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Application of the block factor analysis in the implementation of hydraulic fracturing during oil fields development

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Abstract

The relevance of this study is due to the need to optimize the oil production process in the fields of the West Siberian province. At the moment, the actual oil recovery factor often deviates from the design values, which leads to inefficient production and loss of resources. Therefore, the purpose of the study is to develop a methodology for optimizing the process of monitoring and regulating an oil field development facility using block factor analysis and de-signing hydraulic fracturing cracks. The work uses methods such as block factor analysis, 3D modeling, hydrodynamic modeling, and mathematical modeling. The result of the study is a developed methodology for optimizing the process of monitoring and regulating an oil field development facility. The article also discusses the main reasons for the deviation of actual oil production from calculated values, including hydraulic fracturing technology. Unsuccessful cases of this procedure and their causes were identified. The features of the block factor analysis tool and the proactive analysis method are described, as well as how to use it at the design and modeling stage of hydraulic fracturing to improve the efficiency of the well-stimulation operation. Successful implementation of hydraulic fracturing allows one to approximate the actual oil recovery factor to design values, which is important for increasing the efficiency of production at the field and optimizing the use of resources.

Keywords

oil field development, oil recovery factor, block factor analysis, modeling, hydraulic fracturing

Introduction

Oil and gas markets around the world are in the midst of a global technological revolution. Large fields where hydrocarbon production has been carried out for several years are at a late stage of development (Prishchepa, 2011). Hydraulic fracturing is becoming an increasingly important factor in oil field development, and the issue is widely discussed in scientific papers (Burenina et al., 2019; Guo et al., 2023; Koplos et al., 2014; Li et al., 2023; Molenaar et al., 2022). Modern oil field development design is based on mathematical, geological and hydrodynamic modeling of hydraulic fracturing to calculate predictive indicators of hydrocarbon reservoir development (Dadwani et al., 2023; Hofmann et al., 2022; Li et al., 2018; Pana et al., 2022; Taghipoor et al., 2021). The resulting mathematical models of oil reservoirs should reflect the actual geological conditions and technological parameters that affect the development process (Liu et al., 2022; Qu et al., 2022; Wang et al., 2022).

The estimated oil recovery factor is determined based on the obtained mathematical models. Technological impact on the oil field affects the geological and technical properties of the reservoir.

To monitor development at the present stage of technology progress, various software and hardware systems are used, in particular, for performing 2D and 3D modeling of reservoirs. To achieve the best result when modeling, a large amount of information is used, including geological, field development parameters, data from geophysical and hydrodynamic studies, physical and chemical properties of reservoir fluid, data on geological and technical activities carried out in the field, etc. A large amount of information is accumulated while the oil deposit is developed, which makes it possible to clarify the existing characteristics of the developed field (Wang et al., 2021; Xu et al., 2022).

Based on this, the key trend is the introduction of proactive factor analysis for hydrocarbon deposit development. The oil recovery factor obtained during field development is lower than the design one. The discrepancy between the values obtained in the modeling software and real data is the reason since the parameters of the reservoir and fluids change from the beginning of development. In addition, there are some factors that cannot be taken into account when modeling.

In practice, there are often cases when reserves calculated at the geological exploration stage differ from reserves specified on the basis of data obtained during field development. It happened that the discrepancies ranged from two to two and a half times. This leads to an error in determining the oil recovery factor (Kolevatov, 2013; Nazarova, 2015).

When developing several paired reservoirs, oil movement between them is possible, which increases the error in the oil recovery factor due to an increase in coverage and waterflood coefficients (Demidov, 2014):

$$ORF = E_d \times F_c \times F_{ff} \tag{1}$$

where: ORF – oil recovery factor;
E_d – displacement efficiency;
F_c – coverage factor;
F_{ff} – formation flooding factor.

A certain influence on the deviation of the actual oil coefficient from the calculated one is exerted by the hydraulic conductivity coefficient, porosity, and permeability of the productive formation and their various combinations (Nazarova, 2015). An increase in water inflow into wells due to their wear and tear at the final stage of development also causes a decrease in the actual oil recovery factor, which must be taken into account at the initial design stage (Ustimov, 2007).

Therefore, we see the need for further study of the impact of various processes on the values of the oil recovery factor obtained in the field, as well as studying the effectiveness of using methods for regulating production rates, as well as developing an integrated approach to bringing the current oil recovery factor to the design one.

Materials and methods

Determination of oil recovery factor – calculation error during design

Methods for calculating the oil recovery factor directly affect the correctness of the geological and hydrodynamic modeling. In the existing mathematical models, a number of authors suggest additional parameters, the determination of which requires separate calculations. A large number of calculations at the modeling stage increases the final error in determining the oil recovery factor.

Existing empirical methods for estimating the predicted oil recovery factor make it possible to consider more factors affecting it. They are based on a statistically averaged approach to determining the oil recovery factor. Due to the fact that empirical methods use field data, the value of the design oil recovery factor adjusted on their basis for specific geological and technical conditions has a slight deviation from the current oil recovery factor (Kaarov, 2019).

The error in determining the estimated oil recovery factor is affected by the number of parameters taken into account in the calculation. The more there are, the greater the error of the factor since each subsequent coefficient adds its own error, but the more accurate each of them is, the smaller the discrepancy between the calculated and actual values of the oil recovery factor. Consequently, material balance as a method for calculating oil reserves has its limitations and variations (Nazarova, 2015; Makarenkov, 2021):

$$O_p \cdot OF_v = OR \cdot OF_{vi} \cdot \Delta P \cdot C_e + W_e - W_p \cdot B_w \tag{2}$$

where: Op – cumulative oil production, m^3;
OFv – oil volume factor, m^3/m^3;
O – oil reserves, m^3;
$OFvi$ – initial oil volume factor;
ΔP – pressure change, MPa;
Ce – effective rock compressibility, 1/MPa;
We – inflow of water from behind the contour, m^3;
Wp – cumulative water production, m^3;
Bw – volumetric ratio of water.

The results of the calculations are shown in Fig. 1.

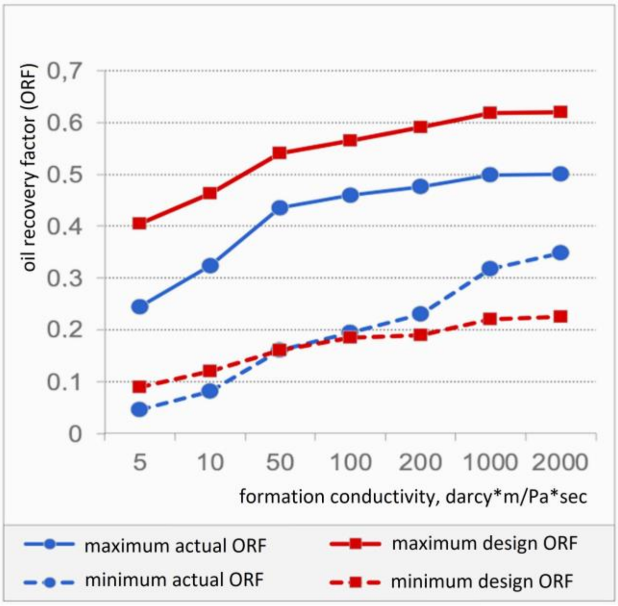

Fig 1. The influence of reservoir hydraulic conductivity on the recovery factor

Method of increasing the actual oil recovery factor to the design value

In the case when current development indicators lag behind the design ones, various methods of influx intensification are used. One of the most common is hydraulic fracturing. Its effectiveness has been proven in practice since after it, the well flow rate increases on average from two to six times. This occurs due to an increase in the drainage radius and the involvement of new interlayers, due to which the coverage factor increases, which leads to an increase in the current oil recovery factor (Salimov et al., 2013; Astafiev et al., 2022).

Mathematical modeling of the resulting cracks is carried out in multi-dimensional form; these models have their own assumptions and limitations, which affect the calculation error. The authors have developed a block diagram for the design of hydraulic fracturing (Fig. 2).

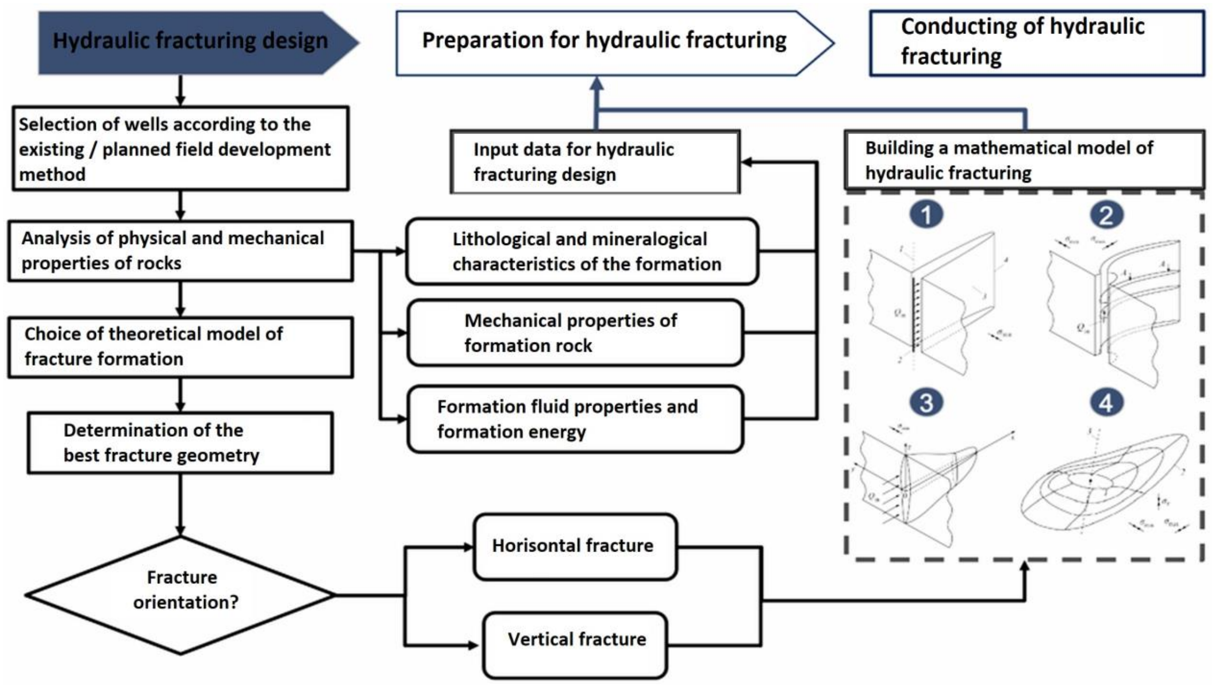

Fig. 2. Block diagram of the hydraulic fracturing design stage: 1 - one-dimensional model, 2 - two-dimensional model, 3 - pseudo-three-dimensional, 4 - three-dimensional model

Currently, leading oil companies offer their software products to solve problems related to modeling cracks during hydraulic fracturing. The most popular programs are: "MFrac" (Baker Hughes), "FRACPRO" (Carbo), etc.

The hydraulic fracturing productivity conditions include the following (Yarkeeva et al., 2018):

- Choosing the low-viscosity fluid to clean the area near the well after hydraulic fracturing;
- Economic efficiency of hydraulic fracturing;
- Skin factor is positive;
- Significant thickness of reservoir formations
- Zones of damage and/or low permeability, stress barriers in the analyzed area;
- Geological oil reserves sufficient for profitable development.

In practice, there are cases when, as a result of hydraulic fracturing, the expected effect of oil flow to the well due to improved permeability in the bottom-hole zone of the formation is not achieved.

An example of such a situation is the unsatisfactory results obtained at the wells of the X_1 oil field. The reservoirs in this field are porous-fractured, and there are also tectonic disturbances. Due to the low level of knowledge of the geological properties of reservoir rocks, the obtained results of the permeability of the bottom-hole zone did not provide the results expected after hydraulic fracturing modeling. As a result, production after stimulation turned out to be less than predicted; in some wells, water broke through to the bottom (Dyk et al., 2014).

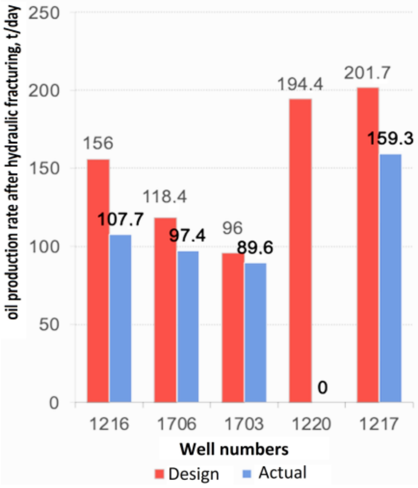

Fig. 3. Estimated and actual oil flow rates at the X_1 field as a result of hydraulic fracturing

The reservoir of the X_2 oil field is represented by the pore type of the supra-coal oil deposit of the X-X-X formation. The effectiveness of hydraulic fracturing is shown in Table 1. One can note a trend toward a decrease in additional production due to the deterioration of the condition of the bottom-hole formation zone (Zimin, 2004).

Tab. 1 Additional annual oil production depending on the number of hydraulic fractures in the X2 field

Year	Amount of hydraulic fracturing in operating wells	Number of hydraulic fracturing, total	Additional oil production, thousand tons
2015	16	37	195.6
2016	2	7	157.5
2017	3	13	117.1
2018	1	2	91.6
2019	1	16	73.6
2020	2	2	62
2021	0	7	46.8
2022	1	12	48.3

To align the actual oil recovery factor with the design one, it is necessary to estimate the described factors when modeling hydraulic fracturing cracks.

A feature of hydraulic fracturing on injection wells is the risk of breakthroughs of injected water into production wells, which causes unpredicted cracks to appear (Baikov et al., 2011). To improve their prediction, the accuracy of fractures of modeling must be increased. All this will improve the results of inflow stimulation, increase the value of the oil recovery factor, and reduce the discrepancy between its actual and design value.

Block factor analysis of the field

To use the method of block factor analysis, it is necessary to divide the deposit into flooding sections (blocks) for further separate calculation of the material balance in each section and distribution of sections depending on the recoverable reserves and the state of the drainage zone. This approach allows you to analyze the current state of field development make forecasts for further production, and the necessary geological and technical measures to maintain development indicators at the design level (Saveliev et al., 2015).

The specificity of this method lies in its inherent algorithm, which can vary depending on the task at hand. Thus, the largest research and technical centers of oil companies use block factor analysis in their practice in the form of an Excel program with the addition of VBA elements and programming in Python and C++.

In contrast to the basic method of block factor analysis, proactive block factor analysis is endowed with greater functionality of interconnected components (Ershov, 2021), which can function separately, taking into account the task at hand. The proactive algorithm includes the following elements:

1. Coordinates of objects.
2. Formation and verification of entered data.
3. Loading well waterflood circuits and selecting PVT characteristics.
4. Selection of injection parameters taking into account reservoir energy and determination of displacement characteristics.
5. Calculation of delay for inter-well response.
6. Forecasting operational parameters for the development of oil wells and the effectiveness of measures to increase production above the base values.
7. Calculation of balance and checking of convergence across blocks, re-adaptation of the model, and conducting factor analysis.
8. Drawing up a report on the block being developed.

Figure 4 shows a diagram of the block factor analysis of the field.

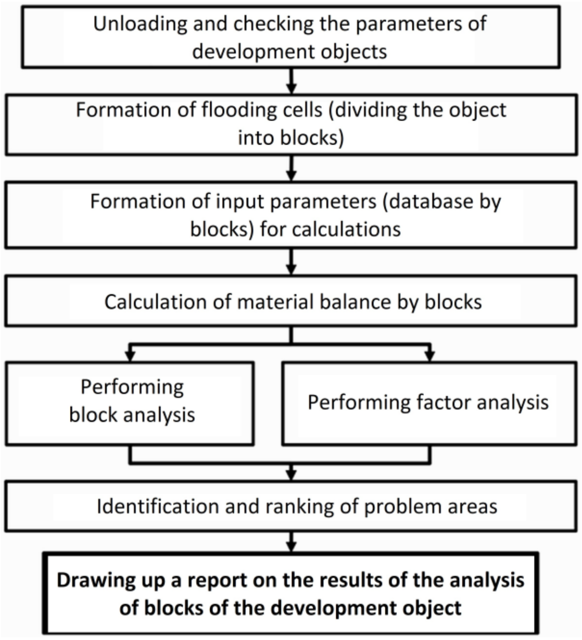

Fig. 4. Schematic diagram of block-factor analysis of the oil field

Results

An approach to the use of block factor analysis in the design of hydraulic fracturing

To use of block-factor analysis (Fig. 5), it is necessary to monitor the correctness of geological and filtration data, as well as development indicators. At the next stage, adaptation mechanisms are applied for material balance, taking into account the parameters that influence the modeling of hydraulic fracturing. The crack models used are refined using a block factor analysis algorithm. As a result, the order of hydraulic fracturing with the greatest efficiency is selected (Kharisov et al., 2018), due to which the selected fracture models are adjusted, which has a positive effect on the result of hydraulic fracturing.

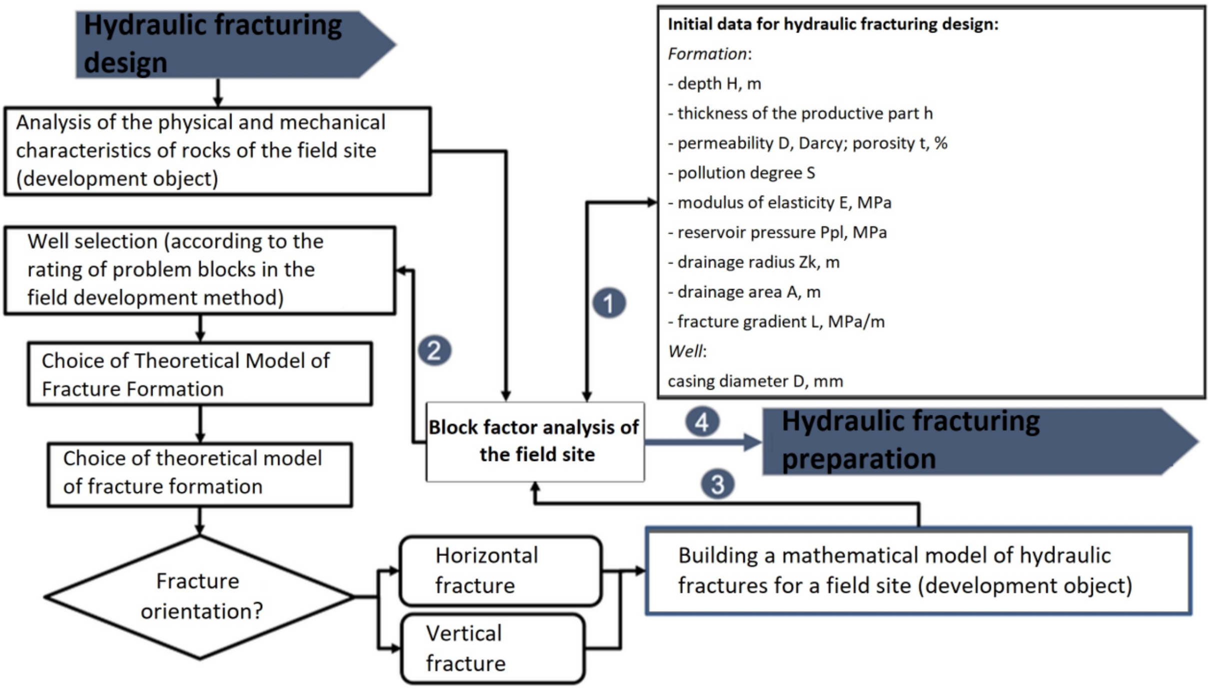

Fig. 5. Approach to taking into account block factor analysis of the field when designing hydraulic fracturing

For this diagram, the following explanations must be given:

1. Waterflood cells are determined and ranked, taking into account the previous stages of oil field development using block factor analysis. As a result, we obtain the data that is input for modeling hydraulic fracturing.
2. To reduce the errors, the hydraulic fracturing model is re-adapted.
3. If a positive result is obtained in predicting hydraulic fracturing and the required level of error is met, we move to the next stage.

A combined method of modeling hydraulic fracturing and block factor analysis was tested at the X3 oil field. The natural reservoir of the analyzed area lies at a depth of 2.3-2.4 km. The oil depth is 2361.2, 2363.4, 2368, 2372.5, and 2376.9 m (Sarvarov, 2009). The well selected for hydraulic fracturing penetrates one of these intervals. Complete information on the geological and physical properties, as well as the physicochemical properties of reservoir fluids, is presented in Tables 2 and Figure 6.

Tab. 2. Initial data for the X_3 field formation

Parameter	**designation**	
Saturation pressure	atm.	102.6
Gas factor	m^3/m^3	75
Effective permeability	millidarcy	0.51
Porosity	%	19
Effective capacity (oil/water-saturated)	m	11.3
Total capasity	m	16.2
Oil viscosity	cPs	1.06
Oil density	g/cm^3	0.832
Volume ratio	m^3/m^3	1.178
General compressibility	1/ atm.	0.0003
Formation temperature	ºC	23
Formation temperature (deep thermometer)	ºC	53
Feeding radius	m	250
Well radius	m	0.072

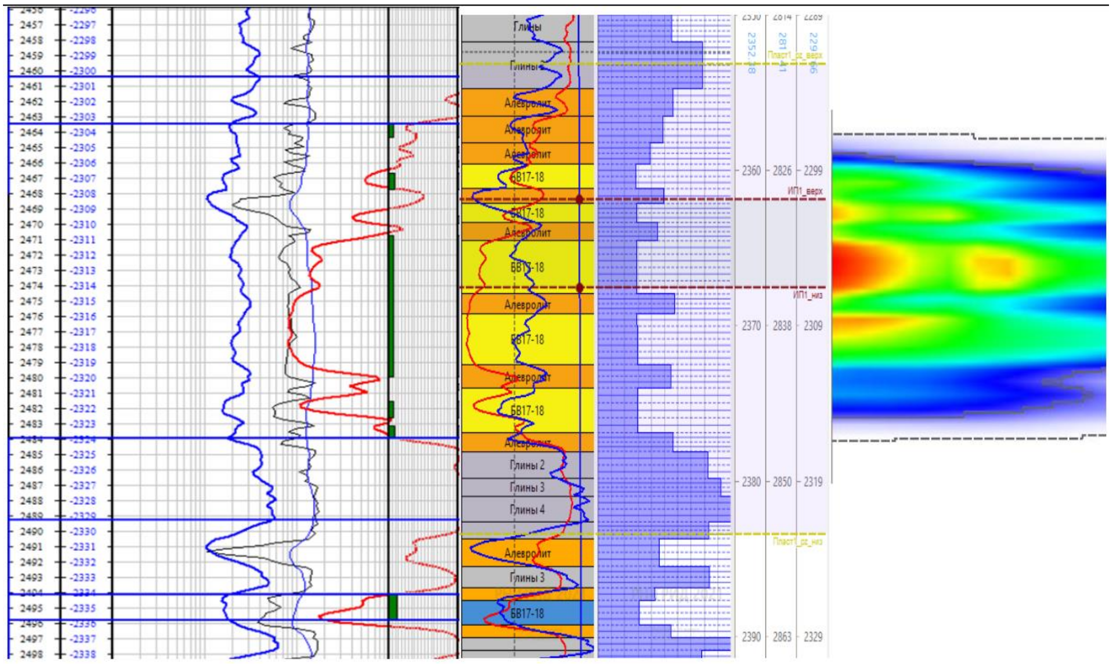

Fig. 6. Geophysical study of a candidate well for hydraulic fracturing of the X_3 field

Using the above data in the RN-GRID software package, modeling of the geometry of hydraulic fracturing cracks was carried out (Figure 7).

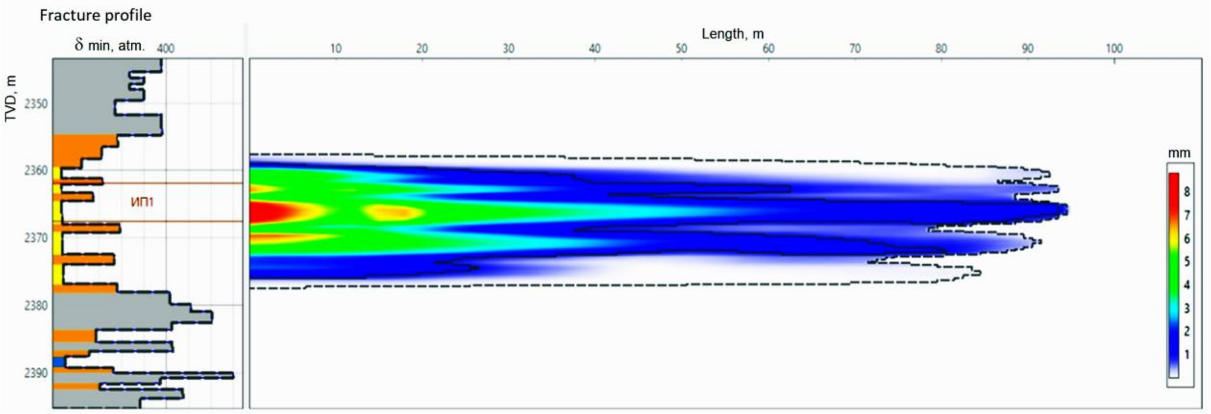

Fig. 7. Hydraulic fracture design profile of candidate well of X3 field

The next step was to check the initial data on the geological and physical properties of the reservoir and the physicochemical properties of reservoir fluids (Perepechkin, 2021). The information obtained was used to adjust the crack parameters (Mishchenko, 2008). The results are shown in Table 3.

Tab. 3. Results of calculated and actual values of fracture geometry and oil production after hydraulic fracturing at the X_3 field

Parameter	Design	Redesign	Actual
Dimensionless fracture conductivity	5.4	7.9	7.6
Skin factor (ideal geometric)	-5.17	-4.80	-4.80
Fixed fracture half-length, m	90	56.3	57
Fixed fracture height, m	15	24.7	24.7
Fixed fracture width, m	2.71	2.94	2.92
Hydraulic fracture half-length, m	94.5	57.3	57.7
Hydraulic fracture height, m	19.4	23.5	23.5
Hydraulic fracture width, mm	8.81	7.39	7.29
Fracture conductivity, mD*m	954	1428	1421
Fracture permeability, mD	277000	415500	415700
Effective pressure (main hydraulic fracturing), atm.	42	23	23
Fluid efficiency (main hydraulic fracturing), %	67	53	55
Oil production rate, m^3/day	23	36.1	35.6

The final crack profile obtained after correction is presented in Figure 8. It is worth noting that the actual profile coincided with the calculated one.

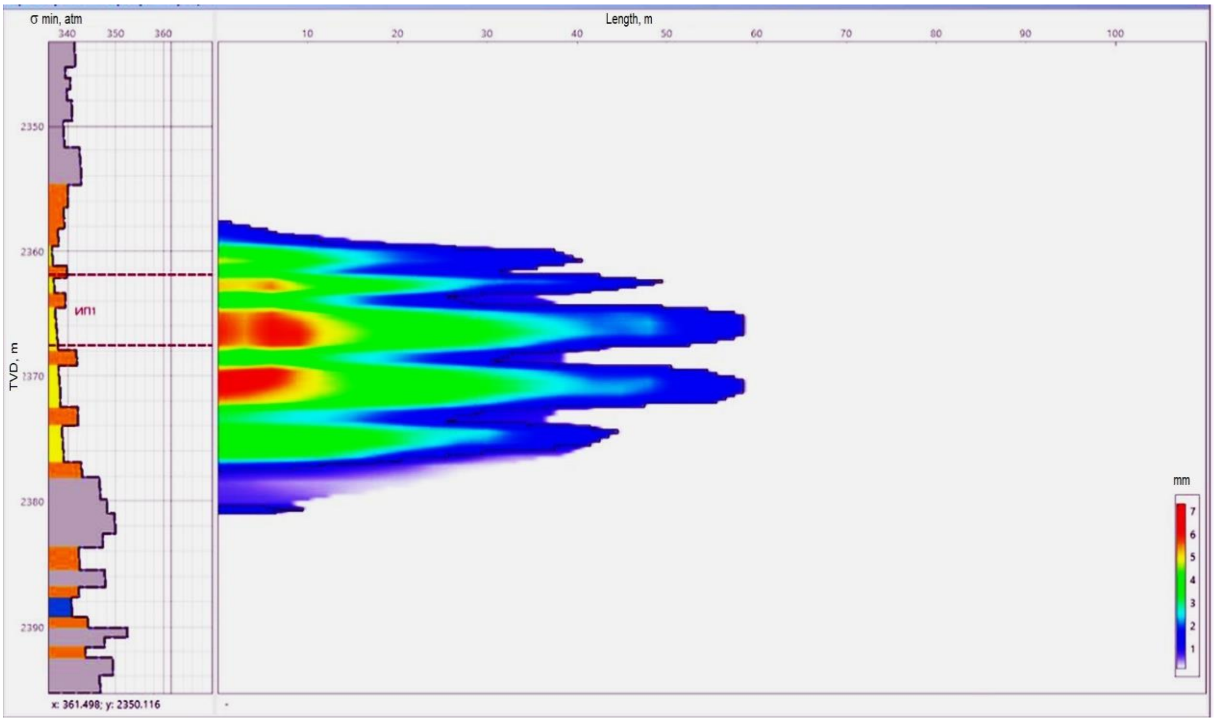

Fig. 8. Hydraulic fracture profile after redesign

As a result of hydraulic fracturing, after using a combined method of modeling hydraulic fracturing cracks and block factor analysis, a positive result was obtained. The well's production rate has tripled. After adjusting the initial data on the geological and physical properties of the reservoir and the physico-chemical properties of reservoir fluids, the parameters of the fractures and the expected increase in well production were clarified. The discrepancy between mathematical calculations and actual results was less than one percent. In addition, thanks to the use of this technique, it was possible to reduce the time spent on selecting the required crack geometry by one and a half times.

Discussion

The main achievements of this research include the following:

- generalized analysis of the problem of maintaining the oil recovery factor at the level of design calculations;
- creation of recommendations and the development of a methodology for an integrated approach to increasing the oil recovery factor to the required values;
- practical joint application of hydraulic fracture design modeling and block factor analysis of the object development.

It is proposed that the calculations of geometric parameters of cracks during hydraulic fracturing be improved, taking into account field data of the oil recovery factor, which is intended to be facilitated by the creation of simulation models of wells. This requires proactive analysis and monitoring of the main parameters of field development, which will allow the identification of priority zones for geological exploration and geophysical studying, as well as improving the selection of candidate wells for hydraulic fracturing. The use of proactive block factor analysis plays a leading role in increasing the reliability of the hydraulic fracturing model, reducing the risk of compromising the integrity of wells, and reducing the oil recovery factor (Figure 9).

The practical application of the block factor analysis module, namely the procedure for verifying the initial data for fracture modeling, made it possible to reduce the time for correcting and selecting the best fracture design for the considered candidate well of the X_3 field. This reduced the difference between the actual results of hydraulic fracturing and the calculated model, as well as increasing the actual oil recovery factor to values corresponding to the design values. As a result, the efficiency of the development of oil fields, including unconventional and hard-to-recover reserves, can be improved.

In the course of the work, we encountered difficulty choosing a program for modeling hydraulic fracturing and incomplete data for calculation. A comparative analysis of software products, taking into account the limitations in computing, led to the use of the Russian software package "RN-GRID", based on the calculation model "PLANAR3D". In addition, difficulties arose when combining the work of the software with the code of the data verification procedure written in the Python programming language used in the construction of a hydraulic fracture model. Due to this, it was necessary to rewrite the code and connect Excel macros to simplify the work.

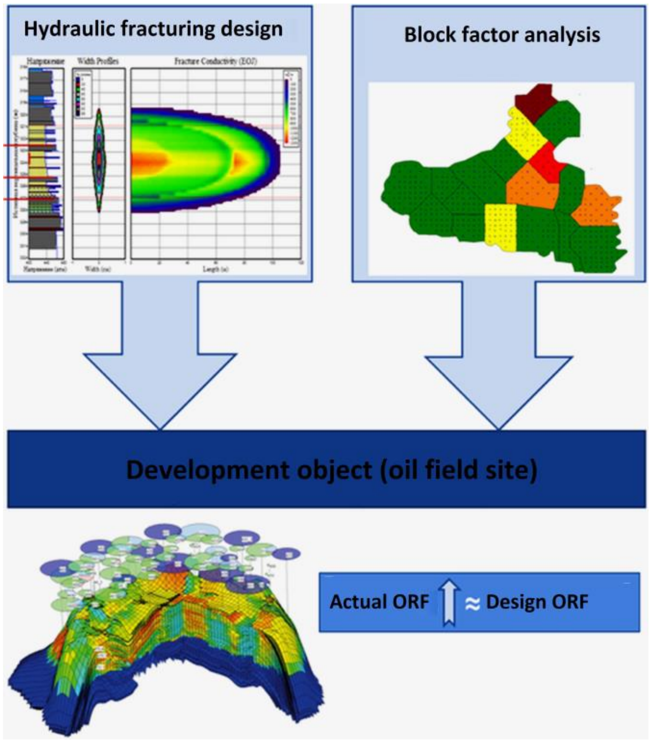

Fig. 9. Brief scheme of an integrated approach to modeling hydraulic fracturing with block factor analysis of the field for increasing the oil recovery factor

Further research is planned to expand the range of applications of combined proactive block factor analysis algorithms for several clusters in order to select candidate wells for hydraulic fracturing and determine the sequence of geological and technical measures by creating a fracture model in each candidate well.

Conclusions

This article discusses the issue of improving the modeling of the oil recovery factor, which plays a primary role in oil field development at the final stage of operation, which is important for most companies engaged in hydrocarbon production. It has been established that a lack of information about the physical and technical properties of the reservoir and well fluids leads to failures in hydraulic fracturing caused by errors in fracture modeling.

In order to improve the quality of hydraulic fracturing with a corresponding increase in the oil recovery factor, ensuring trouble-free operation of wells, block factor analysis acts as a simple tool for modeling individual wells, during the division of areas into blocks (flooding cells), which allows one to relatively quickly identify problem areas and select the most promising candidate wells for hydraulic fracturing.

A practical recommendation for determining crack parameters using the block factor analysis method is to create a block diagram for modeling hydraulic fracturing using the RN-GRID software and the response in the RN-KIN software, which together leads to the development of an integrated approach to increasing the actual oil recovery factor and reducing the error in its forecasting.

References

Astafiev, V.N., and Eltsov, I.N. (2022). The role of geophysical surveys in wells in the evolution of the hydraulic fracturing paradigm. *Problems of collecting, preparing and transporting oil and oil products*, 6 (140), 9-37.

Baikov, V.A., Zhdanov, R.M., Mullagaliev, T.I., and Usmanov, T.S. (2011). Selection of the optimal development system for fields with low-permeability reservoirs. *Oil and Gas*, 1, 84-98.

Burenina, I.V., Avdeeva, L.A., Solovjev,a I.A., and Gerasimova, M.V. (2019). Improving Methodological Approach to Measures Planning for Hydraulic Fracturing in Oil Fields. *Journal of Mining Institute*, 237(3), 344-353. https://doi.org/10.31897/pmi.2019.3.343

Dadwani, A.D., and Shah, M.S. (2023). *Novel Techniques to Prevent Wax Deposition During Hydraulic Fracturing of Low-Temperature Waxy Oil Reservoirs*. Proceedings of Gas & Oil Technology Showcase and Conference, Dubai, UAE, SPE-214193-MS. https://doi.org/10.2118/214193-MS

Demidov, A.V. (2014). Development of hard-to-recover reserves: approaches to the exploitation of two layers vertically connected by a permeable interlayer. *Bulletin of the Perm University. Geology*, 3 (24), 66-81.

Dyk, N.V., Ivanov, A.N., and Karapetov, R.V. (2014). *Technological scheme for the development of the central section of the White Tiger and Dragon deposits*. Vung Tau: PC "Vietsovpetro" NIPImorneftegaz, 282 p.

Ershov, A.O. (2021). *Estimation of oil production potential based on proactive block factor analysis*. PhD Thesis. Peter the Great St. Petersburg Polytechnic University, St. Petersburg, 162 p.

Guo, T., and Chen, M. (2023). Special Issue "Petroleum Engineering: Reservoir Fracturing Technology and Numerical Simulation". *Processes*, 11(1), 233. https://doi.org/10.3390/pr11010233

Hofmann, M., Al-Obaidi, S.H., and Khalaf, F.H. (2022). Modeling and Monitoring the Development of an Oil Field under Conditions of Mass Hydraulic Fracturing. *Trends in sciences*, 19(8), 3436. https://doi.org/10.48048/tis.2022.3436

Kaarov, Zh.Z. (2019). Methods for predicting the oil recovery factor during development on the example of the Taylakovskoye oil field. *Achievements of science and education*, 5 (46), 106-121.

Kharisov, M.N., Karpov, A.A., Petrov, S.V., and Darius, S.D. (2018). Algorithm for determining the optimal displacement characteristics. *Oil industry*, 5, 56-59.

Kolevatov, A.A. (2013). *Increasing the accuracy of forecasting the permeability of carbonate reservoirs according to well survey data*. PhD Thesis Abstract. Moscow, NUST MISiS, 22 p.

Koplos, J., Tuccillo, M.E., and Ranalli, B. (2014). Hydraulic fracturing overview: How, where, and its role in oil and gas. *Journal of American Water Works Association*, 106(11), 38-56. DOI: 10.5942/jawwa.2014.106.0153

Li, D, Zhang, X, and Chen, Z. (2023). Study on the Hydraulic Fracturing of the Inter-Salt Shale Oil Reservoir with Multi-Interfaces. *Processes*, 11(1), 280. https://doi.org/10.3390/pr11010280

Li, Y, Zuo, L, Yu, W, and Chen, Y. (2018). A Fully Three Dimensional Semianalytical Model for Shale Gas Reservoirs with Hydraulic Fractures. *Energies*, 11(2), 436. https://doi.org/10.3390/en11020436

Liu, Y., Wang, F., Wang, Y., Xu, H. (2022), The mechanism of hydraulic fracturing assisted oil displacement to enhance oil recovery in low and medium permeability reservoirs. *Petroleum Exploration and Development*, 49(4), 864-873. DOI: 10.1016/S1876-3804(22)60316-1

Makarenkov, E.S. (2021). Modeling of the water-driven mode of operation of the deposit using the material balance equation. News of higher educational institutions. *Oil and gas*, 1, 316-318.

Mishchenko, I.T. *Calculations for oil and gas production*. Moscow: Oil and gas, 2008. 296 p.

Molenaar, M., Al-Ghaithi, A., Kindi, S., and Alawi, F. (2022). *Performance of 15 Years of Hydraulic Fracturing of Oil Wells in South of Oman*. Proceedings of SPE International Hydraulic Fracturing Technology Conference & Exhibition, Muscat, Oman, pp. SPE-205236-MS. https://doi.org/10.2118/205236-MS

Nazarova, L.N. (2015). Justification of restrictions on the calculated final values of the oil recovery factor when waterflooding is applied. *Territoriya of Oil and Gas*, 3, 86-103.

Pana, I., Gheţiu, I.V., Stan, I.G., Dinu, F., Brănoiu, G., Sudit,u S. (2022). The Use of Hydraulic Fracturing in Stimulation of the Oil and Gas Wells in Romania. *Sustainability*, 14(9), 5614. https://doi.org/10.3390/su14095614

Perepechkin, I.M. (2021). Numerical simulation of hydraulic fracturing in the formulation of PLANAR3D // *Proceedings of the Moscow Institute of Physics and Technology*, 3 (51), 126-142.

Prishchepa, O.M. (2011). Complex method for quantitative assessment of oil and gas resources in oil and gas accumulation zones. Oil and gas geology. *Theory and practice*, 4, 69-84.

Qu, G., Su, J., Zhao, M., Bai, X., Yao, C., and Peng, J. (2022). Optimizing Composition of Fracturing Fluids for Energy Storage Hydraulic Fracturing Operations in Tight Oil Reservoirs. Energies, 15(12), 4292. https://doi.org/10.3390/en15124292

Salimov, V.G., Ibragimov, N.G., Nasybullin, A.V., and Salimov, O.V. (2013). *Hydraulic fracturing of carbonate formations*. Moscow: CJSC "Publishing house" Oil industry ", 472 p.

Sarvarov, A.R. (2009). *Development of oil-water zones of fields using horizontal wells (on the example of the Samotlor field).* PhD Thesis, Ufa, Ufa State Technical University, 197 p.

Saveliev, O.Yu., Borodkin, A.A., and Naugolnov, M.V. (2015). An improved approach to block-factor analysis of development. *Oil industry*, 10, 74-77.

Taghipoor, S., Roostaei, S., Velayati, A., Sharbatian, A., Chan, D., and Nouri, S. (2021). Numerical investigation of the hydraulic fracturing mechanisms in oil sands. *Underground Space*, 6(2), 195-216. https://doi.org/10.1016/j.undsp.2020.02.005.

Ustimov, S.K. (2007). *Forecasting the oil recovery factor in the process of field development*. PhD Thesis, Moscow, I.M. Gubkin Russian State University of Oil and Gas, 143 p.

Wang, F., Wang, X., Liu, Y., and Lu, Y. (2021). Study on Micro Displacement Mechanism of Hydraulic Fracturing by Oil Displacement Agent at High Pressure. *Geofluids*, (9), 1-11. DOI: 10.1155/2021/5541512

Wang, X., Qian, Y., Wang, J. Kong, F., and Ge, H. (2022). *The Mechanical Properties of Three Types of Shale Oil Reservoirs and Its Influence on Hydraulic Fracturing*. Proceedings of 56th U.S. Rock Mechanics/Geomechanics Symposium, Santa Fe, New Mexico, USA, June 2022, pp. ARMA-2022-0664. https://doi.org/10.56952/ARMA-2022-0664

Xu, S., Guo, J., Feng, F., Ren, G., Li, Y., and Wang, S. (2022). Optimization of hydraulic fracturing treatment parameters to maximize economic benefit in tight oil. *Fuel*, 239, 125329. https://doi.org/10.1016/j.fuel.2022.125329.

Yarkeeva, N.R., and Khaziev, A.M. (2018). Application of hydraulic fracturing for oil inflow stimulation in wells. *Oil and Gas*, 16(5), 30-36.

Zimin, S.V. (2004). *Additions to the technological scheme for the development of the Igolsko-Talovoye oil field. Research report*. Tomsk: TomskNIPIneft, 162 p.