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Improvement of oil production in low permeability deposits with a system of horizontal wells

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ABSTRACT

The article describes an approach to the production of difficult to extract oil, confined to deposits with low poroperm properties, using a system of horizontal wells and hydraulic multistage fracturing. The main problems that arise during the development of the well are analyzed. A conclusion is reached on the possibility of continuing to apply the method based on the analysis of pilot tests.

KEYWORDS: Upper Jurassic deposit, Horizontal Wells, production of reserves.

Mejora de la producción de petróleo en depósitos de baja permeabilidad con un sistema de pozos horizontales

RESUMEN

El artículo describe un enfoque para la producción de petróleo difícil de extraer, confinado a depósitos con bajas propiedades de poropermo, utilizando un sistema de pozos horizontales y fractura hidráulica de etapas múltiples. Se analizan los principales problemas que surgen durante el desarrollo del pozo. Se llega a una conclusión sobre la posibilidad de seguir aplicando el método basado en el análisis de pruebas piloto.

PALABRAS CLAVE: Depósito del Jurásico Superior, pozos horizontales, producción de reservas.

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Introduction

Today, Russia's oil industry tends to have more reserves, which is associated with a greater number of discoveries and production targets being developed with difficult geological and physical indicators. Traditional production methods used in recent years do not always lead to the expected result.

There is a fairly large number of borehole systems for developing oil and gas fields known, characterized by the usage of vertical and directional wells. Studies on Horizontal Well (HW) development systems are not enough for now (Grachev & Samoylov, 2015).

Therefore, special attention should be paid to studies and introduction of effective production methods. One of such methods is horizontal directional drilling, which has been playing an essential part in the exploitation strategy of various deposits over the past decade. But in conditions of low-permeable reservoirs, even HWs have insufficient oil production for its profitable recovery.

One of the first works in this area considers the placement of HWs and MHHWs (Kolesnik, 2009). The basic principles of placement and calculation of vertical wells development systems are used therewith. Alternative development plans are proposed in that take into account the nature of filtration flows to HW systems (Borisov & Tabakov, 1962; Brekhuntsov et al., 2004). The following systems (process models) for development of oil and gas fields with HWs were recommended as a result of the research:

- linear (single-row and multi-row) systems, when the rows of production and injection wells are parallel, there is a certain distance between the rows;

- block-linear system uses the principle of a parallel-linear system with development blocks;

- radial systems (“fan”, “ring”) are effective for massive deposits.

It is necessary to increase oil production in a cost-effective way to achieve commercial productions. One of these methods is the use of Multi-Stage Hydraulic Fracturing (MSHF) in wells with horizontal tailing-in.

The article gives consideration to experience of using this technology on the example of Upper Jurassic deposits of the Western Siberia field.

1. Oil production in low permeability deposits from a system of horizontal wells

The field was discovered in 1976 and was brought into pilot development in 1988. The main production target of the considered field is the UV_1 producing layer. Horizon UV_1 refers to complex geological objects characterized by significant lithological and facies variation, expressed both in significant number of beds and frequent change of individual permeable partings with non-permeable varieties, very low poroperm properties, and "stairstep" water-oil contacts (WOCs).

The production target includes UV_1^1, UV_1^{2+3} layers. During the analysis of all the available material it was established that the upper UV_1^1 layer is isolated from two layers below, that is ensured by a mature shale break between them. The latter circumstance served as the basis for distinguishing it as an independent reserve estimation target. The UV_1^2 and UV_1^3 layers were included in the second common reserve estimation target, since the thickness of the shale break between them did not exceed 2 m, which does not ensure their isolation during joint development.

The reservoirs of the considered group of strata are represented mainly by medium- and fine-grained sandstone and siltstone. The UV_1 horizon layers were formed under various facies conditions, both shallow marine and continental due to fluvial processes (including transient ones). Transitions between shallow-water and fluvial facies lead to sharp changes in thicknesses and reservoir properties.

The noted lithological and petrophysical features of the formation determined, on the whole, the low poroperm properties of these strata. Reservoir properties vary over fairly wide ranges. Intercommunicating porosity varies from 10 to 20.7% (average of 15.8%). Permeability of strata rarely exceeds 10 mD (average of 6 mD), and the reservoirs with a permeability of more than 20 mD is only 2%.

Disjunctive faults in Jurassic deposits is another factor complicating development of the field. The disjunctive faults were formed in two stages. The first stage took place during the Jurassic period - the beginning of the Early Cretaceous era. A system of faults of the southwestern-northeastern strike was hypothetically formed at this time. In this case, consistent upward decrease in the horizontal displacements along them has been observed. The second stage falls into the time interval covering the Cretaceous period and the Cenozoic era. As a result, there is a system of disjunctive faults oriented in the southeast-northwest direction. Notably, unlike the first system, the intensity of their formation increases up the section. Apparently, their formation was not due to horizontal tension and compression movement of crustal blocks, which determined formation of the structure of this field as well.

The complex structure of the field determines a number of negative problems during its development, the main of which is low well production that results into the unprofitable field development.

Despite the constant scientific support of the field development, the optimal technology for development of reserves has not been found. Traditional methods and approaches, widely tested in classical fields and proposed by project engineers in the early 90s, were inadequate in such difficult geological conditions.

The analysis of the UV_1 development showed that the potentially achievable oil recovery factor (ORF) in the drilled zone is low, about 92% of recoverable reserves, under the existing development system, will remain undeveloped. The constructed characteristic of displacement before Industrial Experiment Works (Fig. 1) shows the inefficiency of the existing development system.

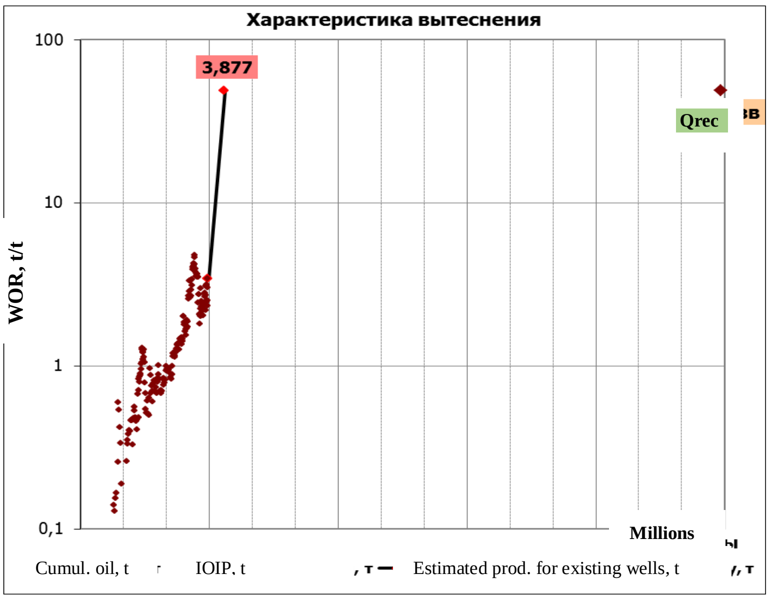

Fig. 1. Characteristic of Displacement for UV_1

The declining recovery trend observed in recent years has been mainly associated with a significant increase in watercut since 1997. The reason for the high watercut of wells was the existing development system, which is rather chaotic and obviously not optimal, both because of the large number of idle wells and because of the "immature" development system. It is also necessary to note a significant decrease in production associated with lower well delivery, which resulted from low performance of the implemented development system. The insignificant effect of the existing Reservoir Pressure Maintenance System (RPMS) led to wells periodic duty. The number of wells operating in this mode increased up to 70% by 2012.

An expert assessment of wells production capacity is required when determining HWs location and plan during design for the development of specific production targets (Aliyev & Sheremet, 1992). presents definition of statistical relationship between the HWs production rates and geological characteristics of productive formation, and technology factors. There is connection found between the initial production rate of a well and such parameters as the length of horizontal wellbore in the formation, opened-up zone thickness, and distance from the lower point of the horizontal wellbore to water-oil contact. The current HW production rate beside these parameters depends on opened-up zone percent and number of productive interlayers crossed by a horizontal wellbore. One of the factors that significantly affect feasibility of the optimal design of a horizontal wellbore is stabilization period of the production rate after the well start-up. It depends on permeability of the formation, presence and degree of pressure communication between the interlayers, thickness and sequence of occurrence of these interlayers, number of interlayers opened-up by a horizontal wellbore, location of the horizontal wellbore, pressure drawdown, etc. Based on mathematical experiments on a reservoir section, it was shown in that when substantiating the optimal length of a horizontal wellbore, it is necessary to provide for a decrease in production rate in time (Purgoyu & Shalomo, 2004). This is due to the peculiarity of oil influx to the horizontal wellbore caused by a change in the geometric shape and dimensions of the drainage zone, since a significant change in the production rate in time is associated with its size (Steklyanin & Telkov, 1962; Steel et al., 1995).

3D detailed seismic studies were performed on the central area of the main deposit to decide and implement the development system at the field in 2011-2012. Based on the results, a tectonic model of the area was built and 3D position of the faults was determined. Additionally, 3D seismic survey was conducted in the east and north in the field season 2012-2013.

Substantiation of the industrial experiment work site was carried out on a sector geological-hydrodynamic model. The options for well placement and wellbore passage were calculated for various types of section: horizontal, upward, downward, sinusoidal (Romanchev et al., 2013). A well placement system along and across tectonic stress was obtained and substantiated for testing, types of wellbore passage and tailing were determined as a result of constructing the sector geological-hydrodynamic model. The implementation of a "rigid" water flooding system (the ratio of production and injection wells is close to 1:1) without delay in organizing a RPMS, with constant monitoring of well operation modes, proved its advantage. Horizontal well bores were planned to be placed in the UV_1^{2+3} horizon where the main oil reserves are concentrated, and as a result of MSHF, the UV_1^1 layer should be additionally developed. The horizontal well portion length was planned to be 600 m, distance between the rows - 500 m, distance between the wells in a row - 200 m. The MSHF consists of four stages, distance between the ports is 200 m, estimated volume of propping agent per Hydraulic Fracturing is 80...100 tons.

In 2012, Industrial Experiment Works for drilling HWs with MSHF were started at the field. As of 01.01.2015, 15 new Horizontal Wells were drilled at the field (Fig. 2). The start-up production rates confirmed the starting advantages of the HW with MSHF technology for low production formations compared to standard technologies. The average input fluid rate of HW is 180 tons/day, oil - 89 tons/day, average input watercut is about 44%.

Over the entire period of their operation, HWs withdrew a total of 210.3 thousand tons of oil (Table 1). On average, one Horizontal Well accounts for 14.0 thousand tons of oil produced. To date, wells with horizontal tailing-in operate with an average oil rate of 46.2 tons/day, fluid of 84.1 tons/day. Current and accumulated indicators of drilled wells correspond to design, with the exception of the 9G well. The reason for this was the watercut above the planned one, due to primary development of the water-saturated part of the UV_1^3 layer against the following geological factors: improved properties of the UV_1^3 layer relative to UV_1^2, no UV_1^2 - UV_1^3 shale break.

Efficiency of the reserves development by Horizontal Wells is confirmed not only by higher initial oil production rates, but also by accumulated indicators. Indicators for Horizontal Wells in comparison to Directional Wells are presented in Table 2.

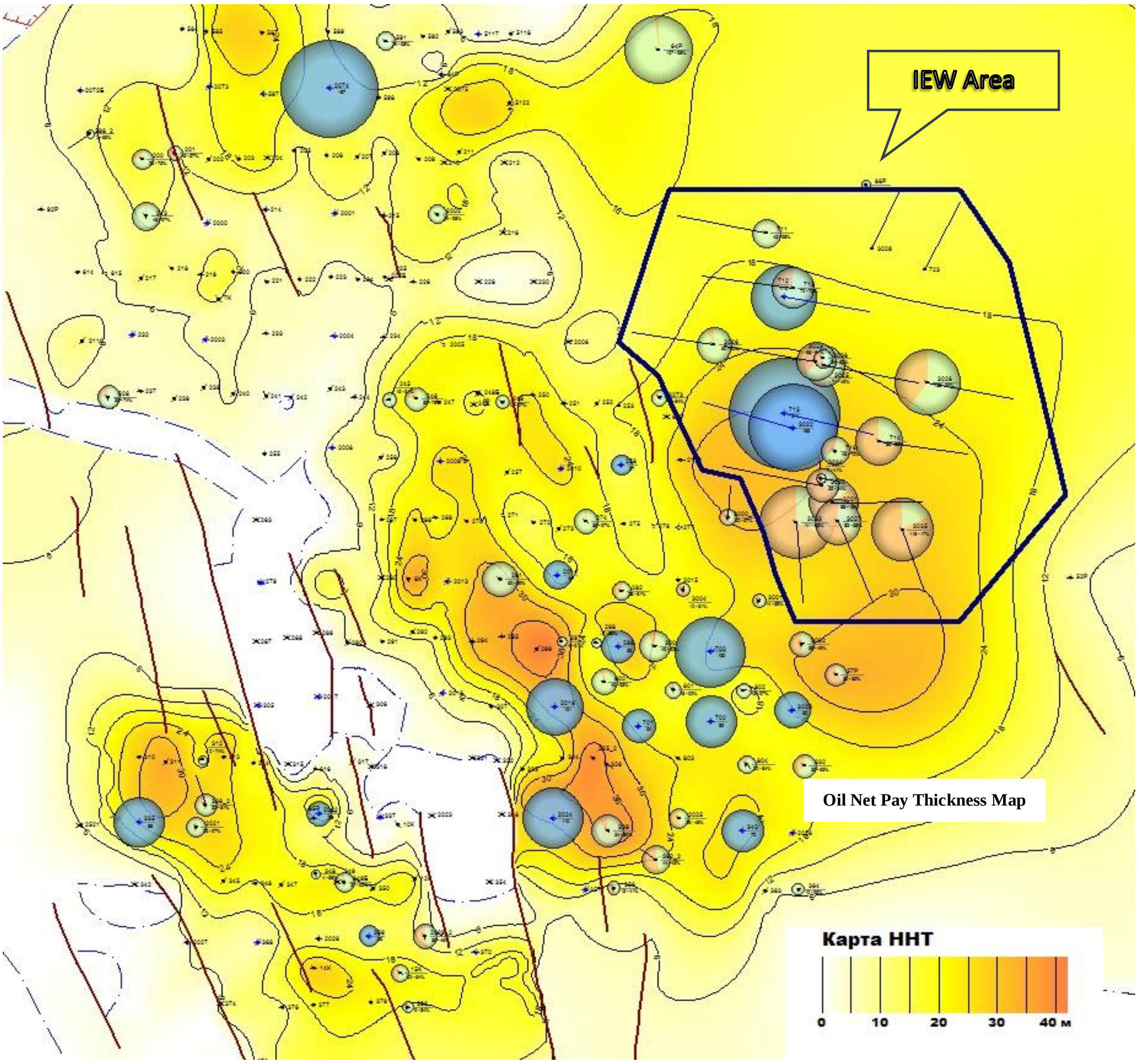

Fig. 2. UV_1 Bubble Map

Table 1. Main Process Parameters of WC with MSHF

Well	Com. Oper. Date	Production Condition of Well	Lift Method	HW Usefull Length	Qty of HF Stages	Start-up mode		
						Qo, t/day	Qf, t/day	WC, %
1G	06.13	switched to RPM	ESP	601	4	103	159	35
2G	07.13	producing	ESP	738	4	107	148	28
3G	08.13	switched to RPM	ESP	671	4	57	127	55
4G	09.13	producing	ESP	716	4	81	107	24
5G	10.13	producing	ESP	734	4	124	181	31
6G	11.13	producing	Nat. flow	656	4	154	217	29
7G	02.14	producing	ESP	714	4	80.1	165	40
8G	04.14	producing	Nat. flow	674	4	148.1	218	16
9G	05.14	producing	ESP	705	4	13.3	206	92
10G	06.14	producing	ESP	693	4	101.8	242	48
11G	07.14	producing	Nat. flow	689	4	60	140	47
12G	08.14	producing	ESP	652	4	14	154	91
13G	09.14	producing	ESP	720	5	132.9	265	38
14G	10.14	producing	ESP	550	4	80.2	168	41
15G	11.14	producing	ESP	674	5	80.1	198	50

Table 2. Horizontal Wells Comparing to Directional Wells

Bore Type	Qty of Wells	Start-up date	Accumulated indicators					Current indicators					
			oil, th.t	oil, per 1 well, th.t	fluid, th.t	fluid, per 1 well th.t	WOR	Qty of wells	oil, th.t	oil, per 1 well, th.t	fluid, th.t.	Fluid per 1 well th.t	WC %
DW	191	May 1988	3746	19,6	7591	39,7	1,0	58	84	0,4	290	0,3	71,1
HW	21	June 2013	380	18,1	649	30,9	0,7	17	170	8,1	305	0,3	44,4

Side-tracking	118	September 2013	72	4,0	141	7,8	1,0	18	46	2,6	96	0,1	51,8
Total	230		4197	18,2	8380	36,4	1,0	93	300	1,3	691	0,7	56,6

Microseismic mapping of Hydraulic Fracturing was carried out in No. 1G HW to analyze the effectiveness of MSHF in the HW. A microseismic study of the treated well No. 1G was carried out using well No. 11. Based on the results of the obtained material, the areas of micro-fractures (areas of the fracture) were visualized (Figs. 3 and 4).

Stage 1 DFIT
Stage 1 Main HF+ Stage 2 DFIT
Stage 2 Main HF + Stage 3 DFIT
Stage 3 Main HF + Stage 4 DFIT
Stage 4 Main HF

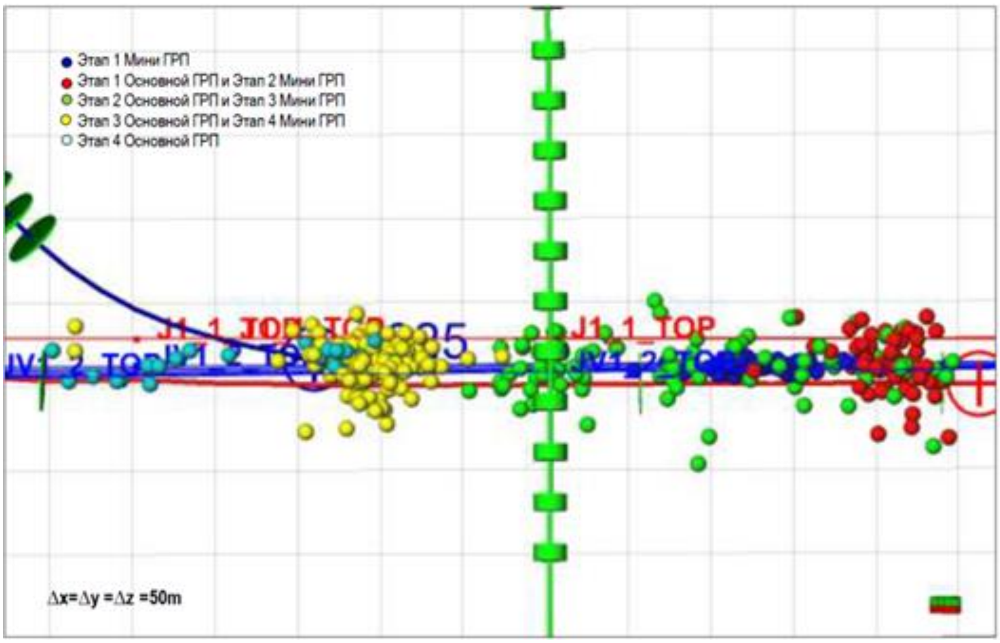

Fig. 3. Vertical Projection (W-E distance)

Stage 1 DFIT
Stage 1 Main HF+ Stage 2 DFIT
Stage 2 Main HF + Stage 3 DFIT
Stage 3 Main HF + Stage 4 DFIT
Stage 4 Main HF

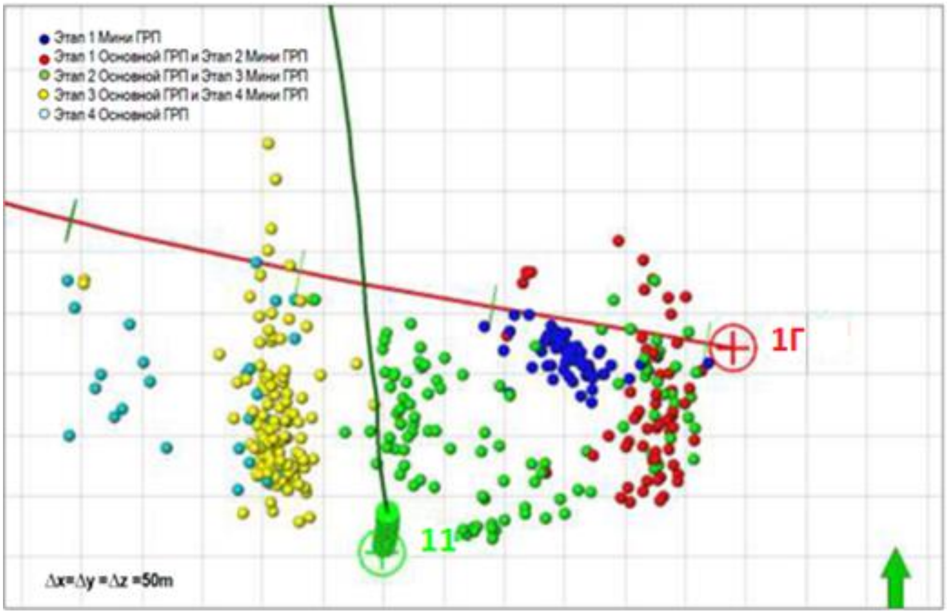

Fig. 4. Horizontal Projection (W-E distance)

When mapping MSHF in the Horizontal Well No. 1G, the following data were obtained:

- average half-length of the microseismic volume of the main stages of HF is about 154 m;
- average height of the microseismic volume of the main stages of HF is about 53 m;
- average number of microseismic events per stage one stage 97;
- average microseismic volume at the stage of 444000 m^3.

As the Figures show, events of the main stages are located opposite the layout ports. All stages of HF (except Stage 1 DFIT), spread orthogonally to the wellbore. Hydraulic Fractures cover the entire stratigraphic thickness of the UV1 layer, which was confirmed by research data. The use of this technology makes it possible to selectively intensify the sections of the horizontal wellbore, which will allow involving 2 UV_1^1 and UV_1^{2+3} layer with different properties into the development.

As a result of Industrial Experiment Works on drilling of Horizontal Wells with MSHF, it was possible to increase production, the percent of reserves involved in development and the oil recovery coefficient, which allowed changing the multiplicity of reserves several times. Fig. 5 shows the actual and design development indicators for the UV_1.

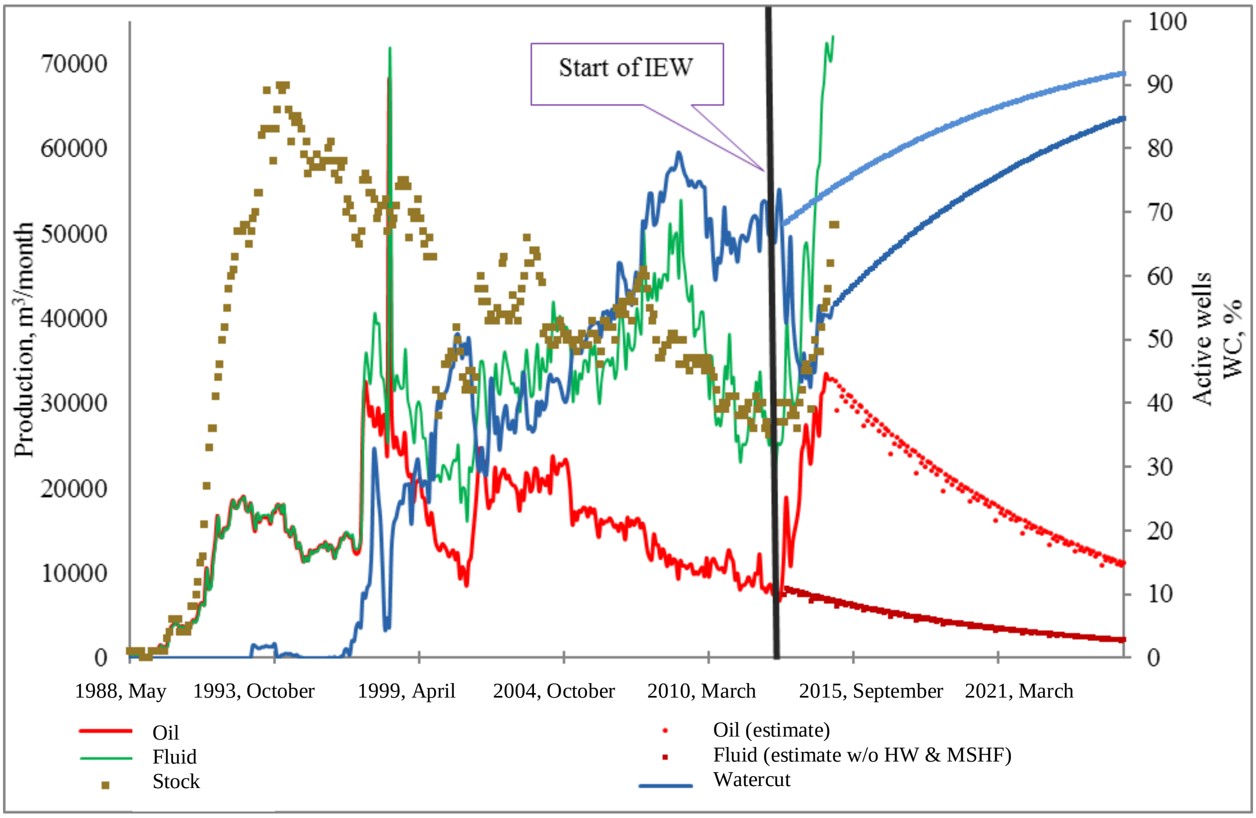

Fig. 5. UV_1 Production Diagram with Arp's Estimate

Conclusion

The introduction of Multi-Stage Hydraulic Fracturing in Horizontal Wells allows for an increase in recoverable reserves, and also allows to recover reserves at the highest possible speed today.

Drilling Horizontal Wells with MSHF shows a higher technological efficiency of putting low-permeability formations into development, in terms of well delivery, which allows recommending this technology for the development of complex fields in Western Siberia.

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