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INTENSIFICATION OF OIL PRODUCTION BY HYDRAULIC FRACTURING METHOD FROM TERRIGENOUS RESERVOIRS IN DEPLETING OIL FIELD

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Abstract. The given article presents the results of industrially applied approaches for intensification of oil production from terrigenous reservoirs at late field development stages. In such condition the oil production is influenced by continuous reserves deterioration. The share of oil resources from low productive reservoirs is increasing. Intensification of oil production with hydraulic fracturing approach is carried in South Romashkinskoe Area of Romashkinskoe Field.

The oil extraction in the given area is 86.1% from recoverable initial oil reserves (IOR). The oil recovery factor is 0.458, however according to project the given coefficient was 0.475. The development is characterized by small decrease in oil production rate (less than 2% from IOR), considerable water-cut of well products and a total transition to mechanical exploitation mean.

As a result of hydraulic fracturing the oil rate has increased twice. Thus, according to the results of industrially applied approaches one can evaluate about high efficiency of the given method in depleting reservoir condition, low production rate and high water-cut of well products.

Although hydraulic fracturing is a mature technology that has been used commercially since the late 1940s, the development of unconventional hydrocarbon fields with the combination of directional drilling and multistage hydraulic fracturing in the last two decades gave rise to a substantial progress in both operations and associated modeling (Osiptsov 2017). Both the traditional viscous fluids used in conventional hydraulic fracturing operations as well as the new family of fluids being developed for both traditional and unconventional reservoirs (Barati and Liang 2014).

The South-Romashkinskoe area of Romashkinskoe oil field is in the final stage of exploration. The oil extraction makes 86.1% of initial recoverable resources. Oil recovery factor is 0.458, however according to project 0.475. One of the features of late stage exploration is its continuous deterioration of reserves. The share of low productive reservoir is increasing. In the next several years as a result of significant oil recovery and increasing water-cut production the natural decrease of yearly oil extraction rate has begun. After that, all geological and technical events that were done in field were directed to create the intensified exploration system, which allows to increase the oil production rate. The field started the final – fourth stage of exploration. It is described by slow decrease in oil production (the extraction rate is less than 2% from initial oil reserves), significant water-cut production and the whole switch to mechanical mean of exploitation. The dynamics of oil, fluid and water-cut production are provided by Figure 1.

From the given data it is obvious that in the beginning period the area has been explored at very low water-cut production rate. It is explained by shutting off the watered wells at comparatively low values (50-60%). At the end of first exploration stage, when the extracted amount of initial oil reserve was 22.7%, the water-cut production was 4.2% and WOR-0.018. The water encroachment rapidly increases after 50% of initial oil reserve extraction. This is explained by depletion and water encroachment of more productive formations and connection of upper formations which are characterized by high heterogeneity and hard-to-recover reserves.

The fluid production is intensively increased due to water and oil production rates, reaching its peak in 1977 with a volume of 11.340 million ton. During 14 years, with decreasing oil production rate, the fluid drainage was almost constant (10-11 million ton) till 1986. Starting in 1987 fluid drainage decreased as a result of focusing process to limit the fluid production by disabling water encroached formations from exploitation, application of cyclic steam stimulation, unbundling development objects and other methods of regulations. To maintain the reservoir pressure in the area water was injected in 1955 and every year the water injection volume had been increasing. However, the injection volume was increased till 1970. Initially, in 1971 the total water injection was compensating accumulated fluid drainage (Figure 1). Thus, the proportion of fluid injection to production in reservoir conditions reached one. The provided data shows that yearly injection was totally compensating fluid drainage. The amount of water injection was decreasing since 1987, thus decreasing fluid drainage. The complex operations to improve the water flooding system and regulating exploitation process allowed to decrease the water injection volume. According to the injected volume of water the pressure of reservoir reached its average. At the end of a year the reservoir pressure was 16 MPa, in the extraction zone – 16.9 MPa. Since 1975 the reservoir pressure was constant with a small fluctuation.

The recoverability of reserves in the horizon D1 is analyzed through formations, rock groups, blocks and whole area.

The highest production rates through the reservoir were from “g1” and “g2”, which extraction from initial reserves was 94.3% and 96.2%, accordingly. The present oil recovery factor is 0.508 and 0.574 respectively. The least produced formation is “D1-a”, with the present recovery factor of only 0.284, while extraction from initial reserves is 61.1%. For other formations of horizon the recoverable reserves are extracted from 65.9% (D1-b1) to 82.9% (D1-b3). The current oil recovery factor varies between 0.299 and 0.423.

Exploitation of oil reserves according to rock groups is also unequal. The most developed reserves belong to high productive non-clay reservoir rocks. The extraction amount is 93.2% from initial reserves. With a big lag the development of high productive clay rocks is run (the extraction from initial oil reserves is 63.4%).

Low productive reservoirs are developed in a special case - when they have a contact with sandstone zone. The extraction from this zones is only 23.5% from initial recoverable reserves. This kind of exploitation relation of reserves according to rock groups is the same through all reservoir and area.

The accumulate oil production from horizon D1 of South-Romashkinskoe area is 135983.8 thousand ton (86.1% from initial recoverable reserves). The oil recovery factor equals to 0.458.

In the period of 2000-2016 the oil production per year was around 320 thousand ton. The extraction rate from initial recoverable reserves per year is 0.2%, from the current reserves 1.32%. Today 60% of production wells work with a production rate of 0.5 to 2 ton oil per day, 6% - more than 8 ton/day. The water encroachment exceeds 2% for 12.5% of production wells and more than 90% for 14.4% of wells. During the development period 330.760 million ton of fluid is extracted and water oil ratio is equal to 1.43.

In order to increase the oil recovery factor of the given object a various approaches are applied for intensification of oil production.

Today in Romashkinskoe oil field, to increase the permeability of bottom-hole zones more than 36 methods are applied (Gubaidullin et al. 2017; Baibekova et al. 2015; Mukhamatdinov et al. 2016). The most common method of Bottom-Hole Zone Treatment (BHZT) in the given area is a hydraulic fracturing. It is a combined technology to treat the Bottom-hole zones with further application of acid compositions with active surface; treating wellbore zones with multifunctional reagents; acoustic-chemical influence; removing clays from bottom-hole zones (with SNPKH 9350); depressed perforations; application of SNPKH 9010 compositions, thermogas chemical influence on reservoir (Vakhin et al. 2015; Varfolomeev et al. 2016; Vakhin et al. 2017).

The BHZT is carried out in all the steps of oil reservoir exploitation to restore and increase rock properties (porosity, permeability and etc.) of bottom hole zones. Thereby the goal of the operation is to increase the efficiency of both production and injection wells.

Among all mentioned methods, hydraulic fracturing gives a maximum techno-logical effect to improve bottomhole zone parameters such as porosity, permeability, hydrodynamic connection between wellbore and reservoir and also covering additional hydrocarbon reserves in case of less permeable rocks. "Stimulated reservoir volume" (SRV) makes it possible for commercial production of shale gas by means of multistage fracturing of horizontal wells (Guo et al. 2014). Laboratory tests using a process simulation device were performed to confirm the characteristics of fracture initiation and propagation in different reservoirs (Yan, Li, and Bi 2011). Hydraulic fracture propagation behavior and geometry through perforated vertical wellbores are studied by a series of servo-controlled tri-axial large-scale fracturing experiments. The experimental results show that the tortuous fracture can be generated by using oriented perforation fracturing technology (Chen et al. 2010).

In many cases, especially in late stages of reservoir exploitation, application of hydraulic fracturing allows to solve problems regarding restoration of hydrodynamic connections between productive reservoir rocks - production wellbores and thus providing to more production of oil reserves. In order to define-determine the efficiency of applying hydraulic fracturing technology in the upper mentioned area two wells are selected: #1777 (in the formation D1-a) and #9405A (in the formation D1-b). The technological results of treated wells are presented in Table 2.

According to the results of industrial experiment provided by figures 2, 3 and Table 2 one can conclude:

The directed fractures in productive formations of given horizon increase the oil recovery more than 30%; Within oil production rise the water encroachment is also increasing by more than 35%; According to upper mentioned conclusions hydraulic fracturing method needs to be combined with isolation of water encroaching sources in empty areas of carbonate reservoirs; Estimation of the effectiveness of hydraulic fracturing was calculated by the methods (Kanevskaya, Diyashev and Nekipelov 2002). The calculation results are presented in Table 3.

Conclusion

This work investigated the application term of hydraulic fracturing method, the well selection criteria, the calculation of hydraulic fracturing process, as well as technological efficiency.

For the well # 1777 the average oil production debit before hydraulic fracturing was 2 ton/day and the average water encroachment was 31.2%. After hydraulic fracturing the debit of oil was 4.19 ton/day. For the well #9405a the average oil production rate before hydraulic fracturing was 3.3 ton/day with an average water encroachment of 18%. After hydraulic fracturing the oil debit was already 7.6 ton/day.

As a result of hydraulic fracturing the oil production rate doubles, for well #1777 598 ton and for well #9405a 1059 ton additional oil production is gained.

Thus, according to applied hydraulic fracturing results we can evaluate the combination of given method with water inflow isolation technology (ASM) as a high efficiency approach in case of significant reserve recovery, low oil debit and high water-cut production.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Table 1. Porosity and permeability properties of D1-a an D1-b1,2 reservoir rocks

Formation	Parameters	Reservoir group			
		1	(l)	2	Average value
A	Porosity	0.214	0.188	0.148	0.188
	Permeability, um^2	0.844	0.273	0.076	0.446
	Oil saturation	0.859	0.773	0.696	0.792
$B_{1,2}$	Porosity	0.214	0.190	0.149	0.188
	Permeability, um^2	0.762	0.304	0.063	0.376
	Oil saturation	0.853	0.772	0.687	0.771

Table 2. The technological results of treated wells

№ wells	Data	Oil production rate, ton/day	Water encroach croach-ment,%	Oil production rate, ton/month	Water production rate, ton/month	Accum. oil, ton
1777	01.01.2016	1.89	26.6	56.70	15.08	56.70
	01.02.2016	1.89	26.6	56.70	15.08	113.40
	01.03.2016	2.09	36.0	62.70	22.57	176.10
	01.04.2016	2.01	33.0	60.30	19.90	236.40
	01.05.2016	1.98	34.0	59.40	20.20	295.80
	01.06.2016	1.98	34.0	59.40	20.20	355.20
	01.07.2016	4.10	50.0	123.00	61.50	370.0241
	01.08.2016	4.50	51.8	135.00	69.93	412.428
	01.09.2016	4.19	51.1	125.70	64.23	443.4947
	01.10.2016	4.25	50.5	127.50	64.39	469.6158
	01.11.2016	4.15	51.3	124.50	63.87	491.5871
	01.12.2016	3.95	58.5	118.50	69.32	510.7794

9405A	01.01.2016	3.64	15.1	109.20	16.49	109.20
	01.02.2016	3.33	22.9	99.90	22.88	209.10
	01.03.2016	3.37	15.6	101.10	15.77	310.20
	01.04.2016	3.31	16.8	99.30	16.68	409.50
	01.05.2016	3.32	16.2	99.60	16.14	509.10
	01.06.2016	3.06	20.9	91.80	19.19	600.90
	01.07.2016	8.16	35.00	244.80	85.68	652.4495
	01.08.2016	8.09	38.10	242.70	92.47	730.7942
	01.09.2016	7.34	38.60	220.20	85.00	786.9909
	01.10.2016	7.34	38.42	220.20	84.60	833.719
	01.11.2016	7.34	40.30	220.20	88.74	874.261
	01.12.2016	7.34	41.20	220.20	90.72	909.8833

Table 3. The calculation results

Accumulated production without hydraulic fracturing, ton		Additional production after hydraulic fracturing, ton	
1777	**9405A**	**1777**	**9405A**
56.70	109.20	-	-
113.40	209.10	-	-
176.10	310.20	-	-
236.40	409.50	-	-
295.80	509.10	-	-
355.20	600.90	-	-
370.0241	652.4495	108.18	193.25
412.428	730.7942	200.77	357.61
443.4947	786.9909	295.41	521.61
469.6158	833.719	396.78	695.08
491.5871	874.261	499.31	874.74
510.7794	909.8833	598.62	1059.32

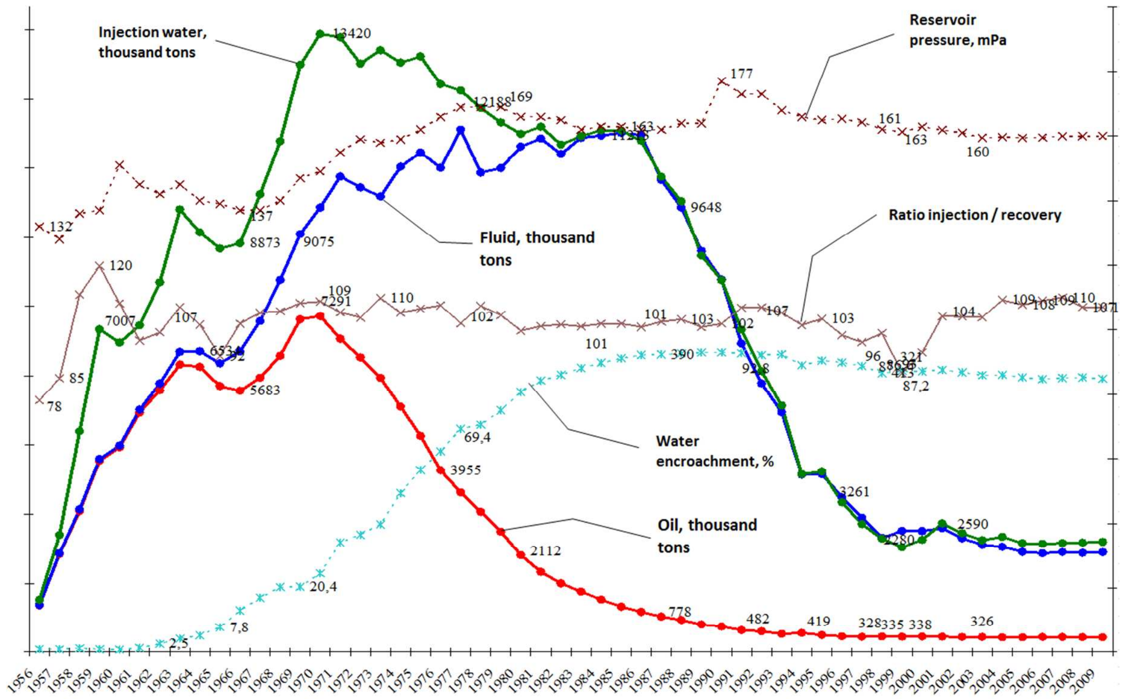

Figure 1. The dynamics of most important technological parameters in South-Romashkinskoe exploration area

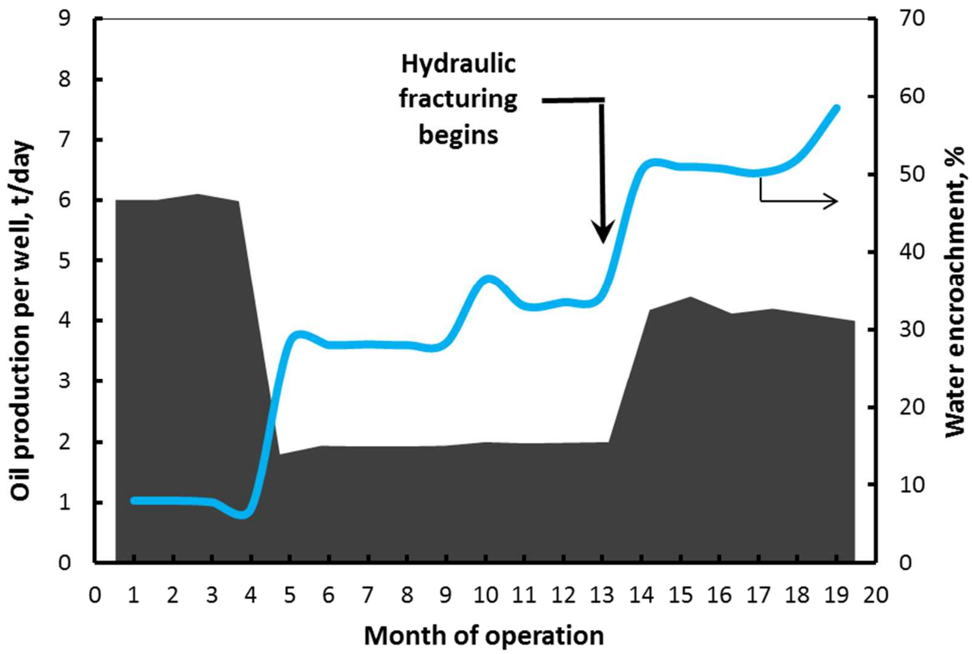

Figure 2. The flow dynamics of well #1777 before and after hydraulic fracturing technology

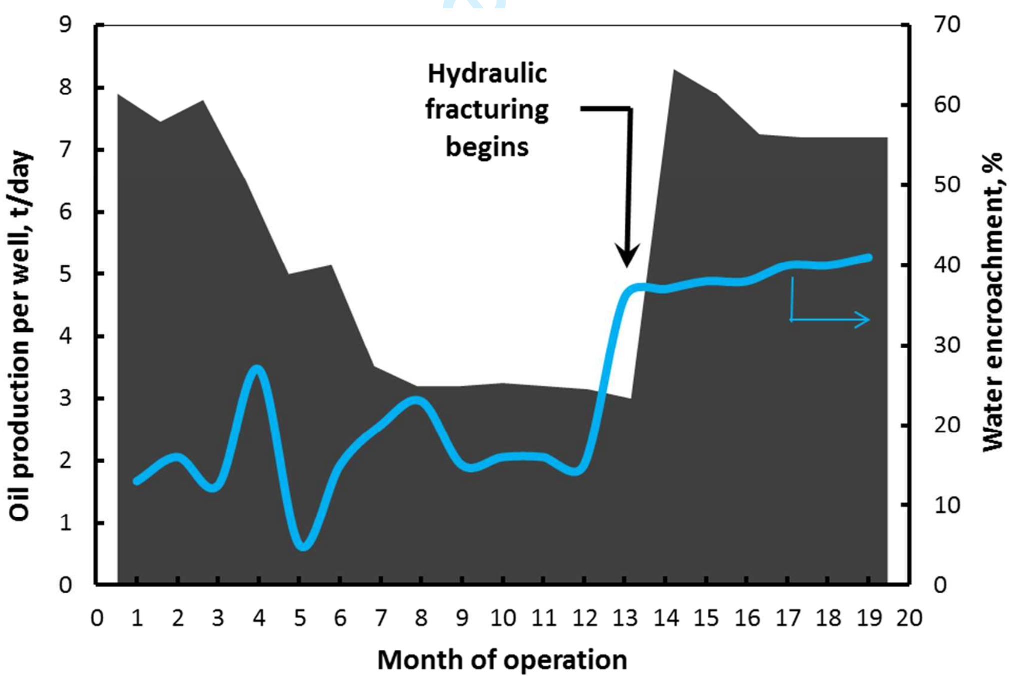

Figure 3. The flow dynamics of well #9405A before and after hydraulic fracturing technology