The analysis of the hydraulic fracturing efficiency at the Potochnoe field facility AV_{1-2}

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Abstract. Currently, large deposits of the Russian Federation are in the final stages of development. Taking this into account, the new methods of enhanced oil recovery are required in the final stages of developing formations with hydrocarbon stock hard to recover. The use of hydraulic fracturing allows increasing the degree of oil recovery from flooded formations, optimizing production and prolonging the economically profitable period of development. This paper examines the application of hydraulic fracturing based on the production figures for the facility AV_{1-2} in the Potochnoe field. The results, obtained on the basis of analysing the formation AV_{1-2}, show that the highest post-frac fluid rate is achieved in the formations of a greater power. The application of large proppant masses allows obtaining higher post-treatment fluid rate. Similarly, the increase of the proppant specific mass results in the growth of the specific post-frac fluid rate.

1. Introduction

Hydraulic fracturing (HF) represents:
- a productive physical mode of incremental oil production;
- an effective way to enhance the well injection capacity.

The technique of hydraulic fracturing is to form high-conductive fractures in the target formation where under the influence of high pressure the fluid is served to ensure the fluid influx to the bottomhole [1].

2. Methods and materials

The deduced outcomes, discussed in the article, are explained through geological, technological and performance characteristics before and after holding FHF at the facility AV_{1-2} of the Potochnoe field. When processing commercial information there were extensively used popular and proven methods of analysis using a PC. The developed recommendations passed field-testing with positive technological effect [2].

The results given in the work were applied to planning and introducing methods of enhanced oil recovery for the purpose of effective development of the Potochnoe field.

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3. Results and discussion

Formation hydraulic fracturing started at the facility AV_{1-2} of the Potochnoe field in 1996 and includes 25 operations out of 399 FHF hold in the entire field [3]. The use of the hydraulic fracturing method for developing wells covers 4.9%. Monitoring incremental oil production shows that due to 25 hydraulic fracturing operations in development wells of the field the incremental oil production amounts to 74.3 th. tonnes or 3.0 th. tonnes/well per one WO (the field data include 2490.9 th. tonnes or 6.4 th. tonnes per one WO), including 51.4 th. tonnes or 2.6 th. tonnes/well in 20 operating wells, 3.2 th. tonnes or 1.1 th. tonnes/well in 3 wells shifted from hydraulic fracturing, 19.7 th. tonnes or 9.9 th. tonnes/well in 2 suspended wells after drilling [4].

At the facility, 25 wells went into operation after hydraulic fracturing. The highest FHF volume accounts for the formation AV_{2} and includes 13 operations, as well as the combined effect on the formations AV_1^3 and AV2 – 10 FHF, the statistics for the formation AV_1^3 includes 2 operations (figure 1) [5].

In the present period the share of incremental oil production due to hydraulic fracturing in General, accumulated oil uptake is 2.1 %.

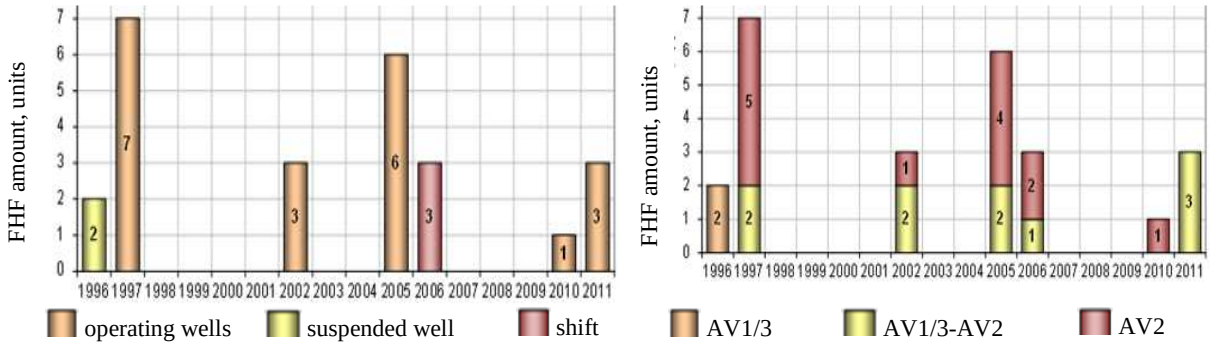

Figure 1. The distribution of the FHF amount arranged by years, well categories and formations of the facility AV_{1-2}

The first FHF treatment 1996 revealed the formation AV_1^3 with a low effective power and permeability (~1.9 m and ~2,4 mD, table 1) and was conducted with a proppant mass of 6 t and with the injection rate of fracturing fluid, 4.5 cbm/min [6]. In subsequent years, hydraulic fracturing is carried out with larger values of thickness and permittivity (~8.8 m and ~86,3 mD) and proppant volume (20.8 t) according to the data of 2005, in 2011 it amounted to 17.1 t; but the injection rate, on the contrary, is decreasing over the years and in 2011 it amounted to 2.4 cbm/min).

Table 1. Basic geological and physical, process parameters and well operation indicators before and after FHF arranged by the years of treating the facility AV_{1-2} as of January 1, 2012.

Parameter	**1996**	**1997**	**2002**	**2005**	**2006**	**2010**	**2011**	***In total***
FHF amount, unit	2	7	3	6	3	1	3	25
Geological characteristics								
Effective thickness, m	1.9	8.4	10.7	8.6	12.6	2.7	6.7	8.3
Oil-saturated thickness, m	1.9	7.8	9.6	7.5	7.4	2.7	6.5	7.1
Pore volume, unit fraction	0.18	0.22	0.22	0.22	0.22	0.17	0.20	0.21
Permeability, mD	2.4	98.9	125.4	106.5	74.9	3.2	16.7	79.6
Net to gross, unit fraction	0.18	0.29	0.34	0.32	0.43	0.11	0.19	0.28
kh-factor of the formation, mD·m	4.9	879.9	1245.9	1114.0	1421.0	8.7	118.8	848.8

Process parameters								
Proppant mass, t	6.0	8.3	9.0	20.8	12.1	15.7	17.1	12.7
Specific proppant mass, t/m	3.1	1.0	0.8	2.4	1.0	5.8	2.5	1.5
Highest concentration, kg/cbm		891	900	740	702	1000	967	837
Injection rate, cbm/min	4.5	4.0	2.2	2.0	1.9	2.2	2.4	2.8
Performance Indicators								
Fluid rate for 3 months prior to FHF, t/day	-	5.2	5.0	9.7	-	-	-	6.8
Oil rate 3 months prior to hydraulic fracturing, t/day	-	2.2	3.1	4.2	-	-	-	3.1
Water content 3 months prior to hydraulic fracturing, %	-	58.8	37.6	57.2	-	-	-	54.6
Fluid rate for 3 months after FHF, t/day	9.4	42.6	13.2	56.1	48.9	15.6	35.4	38.5
Oil rate 3 months after hydraulic fracturing, t/day	6.8	6.6	6.1	15.9	2.2	5.3	4.5	8.0
Water content 3 months after hydraulic fracturing, %	27.8	84.5	54.2	71.6	95.5	65.7	87.3	79.3
Specific post-frac fluid rate, t/day/m	4.8	5.1	1.2	6.5	3.9	5.8	5.3	4.7
The initial incremental fluid rate, t/day	9.4	37.4	8.2	46.4	48.9	15.6	35.4	31.7
The initial incremental oil rate, t/day	6.8	4.4	2.9	11.8	2.2	5.3	4.5	4.9
The total incremental oil production during over the period, th. tonnes	19.7	7.5	2.0	40.0	3.2	1.7	0.2	74.3
Total time in operation over the period, days	4754	2019	1069	8155	1940	659	42	18638
Average incremental oil rate over the period, t/day	4.1	3.7	1.9	4.9	1.6	2.5	5.0	4.0

In 3 months after fracturing the maximum flow of oil and fluid was obtained in the amount of 15.9 and 56.1 t/day by treatments in 2005, while water content made up 71.6%. In 2006, the wells No. 850, 1809 and 208 underwent 3 HF operations during their shift from the underlying bed. The flow rate reached high values, which is on average 48.9 t/day for 3 months, however the performance was low, as oil rate ranged from 1.9 to 2.7 t/day and water content comprised 95.5% (that resulted in the fact that 9 months after the well operation No. 208 and 1809 was stopped) [7]. In 2011, the well No. 208 underwent secondary HF at the same interval with the effective formation power of 8.9 m, permeability of 25.7 ppm, but using another technology: we applied less proppant mass (30 t in the first treatment and 19.8 t in the second) and concentration of 998 $кг/м^3$in the first treatment and 900 $кг/м^3$ in the second treatment, and increased the injection rate from 2.0$м^3$/мин to 2.4$м^3$/мин. After the first treatment the oil and fluid rate per 1 month of operation amounted to 5.0 and 23.5 t/day, water content – 79.0 %, and after the second treatment the figures were 4.0 and 23.7 t/day, 83.1% [8].

In general, the facility AV $_{1-2}$ witnessed moderate oil and fluid flow which amounted to 8.0 and 38.5 t/day in 3 months after FHF, while water content made up 79.3%. Let us analyse the results of the application at the facility AV $_{1-2}$ on a formation-by-formation basis (table 2).

Table 2. Basic geological and physical, process parameters and well operation indicators before and after FHF arranged by the years of treating the formations of the facility AV $_{1-2}$ as of January 1, 2012.

Parameter	**AB1/3**	**AB1/3-AB2**	**AB2**	***In total***
FHF amount, unit	2	10	13	25
Geological characteristics				
Effective thickness, m	1.9	7.2	10.1	8.3
Oil-saturated thickness, m	1.9	7.0	7.9	7.1
Pore volume, unit fraction	0.18	0.21	0.22	0.21
Permeability, mD	2.4	59.1	107.3	79.6
Net to gross, unit fraction	0.18	0.22	0.37	0.28
kh-factor of the formation, mD·m	4.9	426.4	1303.4	848.8
Process parameters				
Proppant mass, t	6.0	16.3	11.5	12.7
Specific mass, t/m	3.1	2.3	1.1	1.5
Highest concentration, kg/cbm	-	920	783	837
Injection rate, cbm/min	4.5	2.5	2.8	2.8
Performance Indicators				
Fluid rate for 3 months prior to FHF, t/day	-	4.2	8.7	6.8
Oil rate 3 months prior to hydraulic fracturing, t/day	-	2.3	3.6	3.1
Water content 3 months prior to hydraulic fracturing, %	-	44.7	58.3	54.6
Fluid rate for 3 months after FHF, t/day	9.4	29.5	49.9	38.5
Oil rate 3 months after hydraulic fracturing, t/day	6.8	5.9	9.7	8.0
Water content 3 months after hydraulic fracturing, %	27.8	80.0	80.5	79.3
Specific post-frac fluid rate, t/day/m	4.8	4.1	4.9	4.7
The initial incremental fluid rate, t/day	9.4	25.2	41.2	31.7
The initial incremental oil rate, t/day	6.8	3.6	6.1	4.9
The total incremental oil production during over the period, th. tonnes	19.7	7.9	46.7	74.3
Total time in operation over the period, days	4754	7186	6698	18638
Average incremental oil rate over the period, t/day	4.1	1.1	7.0	4.0

As previously recorded, the formation AV_1^3 is characterized by low poroperm properties: the effective power of the formation made up 1.9 m, permeability - 2.4 mD. Therefore, low FHF results were obtained: oil and fluid rate for 3 months - 6.8 and 9.4 t/day, water content - 27.8%.

According to separate treating the formation AV_2, there were obtained the highest oil and fluid rates – 9.7 and 49.9 t/day, while water content made up 80.5 %. According to combined treating the formations AV_1^3- AV_2 there were obtained 5.9 и 29.5 t/day, while water content made up 80.0 %. Within 24 months we observe an increase in water content up to 89.2 % a decrease in oil rate to 2.8 t/day (figure 2).

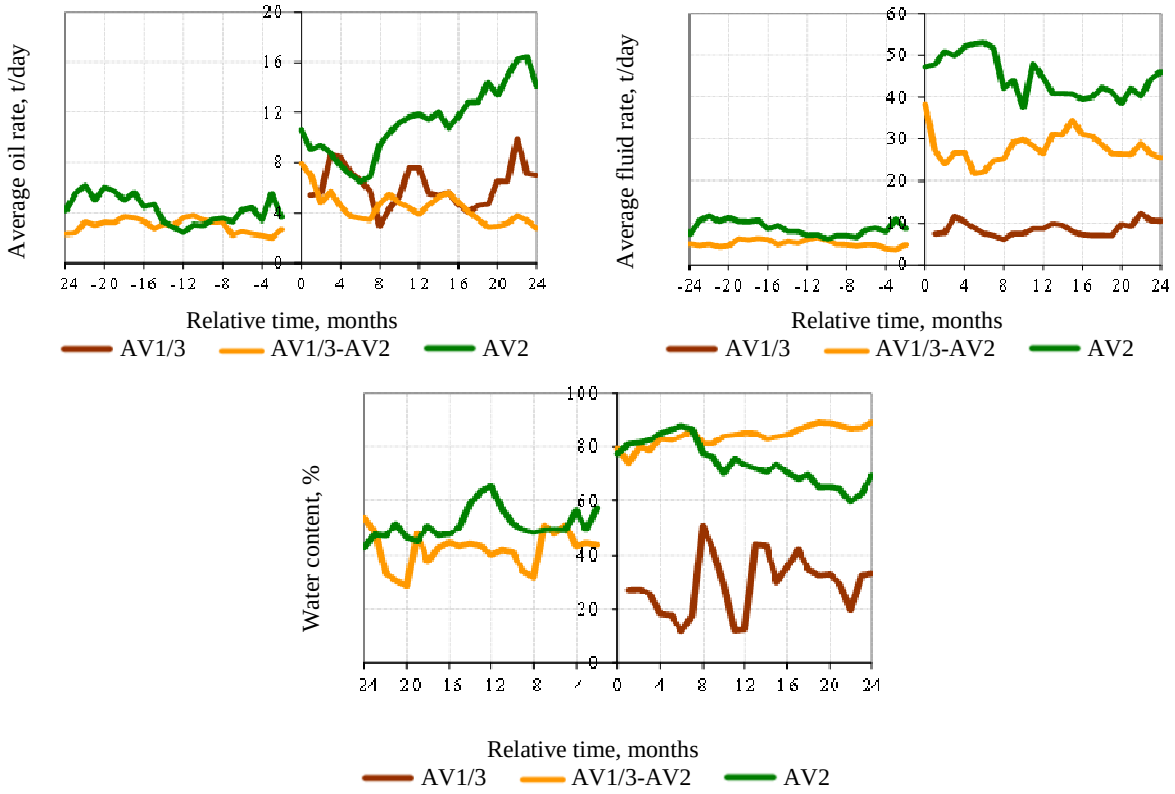

Figure 2. Average flow rates of fluid and oil, given on the date of hydraulic fracturing, arranged by formation groups at the facility AV_{1-2}

The picture presents the paired relationship between the FHF performance characteristics and key influencing factors. There is registered an increase in the fluid rate after FHF and the growth of the effective formation thickness. The obvious relationship between the fluid rate and the proppant mass and between the specific fluid rate and the specific proppant mass could not be traced. According to the treatments with a significant water content (over 80 %) oil rate averaged 3.8 t/day. The well No. 145B provided the maximum oil flow of 61.1 t/day with the highest fluid rate of 153.5 t/day, while water content was 60.2 %.

According to the bar charts of FHF distribution arranged by the effective thickness (figure 3), it was determined that an increase in effective thickness increases the oil and fluid flow after FHF. The figure shows the general relationship between oil and fluid rate and the average effective formation power after hydraulic fracturing which are supposed to apply as expected.

Thus, the significant water content of the facility AV_{1-2} limits the extensive use of hydraulic fracturing because of waterflooding and coning of bottom waters. According to the data of the formation AV_1^3, an effective thickness of 1.9 m and a proppant mass of 6 t resulted in a flow rate of 9.4 t after FHF; according to the data of the formation AV_2, an effective power of 10.1 m and a proppant mass of 11.5 t resulted in a flow rate of 49.9 t/day (increase ratio – 5.7 times); when holding overall treatment of formations AV_1^3 and AV_2, an effective power in the FHF interval of 7.2 m and the proppant mass of 16.3 t led to 29.5 t/day (increase ratio – 7 times). Average incremental oil rate amounted to 4 t/day over the time of benefit for 2 years at the entire facility AV_{1-2}.

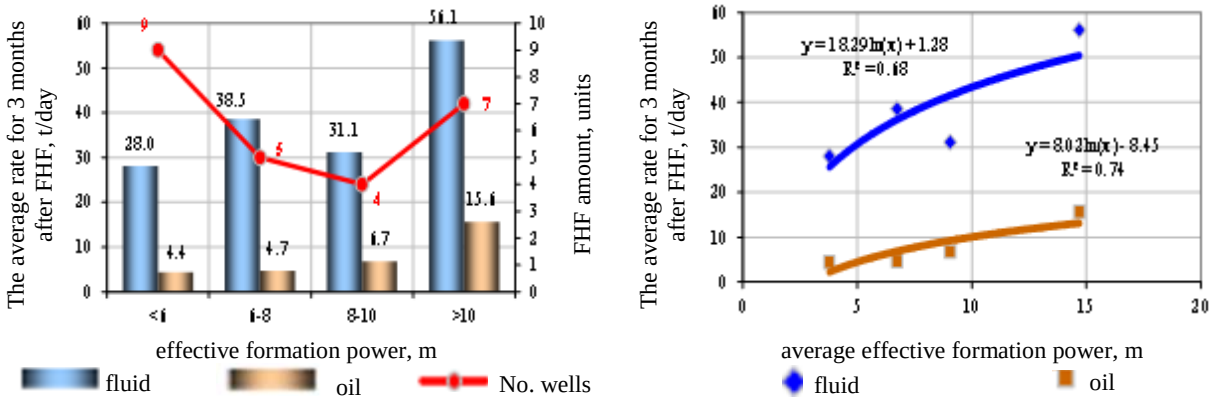

Figure 3. The distribution of flow rates after fracturing arranged by formation thickness intervals and generalized dependence of the flow rates on fracturing of the average formation thickness

4. Conclusion

At the facility AV_{1-2}, 4.9 % of wells were treated with hydraulic fracturing method.

Current incremental oil production amounts to 74.3 th. tonnes or 3.0 t/well due to FHF. The share of additional oil production due to FHF is 2.1 % of general accumulated oil uptake at the facility.

In general, the facility AV_{1-2} witnesses average oil and fluid rate which amounts to 8.0 and 38.5 t/day in 3 months after FHF, while water content makes up 79%. The proppant under use weighted mainly less than 20 t and averaged 12.7 t, the specific mass was less than 4 t/m.

In general, the low result factors of FHF along the formation AV_1^3 (the post-frac fluid rate of 9.4 t, the proppant mass of 6 t) are considered low poroperm properties of the formation: the effective power of the formation made up 1.9 m, permeability - 2.4 mD. According to the data of the formation AV_2, an effective thickness of 10.1 m and a proppant mass of 11.5 t resulted in a post-frac fluid rate of 49.9 t (increase ratio – 5.7 times); when the formations AV_1^3 and AV_2 experienced a combined effect, an effective power in the FHF interval of 7.2 m and the proppant mass of 16.3 t led to 29.5 t/day (increase ratio – 7 times). Average incremental oil rate amounted to 4 t/day over the time of benefit for 2 years at the entire facility AV_{1-2}.

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