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Hydrodynamic modeling of field development using enhanced oil recovery methods

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ANNOTATION
This article discusses a digital geological model, the transfer of borehole data to the geological grid, and the modeling of the technology of alternating steam and water injection. Alternating injection involves the cyclic injection of steam and water into an injection well in high-viscosity oil fields. The essence of this technology is that during the steam injection for 2-4 months, the formation warms up, leading to a decrease in viscosity and an increase in oil mobility. Then comes the period of water injection, during which the production of already warmed oil continues and the formation pressure is maintained. For digital geological modeling, the following data were collected, processed and prepared: a list of wells that open the object of modeling, coordinates of wellheads, well altitudinal data, inclinometry of well trajectories, GMS data on wells, analysis of wells drilled with core sampling, and digitized seismic data (structural surfaces on the roof of stratigraphic horizons, parameter maps, contact surfaces, faults, structural maps on the roof of target horizons with faults, isochron maps, velocity maps).

Keywords: modeling, well, analysis, core sampling, hydrodynamic study.

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Introduction

Evaluation work on alternating injection steam and water was carried out on the basis of geological and hydrodynamic modeling, by creating a thermal composite model of the selected site. A digital geological model of a field is a representation of productive formations and their host geological environment in the form of a set of digital data in a three-dimensional grid of cells.

The project of geological modeling of the sectors of the development objects of interest was created in the modeling program Petrel of Schlumberger, then the collected, processed and prepared data was loaded into it.

Experimental part

The geological model of the sector of the western section includes three productive horizons of the Lower Cretaceous deposits: A, B, and C. All deposits are oil [1].

The simulation consists of the following procedures:

1. Download all available data, including interpreted GMS, seismic, and sampling data;
2. Correlation and construction of a structural framework taking into account discharge violations;
3. Distribution of lithology and FCP [2].

A fragment of the horizontal correlation scheme is shown in Figure 1.

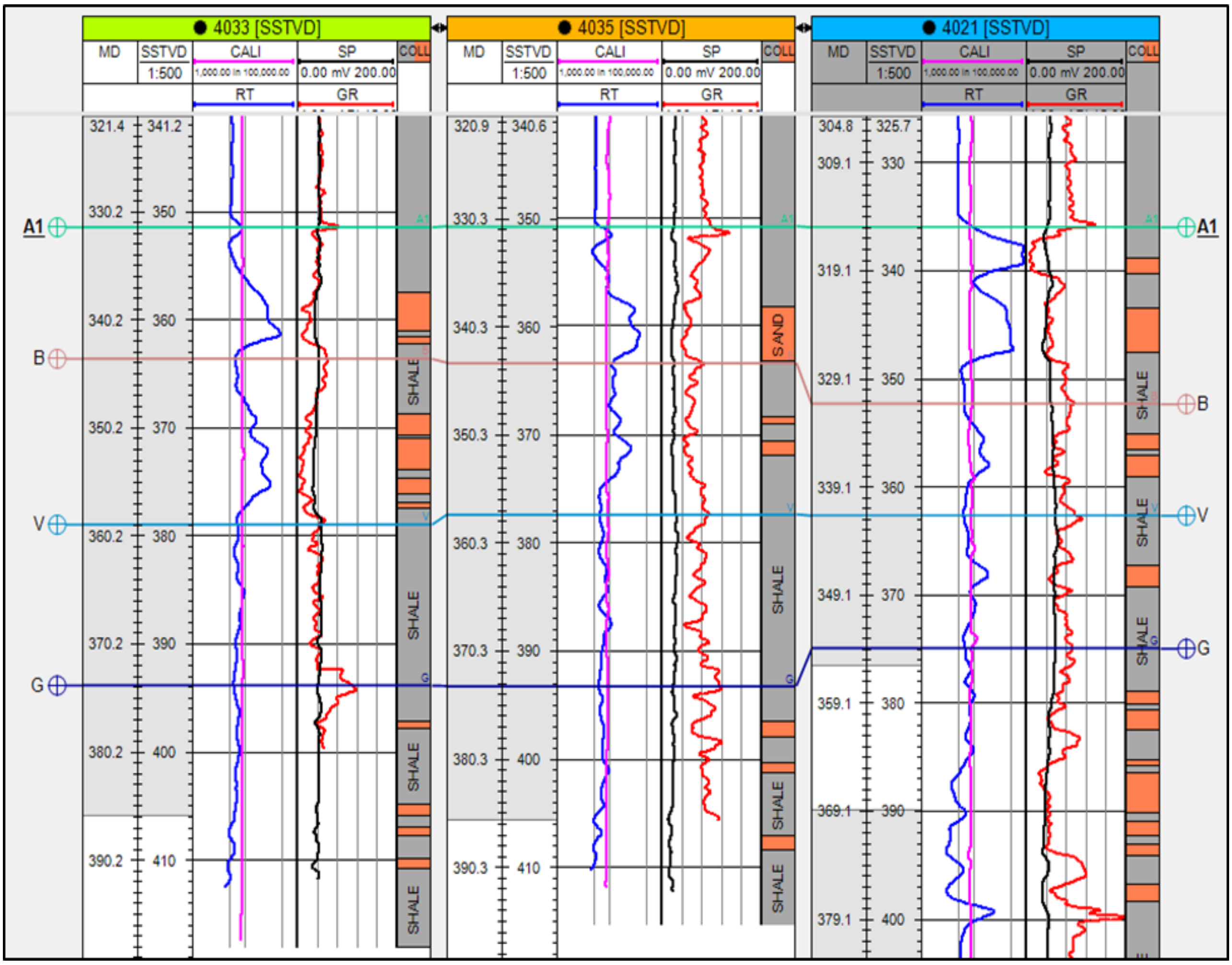

Figure 1 - Fragment of the correlation scheme for wells No. 4033, 4035, 4021

Structural modeling

The fundamental stage of geological modeling is the creation of a structural framework. Sequentially, the modeling process using a structural framework looks like this:

Construction of structural maps on the roof of horizons using stratigraphic chops (markers) on the roof of formations in wells.

Building a fault model. According to the available interpretation data, a fault model is constructed, in which each fault is represented by a surface, and these surfaces are correctly connected to each other in the intersection area.

The final stage of structural construction is the conversion of the structural framework into a 3D model consisting of cells of a given size, within which lithology and petrophysical properties can be distributed based on borehole data.

All structural maps were constructed using the Convergent Interpolation method with a grid size of 25m*25m, the rotation angle is -1080, which corresponds to the direction of the seismic cube [3].

Creating a three-dimensional geological grid. The main stage in modeling is the construction of a three-dimensional grid (a framework that consists of cells with a set of digital geological data).

A properly constructed three-dimensional grid is the basis for building a correct geological model.

The size of the grid cells in the plane during geological modeling is 30x30 meters for all horizons. The number of vertical cells was chosen in such a way that the cell size was on average about 0.6 meters [2]. Such grid sizes are most optimal when constructing geological models, since on the one hand they are more comparable to the sampling step of GMS curves, and on the other hand they provide an acceptable number of cells in terms of calculation time. Discontinuous faults were modeled based on the results of 3D seismic interpretation. To avoid cell curvature when modeling tectonic faults in a 3D grid, the zig - zag type faults method was chosen. The grid characteristics of the three-dimensional geological model are presented in Table 1.

Table 1 - Characteristics of the sector grid

Horizon	*Number of cells on the axis*			*Cell size by axis*			*Total number of cells by model*
	Nx	*Ny*	*Nz*	*Dx,м*	*Dy,м*	*Dz average, m*	
A_1	*42*	*55*	*25*	*30*	*30*	*0.6*	*57750*
Б	*42*	*55*	*21*	*30*	*30*	*0.6*	*48510*
B	*42*	*55*	*22*	*30*	*30*	*0,6*	*50820*
total	*42*	*55*	*68*	*30*	*30*	*0.6*	*157080*

Transfer of borehole data to the geological grid. In the future, the results of the GMS interpretation were transferred to the model cells located along the well trajectory. The correctness of their transfer was checked visually on the well section for each well. To create the average values of the lithology, the Coll curves were taken, for the PHIE porosity [2, 5].

Lithological modeling. To distribute the value of a continuous cube of facies in the inter-well space, we used the deterministic interpolation method Indicator kriging available in Petrel. In the constructed facies cube, the parameter values ranged from 0 to 1, dividing the volume of the simulated area into a collector and a non-collector.

Building a porosity cube. The porosity cubes were calculated after converting the GMS porosity to the grid cells for all wells within the permeable layers and conducting Data analisys. Further, the porosity was distributed using the stochastic Gaussian algorithm SGS (Sequential Gaussian Simulation).

To monitor the quality control of the porosity cube construction, histograms were used, which can be used to compare the results of common, averaged, and original GMS data [1, 2].

Construction of a sector hydrodynamic model of the Western section. The hydrodynamic sector is cut out of the geological model with the preservation of all structural structures and petrophysical properties. All vertical and horizontal geological heterogeneities are preserved.

The creation of a hydrodynamic model was carried out in the tNavigator software product of Rock Flow Dynamics using a composite core (e300) with the thermal option enabled, since steam-thermal treatment of wells (STTW) was carried out at this site and steam was pumped. Table 2 shows the parameters of the western sector.

Properties of fluids. In the sector model, a two-component PVT model was used, using the dependence of oil viscosity on temperature (Table 3).

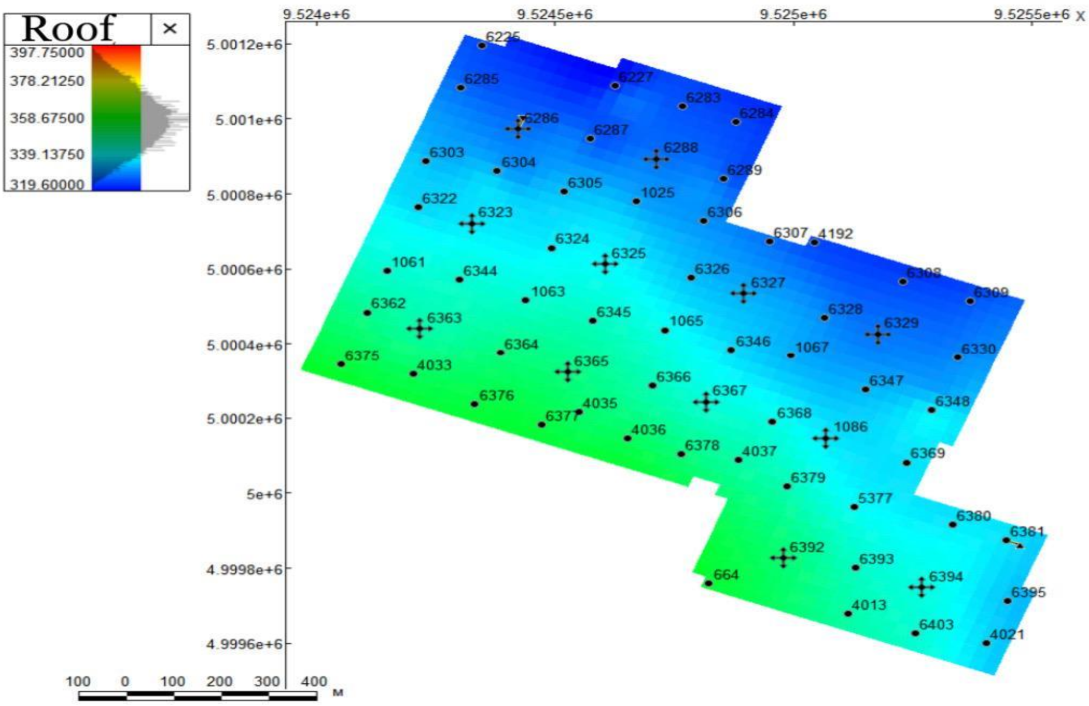

Figure 2 - Sector model of the western section

Table 2 - Sector parameters

Dimension	*30x30x0.6*
Number of wells	*65*
Start date of development	*01.02.2001*

Table 3 - Dependence of oil viscosity on temperature

Temperature, C	*Oil viscosity*
10	*700*
20	*500*
30	*400*
50	*150*
80	*50*
100	*20*
120	*12*
180	*5*
200	*2*
250	*1*
300	*1*

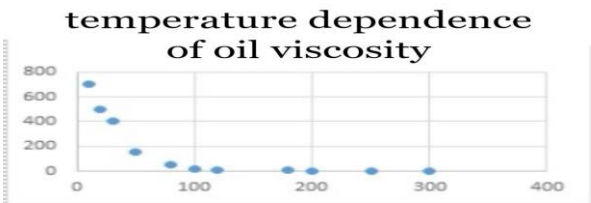

Figure 3. Dependence of oil viscosity on temperature

Table 4 - Results of determining RPP in the "oil-water" system on model № 1

№ modes	*Percentage of fluid in the flow, %*		*Saturation, fractions of units.*		*Phase permeability, µm2*10-3*		*Relative phase permeability, fractions of units.*	
	oil	*water*	*oil*	*water*	*oil*	*water*	*oil*	*water*
1	*0*	*100*	*0*	*1*	*0*	*3021,38*		
2	*100*	*0*	*0,769*	*0,231*	*2818,45*	*0*	*1*	*0*
3	*75*	*25*	*0,694*	*0,306*	*2209,7*	*14,092*	*0,784*	*0,005*
4	*50*	*50*	*0,645*	*0,355*	*1739,01*	*31*	*0,617*	*0,011*
5	*25*	*75*	*0,592*	*0,408*	*1319,1*	*70,46*	*0,468*	*0,025*
6	*10*	*90*	*0,526*	*0,474*	*808,91*	*129,65*	*0,287*	*0,046*
7	*5*	*95*	*0,477*	*0,523*	*532,7*	*183,2*	*0,189*	*0,065*
8	*0*	*100*	*0,367*	*0,633*	*0*	*763,81*	*0*	*0,271*

The boundary value of porosity for Cretaceous and Jurassic sediments is determined by the intersection of the boundary value of permeability with the trend of the dependence of the permeability coefficient on the porosity coefficient, respectively, equal to 20.6% and 18.2% (Fig. 4) [6-12].

Relative phase permeabilities and capillary pressures. Figure 5 shows the relative phase permeabilities used in the model.

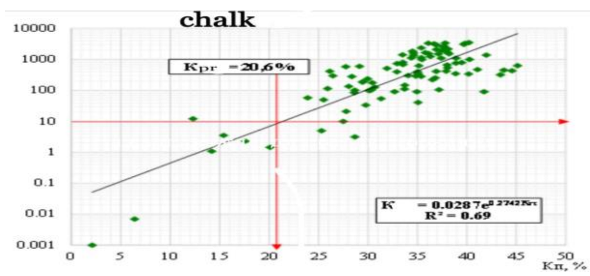

Figure 4 - Dependence of the coefficient of permeability and porosity (chalk)

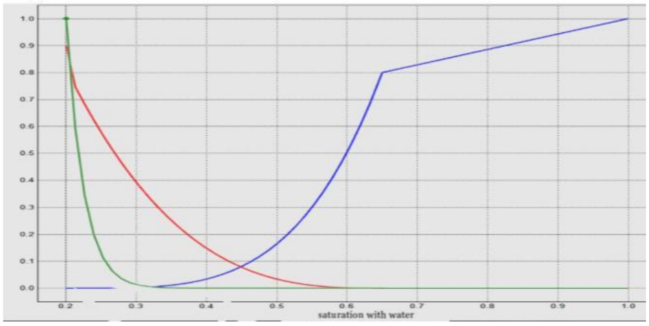

Figure 5 - Relative phase permeability curves for the western section

Permeability

When constructing the permeability cubes, the dependences obtained during laboratory core studies were used. But during the adaptation, the permeability multipliers were used for individual regions of wells, in which the operation was carried out using the technology of non – limiting sand removal to the bottom of the well (CHOPS-the technology of cold production of heavy oil with sand extraction). During the extraction of sand, long channels with increased permeability (wormholes) are formed, which grow from the well into the oil reservoir at distances of 200 m or more.

Modeling of thermal properties. Cubes of specific heat capacity and thermal conductivity were used to model the thermal properties of the rock. Since there are no initial data on these properties, the parameters were selected by reproducing oil production in the areas using steam injection.

In all sections, the values were used: specific heat capacity (HEATCR) in sandstones of 1200 kJ/m3/K and in clays of 1600 kJ/m3/K; specific heat conductivity (THCONR) in sandstones of 1800 kJ/m/day/C and in clays of 3000 kJ/m/day/C.

Adaptation to the development history. Since the purpose of building a hydrodynamic model is to be able to plan development and predict the results of drilling wells and GTE, the model should adequately describe the development process. The results of the hydrodynamic calculations generated by the simulator should be close to the actual development history. Due to the fact that this model belongs to the category of the most complex – thermal-compasional, there are inconsistencies in the downhole adaptation. This is also due to the fact that the model is a sector, which accordingly requires the connection of side aquifers. The results of the adaptation are shown in Figures 7-8.

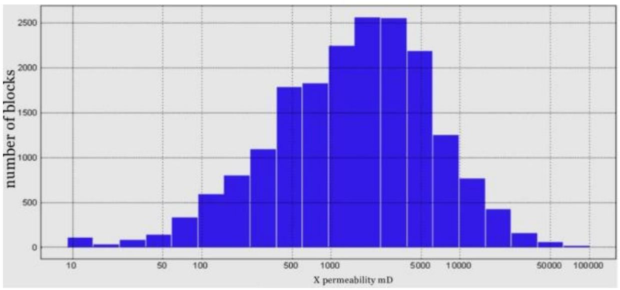

Figure 6 - Histogram of the distribution of the permeability cube in the model

Calculation of forecast indicators for options. After preparing the model and carrying out the adaptation, forecasts of the main technological indicators of the development were made for different schemes of alternating steam-water injection, and different volumes of steam and water. 2 schemes of steam and water injection were modeled, steam with parameters-240C and 40% dryness, water-20C, injection period 3-3 and 1 scheme basic version: a total of 10 options (Table 5).

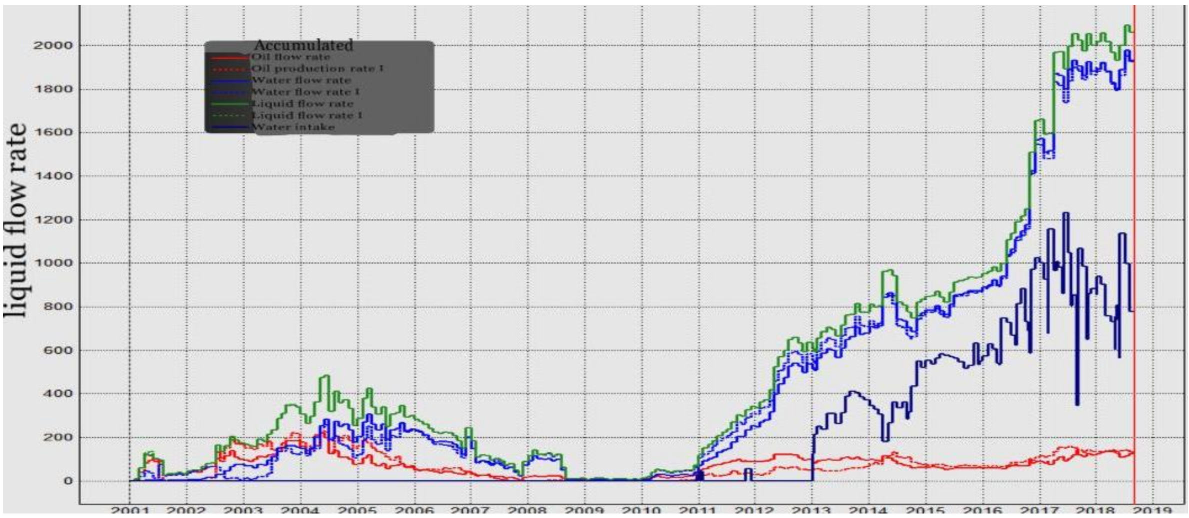

Figure 7 - Results of adaptation by dynamic indicators

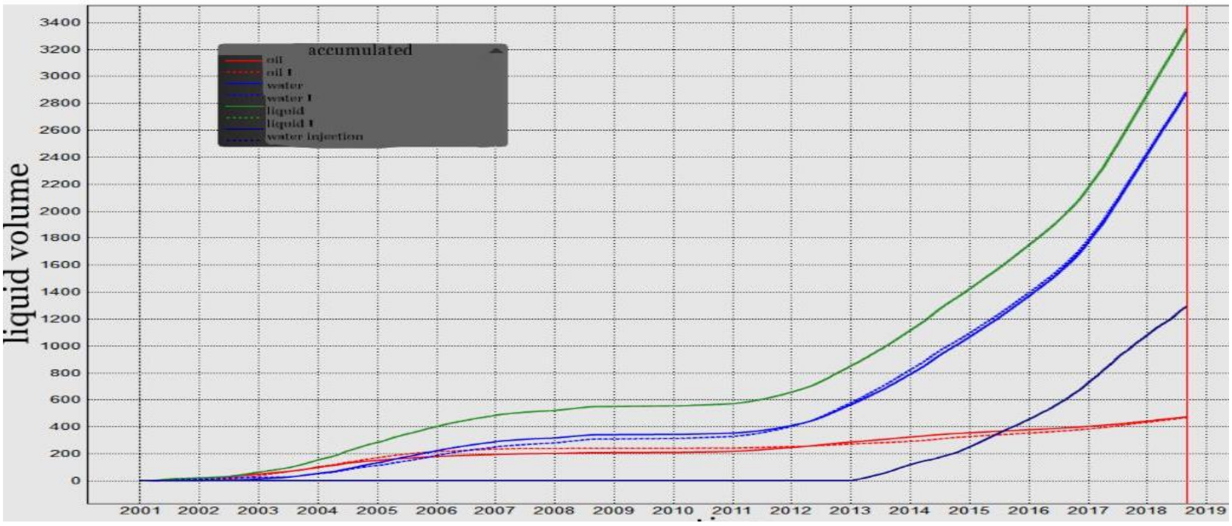

Figure 8 - Adaptation results for accumulated indicators

Table 5 - Forecast by options

Variants	*Loading System*	*Loading period*	*Steam injection volume*	*Steam generators*	*Number of injection wells*	*Water injection volume*
1	*Basic*					
2	*Situational*	*3/3*	*11 t/h*	*2*	*3*	*50% - 100%*
3	*Chessboard*		*11 t/h*	*2*	*3*	*50%*
4	*Chessboard*		*11 t/h*	*2*	*3*	*100%*
5	*Chessboard*		*22 t/h*	*2*	*3*	*50%*
6	*Chessboard*		*22 t/h*	*2*	*3*	*100%*
7	*G shaped*		*11 t/h*	*2*	*3*	*50%*
8	*G shaped*		*11 t/h*	*2*	*3*	*100%*
9	*G shaped*		*22 t/h*	*2*	*3*	*50%*
10	*G shaped*		*22 t/h*	*2*	*3*	*100%*

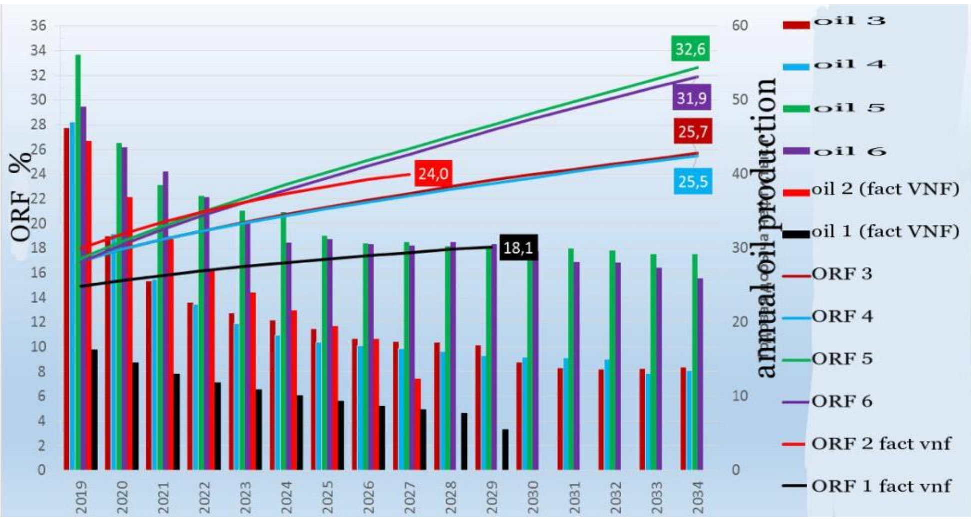

Figure 9 - Dynamics of project oil production and ORF

The results of the forecasts for 10 variants were plotted on the graph (Fig. 9) for the convenience of visual analysis

As can be seen from the dynamics of project oil production and ORF, the highest accumulated production is demonstrated by option 5.

Conclusions

The technology of alternating steam and water injection is aimed at increasing the displacement coefficient in poorly drained zones of the reservoir saturated with high-viscosity oil. This technology was considered both as a replacement for traditional water flooding, and as a replacement for steam injection.

The interim results of the PILOT TESTS on the use of this technology were mixed. In some areas, a significant effect was obtained. For example, in the western section of the first facility, significant increases in production rates and additional oil production were obtained. At the same time, in some areas, a significant effect is not observed.

Thus, from the point of view of technological efficiency, option 5 is preferred - a staggered system of steam and water injection, the injection period is 3-3, the volume of steam and water injection is 22 t/h for 3 injection wells, the volume of water injection is 50% of steam for 3 injection wells, since it provides the highest ORF value (34.1% in 2034).

Conflict of interest. On behalf of all authors, the corresponding author declares that there is no conflict of interest.

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Қабаттың мұнай бергіштігін күшейтетін әдістерді қолдана отырып кен орнын игеруді гидродинамикалық модельдеу

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ТҮЙІНДЕМЕ
Бұл мақалада цифрлық геологиялық модельдеу, ұңғымалар туралы мәліметтерді геологиялық торға орналастыру, бу мен суды кезекпен айдау технологиясын модельдеу туралы айтылады. Кезекпен айдау - тұтқырлығы жоғары мұнай кен орындарындағы айдау ұңғымасына бу мен судың циклдік айдалуын қамтиды. Бұл технологияның мәні - 2-4 ай бойы буды айдау кезінде қабат қызады, нәтижесінде мұнайдың тұтқырлығы төмендейді және қозғалғыштығы артады. Содан кейін су айдау кезеңі басталады, бұл кезде қабаттағы қыздырылған мұнай өндірісі жалғаса береді және қабат қысымы сақталады. Сандық геологиялық модельдеу үшін келесі мәліметтер жинақталып, өңделіп дайындалды: модельдеу объектісіндегі ұңғымалар тізімі, ұңғыма сағаларының координаттары, ұңғыма альтитудасы, ұңғыма траекторияларының инклинометриясы, ұңғымаларды есепке алу деректері, жынысөзек алынып бұрғыланған ұңғымаларды талдау және цифрлық сейсмикалық мәліметтер, олар (стратиграфиялық горизонттардың жоғарғы жағындағы құрылымдық беттер, параметрлердің карталары, жанасу беттері, жер қыртысының жарылған жерлері, мақсатты горизонттардың жоғарғы жағындағы құрылымдық карталар, изохрондық карталар, жылдамдық карталары).
Түйін сөздер: *модельдеу, ұңғыма, талдау, жынысөзек алу, гидродинамикалық зерттеу.*

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Гидродинамическое моделирование разработки месторождения с применением методов повышения нефтеотдачи пластов

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АННОТАЦИЯ
В данной статье рассматривается цифровая геологическая модель, перенос скважинных данных на геологическую сетку, моделирование технологии чередующейся закачки пара и воды. Чередующая закачка подразумевает циклическую закачку пара и воды в нагнетательную скважину на месторождениях высоковязких нефтей. Суть данной технологии заключается в том, что во время закачки пара на протяжении 2–4 мес. происходит прогрев пласта, приводящий к снижению вязкости и увеличению мобильности нефти. Далее наступает период закачки воды, во время которого продолжается выработка уже прогретой нефти и поддержка пластового давления. Для цифрового геологического моделирования проводился сбор, обработка и подготовка следующих данных: список скважин, вскрывающих объект моделирования, координаты устьев скважин, альтитуда скважин, инклинометрия траекторий скважин, данные ГИС по скважинам, анализ скважин, пробуренных с отбором керна и оцифрованные сейсмические данные (структурные поверхности по кровле стратиграфических горизонтов, карты параметров, поверхности контактов, разломы, структурные карты по кровле целевых горизонтов с разломами, карты изохрон, карты скоростей).

Ключевые слова: *моделирование, скважина, анализ, отбора керна, гидродинамическое исследование.*

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