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DESIGNING HORIZONTAL WELLS IN CARBONATE RESERVOIRS USING GEOLOGICAL AND HYDRODYNAMIC MODELING TOOLS

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A B S T R A C T

The paper considers one of the ways to determine the optimal arrangement of production and injection horizontal wells in the Vereisky horizon, which formations are composed of interbedded carbonate and terrigenous rocks. The geological and production analysis of the drilled wells was carried out. Multistage hydraulic fracturing was used to increase the proportion of reserves involved in development. When drilling horizontal wells, using hydraulic fracturing, it is possible not only to increase the drainage zone of the target reservoir, but also to involve the above- and below-lying layers in the development. The performed analysis confirmed the high efficiency of horizontal wells with multistage fracturing. Various variants of arrangement of production and injection horizontal wells were designed and modeled using the geological and hydrodynamic model of one of the object's sections. Based on the performed analysis and calculations, the most effective schemes of well arrangements were selected.

Keywords: carbonate rocks; horizontal well; forecast; modeling; multistage fracturing; injection; pressure maintenance system.

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Due to the increasing share of hard-to-recover reserves, the development of fields with deteriorated reservoir porosity and permeability, and complex geological structure is becoming urgent. It is practically impossible to develop such fields efficiently without the use of modern technologies. The global experience of field development using horizontal drilling shows that this technology makes it possible to increase the technical and economic indicators of the development of low-permeability reservoirs, the coverage factor, and the rate of withdrawal [1-5]. Designing the optimal location of horizontal wells in field with complex geological structure cannot be performed without the use of geological and hydrodynamic modeling tools [6]. The well-known methods and design criteria in such cases may be ineffective. It is worth noting that today it is important to have several standard solutions for the development of the object depending on the development strategy of the company and allocated investments, with the possibility of achieving different rates of withdrawal and maximum oil recovery factor. This paper considers one of the ways to determine the optimal arrangement of production and injection horizontal wells on the Vereisky horizon [7-9].

The Vereisky horizon is an interbedding of carbonate and terrigenous rocks. The carbonate layers Svr-5, Svr-4, Svr-3, and Svr-2, composed of limestone and separated by interlayers of compacted terrigenous-carbonate rocks 1.5 m to 4.5 m thick, possess reservoir properties. The two lower layers, Svr-3 and Svr-2, are more consistent in area. Compared to the rest of the Vereisky layers, they are characterized by greater thicknesses, better reservoir properties, and greater productivity. The Vereisky deposits are covered by a clay-carbonate package of the upper part of the Vereisky horizon, above which lies a thick formation of mostly dense carbonate rocks of the Kashirsky horizon. The average depth of occurrence of deposits of the Vereisky horizon is 850-950 m. The reservoir pressure is 4.34 MPa. The water-bearing rocks in the deposits of the Vereisky horizon are fractured limestones.

Figure 1 shows a typical section of the considered object.

There are 14 production wells with an average flow rate of 3.3 t/day at the Vereisky horizon, with no injection. The current oil recovery factor is 0.04, while the approved one is 0.247. In this regard, the task is to select a scenario for the development of the Vereisky horizon. Most of the operating wells are transit wells drilled for the lower carbonates, the objects are operated as part of the dual completion system.

The Vereisky horizon can be developed according to the following scenarios:

- Connection of the object by the drilled transit stock;
- Drilling by directional wells;
- Drilling by horizontal wells.

As pilot works, two wells were drilled in the Vereisky horizon of this field with horizontal section lengths of 800 m and 400 m (fig. 2). The results of the pilot testing showed the high efficiency of this technology, with starting oil flow rates comparable to those of horizontal wells in terrigenous reservoirs. The high oil flow rate drop is explained by the reservoir pressure drop due to the lack of injection and

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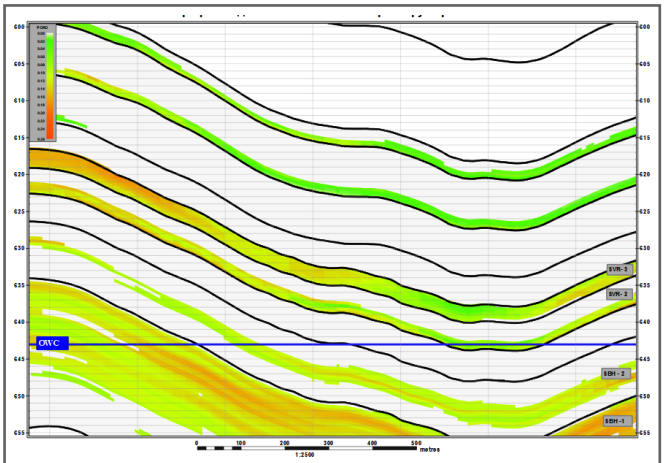


Fig. 1. A typical section of the Vereisky horizon

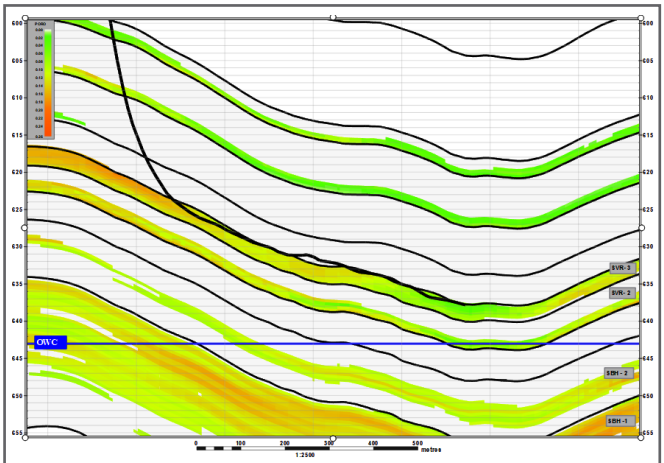


Fig. 2. Schematic profile of a drilled horizontal well

poor connection with the peripheral area [10]. For further development of the field, it is necessary to introduce injection wells and determine the optimal layout of production and injection wells. For this purpose, the constructed hydrodynamic model was modeled [11, 12].

Three options for the arrangement of production and injection wells with different grid densities were calculated in the hydrodynamic model. Figure 3 shows the layout of the wells. The production wells are indicated in red, the injection wells are indicated in blue. In the first scheme (fig. 3a), production and injection wells alternate. In the second scheme (fig. 3b), 2 production wells are placed between the injection wells. In the third scheme (fig. 3c), 3 production wells are placed between the injection wells. Three series of similar calculations were carried out with a distance between wells from 200 to 300 m. These arrangement schemes were selected with the aim to search for the most optimal location of wells for maximum recovery of reserves at various rates of withdrawal.

The operating mode of production wells is set by the minimum allowable bottomhole pressure limit. For injection wells, the maximum injectivity limit is 35 m^3/day, and the maximum compensation value cannot exceed several units to prevent premature watering of wells. All wells are launched with multistage fracturing [13-15].

The field section is represented by several carbonate reservoirs separated by thin interstices. When drilling horizontal wells, only one target interlayer is developed. Hydraulic fracturing is an effective method for increasing the share of reserves involved in the development of reserves. In particular, when drilling the horizontal wells for the Svr-3 reservoir, hydraulic fracturing makes it possible not only to increase the drainage area of the target layer but also to involve the Svr-2 reservoir in the development. In most cases, acid fracturing is used at the carbonate reservoirs. Cracks and caverns created by the successive injection of a highly viscous fluid and acid do not require fixing. The highly viscous fluid prevents acid from entering natural voids, filling them, and at the same time creating the main fracture, moving along which the acid dissolves the rock, as a rule, in low-permeability interlayers along the direction of the fracture. As a result of acid fracturing, the filtration surface and, accordingly, the well productivity increase [16-18].

When performing pilot works described above, horizontal wells were put into operation with multi-stage acid fracturing, which allowed to significantly increase the technological performance. In this connection, horizontal wells in the

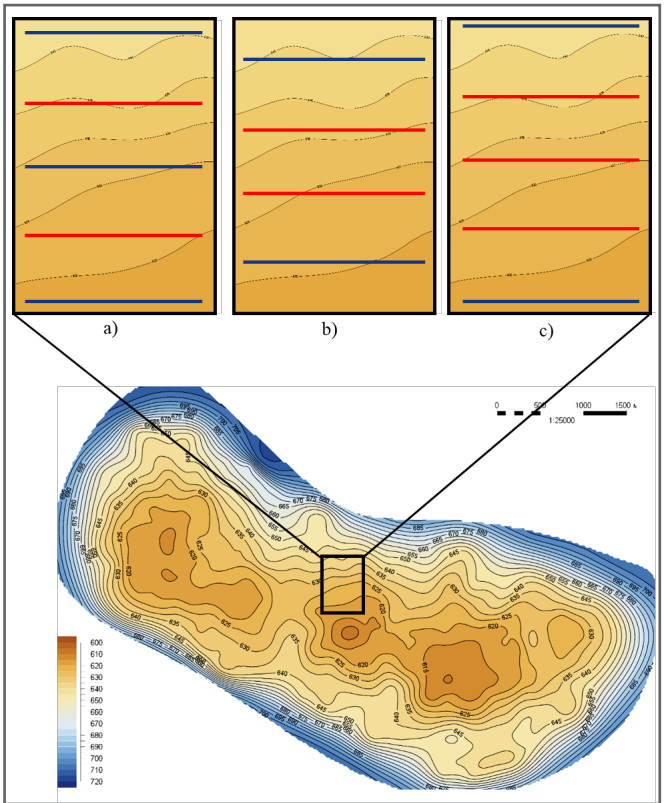


Fig. 3. A segment for calculations and arrangement of wells

forecast variant were launched with hydraulic fracturing. The main stock of wells did not participate in the calculations. The forecast was launched for 10 years.

Figures 4 and 5 and table show the calculation results (cumulative oil production, fluid production, and injection).

The performed calculations show that the maximum cumulative oil production (81.75 ths. m^3) was achieved in the 1st variant of well arrangement, with the distance between the wells of 300 m. This option involved 5 wells (3 injection wells and 2 production wells). At the same time, the maximum specific additional oil production was achieved (16.35 ths. m^3 per well during 10 years). In a similar arrangement option with the distance between the wells of 200 m, the cumulative production in 10 years was 80.66 ths. m^3 and differed only by 1.3%. However, the graph of the cumulative oil production shows that for this arrangement, higher withdrawal rates were achieved. It is explained by the increased grid density.

Figure 6 shows residual reserves maps for the 1st and 3rd options with the 300 m well spacing. For the 3rd option,

the density of residual reserves between production wells is higher, which is associated with a drop in reservoir pressure in the center of the area and, consequently, low withdrawal.

We can conclude that the first arrangement scheme with alternation of production and injection wells is optimal. This option provides a fuller extraction of reserves takes place in this case. At the same time, it should be noted that for this scheme with increased distance between the wells, specific additional oil production per well increases. This indirectly may indicate better economic efficiency.

According to the results of calculations, we obtained several options with almost the same cumulative oil production, but with different rates of withdrawal. Thus, it is possible to implement various development options depending on the company's development strategy and allocated investments. Pilot work on injection will allow one to define the injection efficiency more accurately, to carry out calculations on a full-scale model with real data, and to calculate the final feasibility study of the development project.

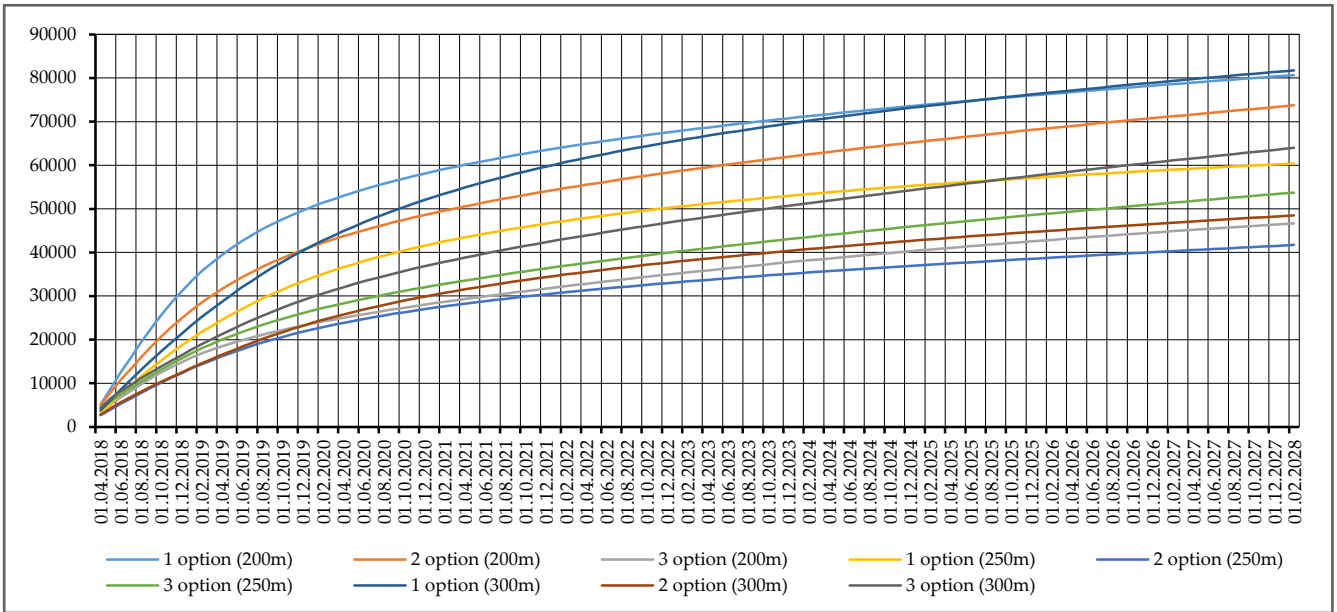


Fig. 4. Cumulative oil production

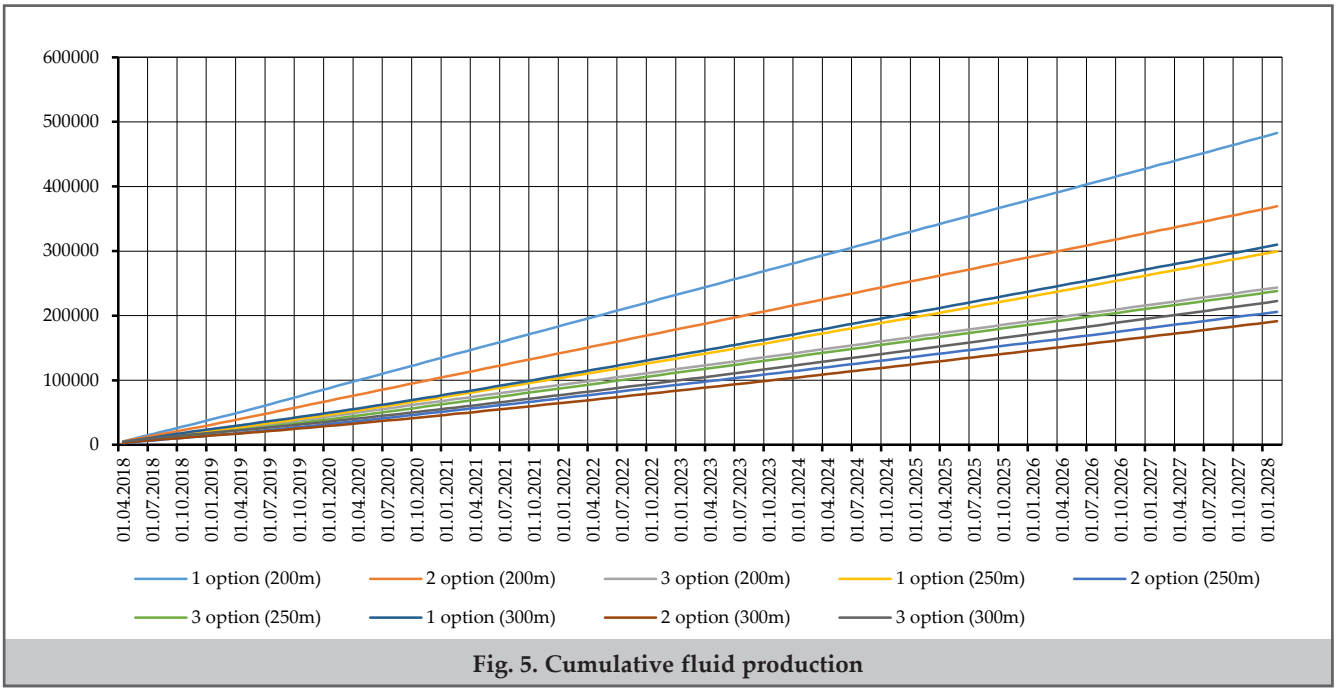
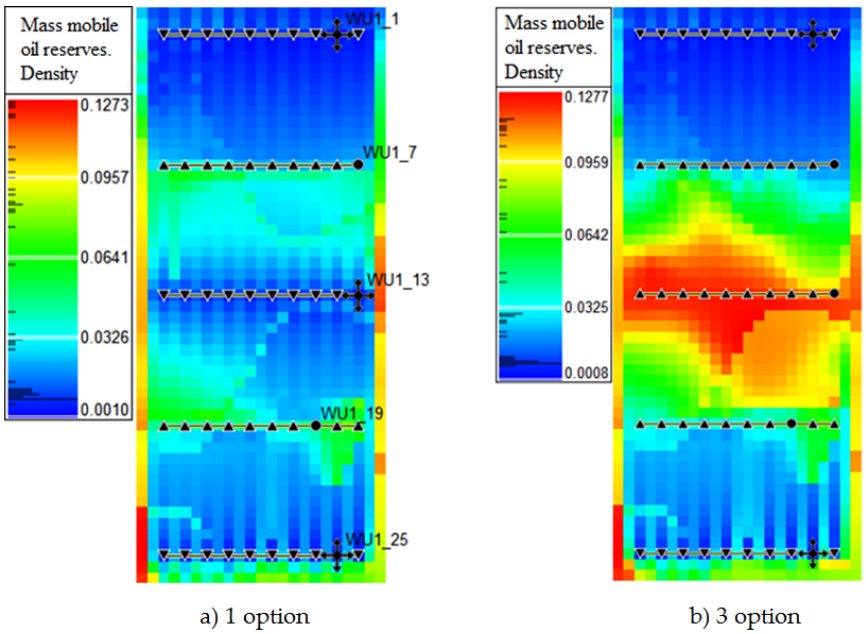


Fig. 5. Cumulative fluid production

Table

The cumulative characteristics									
	1st option	2nd option	3rd option	1st option	2nd option	3rd option	1st option	2nd option	3rd option
Distance between wells	200	200	200	250	250	250	300	300	300
Cumulative oil production, ths.m^3	80.66	73.73	46.69	60.39	41.71	53.73	81.75	48.50	63.98
Cumulative fluid production, ths.m^3	482.70	369.20	243.69	299.58	206.03	238.04	309.92	191.45	222.49
Cumulative injection, ths.m^3	347.65	217.94	238.67	301.29	206.48	234.03	311.54	192.07	220.96
The amount of production wells	3	3	3	2	2	3	2	2	3
The amount of injection wells	4	4	2	3	2	2	3	2	2
Specific oil production per a well, ths.m^3/well	11.52	10.53	9.34	12.08	10.43	10.75	16.35	12.13	12.80



a) 1 option b) 3 option

Fig. 6. Residual reserves density, t/m

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Проектирование горизонтальных скважин на карбонатных коллекторах с использованием инструментов геолого-гидродинамического моделирования

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Реферат

В статье рассматривается один из способов определения оптимальной расстановки добывающих и нагнетательных горизонтальных скважин на верейском горизонте, пласты которого сложены переслаиванием карбонатных и терригенных пород. Проведен геолого-промысловый анализ пробуренных скважин. Для увеличения доли вовлеченных в разработку запасов применялся многостадийный гидроразрыв пласта. При бурении горизонтальных скважин, применяя гидроразрыв пласта, можно не только увеличить зону дренирования целевого пласта, но и вовлечь в разработку выше- и нижележащие пласты. По результатам проведенного анализа подтверждена высокая эффективность применения скважин с горизонтальным окончанием с многостадийным гидроразрывом пласта. Далее в работе спроектированы различные варианты расположения добывающих и нагнетательных горизонтальных скважин, которые были рассчитаны на геолого-гидродинамической модели одного из участков объекта. На основании проведенного анализа и расчетов выделены наиболее эффективные схемы расположения скважин.

Ключевые слова: карбонатные породы; горизонтальная скважина; прогноз; моделирование; многостадийный ГРП; закачка; система ППД.

Geoloji-hidrodinamiki modelləşdirmə alətlərindən istifadə etməklə karbonatlı laylarda üfüqi quyuların layihələndirilməsi

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Xülasə

Məqalədə lay quruluşu karbonatlı və terrigen süxurlarla təbəqələnmiş Vereisk horizontunda üfüqi hasilat və vurucu quyularının optimal yerləşdirilməsinin müəyyənləşdirilməsi üsullarından biri nəzərdən keçirilir. Qazılmış quyuların geoloji-mədən təhlili aparılmışdır. İşlənməyə cəlb edilmiş ehtiyatların payının artırılması üçün çoxmərhələli hidravlik yarılmadan istifadə edilmişdir. Üfüqi quyuların qazılmasında hidravlik yarılmanın tətbiqi ilə yalnız hədəf layın drenaj zonasını artırmaq deyil, eyni zamanda üst və alt layları da işlənməyə cəlb etmək mümkündür. Təhlillərin nəticələrinə əsasən horizontal quyularda çoxmərhələli hidravlik yarılmanın tətbiqinin yüksək səmərəliliyi təsdiqlənmişdir. Obyektin sahələrindən birinin geoloji-hidrodinamik modeli əsasında hesablanmış üfüqi hasilat və vurucu quyuların yerləşdirilməsinin müxtəlif variantları layihələndirilmişdir. Təhlil və hesablamalar əsasında quyuların ən səmərəli yerləşdirilmə sxemləri müəyyən edilmişdir.

Açar sözlər: karbonatlı süxurlar; üfüqi quyu; proqnoz; modelləşdirmə; çoxmərhələli hidravlik yarılma; vurma; lay təzyiqinin saxlanılması sistemi.