filtration characteristics based on hydrodynamic well testing data

Parameter	Values for sidetracks					Values for horizontal sidetracks			
	Baranovskoe	Pavlovskoe	Ulykskoe	South Pavlovskoye	Average value	Baranovskoe	Pavlovskoe	Ulykskoe	Average value
Permeability of the remote reservoir area, μm^2	0.0765	0.0272	0.0365	0.0223	0.0295	0.1634	0.0198	0.0522	0.0731
Permeability of the reservoir bottom hole zone, μm^2	0.1711	0.0476	0.0541	0.043	0.0512	0.4086	0.0329	0.0767	0.1168
Reservoir pressure, MPa	13.772	11.457	10.744	9.328	10.861	7.841	11.017	7.741	9.413
Skin factor	-5.6	-4.17	-3.83	-4.5	-4.19	-3.75	-4	-4.6	-4.02
Productivity coefficient, m^3/day*MPa	3.55	2.01	3.15	2.25	2.39	5.94	1.94	5.43	3.44

The parameter characterizes the average oil production per month of operation. For the considered wells, the parameter takes approximately the same value: 137.4 for wells with horizontal sidetracks and 131.4 for wells with sidetracks. This conclusion questions the effectiveness of constructing sidetracks with horizontal completion, as it is evident that the flow rates of the wells with horizontal sidetracks are initially higher, but subsequently drop sharply. Ultimately, the average monthly production is approximately the same for either technology. Most likely, the change in well flow rates is related to the energy state of the areas being drilled with sidetracks. Therefore,

Table 4

Results of the viscosity-debit curve interpretation

Parameter	Well No.					
	331		888		733	
Date of horizontal sidetracks commissioning	12.05.2009		10/30/2009		31.03.2008	
Actual length of the horizontal wellbore	140		203		34	
Initial liquid flow rate, m^3/day	26.0		13.2		35.2	
Date of research	15.01.2010	12.04.2018	26.07.2010	23.08.2017	27.06.2009	20.10.2015
Liquid flow rate, m^3/day	20.6	9.0	8.3	4.2	5.5	4.5
Reservoir pressure, MPa	7.97	8.18	9.69	2.79	7.36	6.34
Permeability of the remote reservoir area, μm^2	0.012	0.007	0.021	0.009	0.024	0.016
Skin factor	-4.5	-1.0	-4.1	-3.9	-5.8	-1.4
Working length of the horizontal wellbore	140	135	209	202	-	35
Parameter	Well No.					
	940		1047		2137	
Date of horizontal sidetracks commissioning	24.08.2009		08.05.2008		30.06.2009	
Actual length of the horizontal wellbore	90		158		148	
Initial liquid flow rate, m^3/day	16.1		26.4		71.9	
Date of research	18.01.2010	16.08.2018	24.07.2009	01.04.2017	26.12.2009	12.03.2016
Liquid flow rate, m^3/day	7.7	4.7	14.8	9.0	6.8	11.3
Reservoir pressure, MPa	12.63	8.42	11.09	8.17	9.64	3.61
Permeability, μm2	0.026	0.017	0.045	0.019	0.015	0.017
Skin factor	-3.0	-3.5	-4.3	-4.6	-6.0	-1.0
Working length of the horizontal wellbore	99	96	149	158	145	144

further verification of this preliminary conclusion is advisable.

The previously conducted analysis established that wells with sidetracks and horizontal sidetracks are characterized by different average initial flow rates. It may be attributed not only to different designs but also to the varying properties of the reservoir. Table 3 presents the results of the pressure recovery curves interpretations obtained shortly after commissioning.

The data in Table 3 shows that the filtration characteristics of horizontal sidetracks are better, which is also confirmed by the higher initial flow rates compared to sidetracks.

The previously noted dynamics of flow rates for wells with horizontal sidetracks, characterized by a sharp decrease in the initial operation period, also requires analysis. Thus, the following probable reasons for the sharp decrease in flow rates for wells with horizontal sidetracks can be identified:

1) A decrease in the filtration parameters of the reservoir, including the bottomhole zone;

2) The working length reduction of the horizontal section in the wellbore;

3) The formation energy reduction in the well production zone.

To identify the most probable reason, the hydrodynamic research materials (the first after horizontal sidetracks commissioning and the last for the period under consideration) were used for the analysis of all wells with horizontal sidetracks. The research materials were interpreted in the ECRIN software package (SAPHIR module), which allows us to assess the working length of the horizontal wellbore section and the reservoir filtration parameters in the drainage zone. As an example, Fig. 4 shows the diagnostic chart and the results of processing the first pressure recovery curve (from January 15, 2010) for well No. 331.

The interpretation results for other wells, and well operation parameters for the studied period, are summarized in Table 4.

As follows from Table 4, for almost all wells, an approximately constant working length of the horizontal wellbore section is observed, corresponding to the actual value. It should also be noted that many wells are characterized by a significant decrease in reservoir pressure during operation. Furthermore, during the interpretation, it was established in almost all cases that the pressure recovery curve (see Fig. 4) corresponds to the so-called "dual porosity" model, which is a feature of natural fracturing in the reservoir.

As is known, a characteristic feature of a fractured reservoir is its ability to deform the void space leading to a reduction of fracture openning when pressure decreases. This ability negatively influences the productive characteristics of wells. Obviously, the reason of the sharp decline in flow rates for wells with lateral horizontal wellbore after they are put into operation is the deformation of the reservoir due to the reduction in pressure with increased production.

Thus, the effective well operation with horizontal sidetracks is possible only if the reservoir pressure is maintained at the necessary level through the effective flooding system at the development site.

Conclusion

1. The construction of sidetracks and horizontal sidetracks has a significant difference in capital costs only if the sidetracks are drilled using water-based fluids.

2. The initial flow rate of horizontal sidetracks practically exceeds the sidetracks by almost 1.5 times, with a maximum flow rate period of 16 months (Q_{oil} = 9.6 t/day) according to horizontal sidetracks and 18.4 months (Q_{oil} = 7.8 t/day) for sidetracks. When comparing the accumulated oil production for the operation period of sidetracks/ horizontal sidetracks, these parameters have the same values.

3. The filtration characteristics of the horizontal sidetracks are better than those of the sidetracks, but it does

not greatly influencet the final result of operation (the volume of oil produced).

4. The main reason for the fall-off in flow rates in wells with horizontal sidetracks is considered to be a decrease in the filtration characteristics of the reservoir, for which fracturing has been established due to the deterioration of the energy state (decrease in reservoir pressure).

5. The major task of efficient well operation with horizontal sidetracks is to maintain the reservoir pressure in the covering zone.

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