PESQUISA DO MECANISMO DE PRODUÇÃO DE PETRÓLEO A PARTIR DE DEPÓSITOS DE HIDROCARBONETOS COM COLETORES DE BAIXA PERMEABILIDADE**RESEARCH OF THE MECHANISM OF OIL RECOVERY FROM HYDROCARBON DEPOSITS WITH LOW PERMEABILITY RESERVOIRS****ИССЛЕДОВАНИЕ МЕХАНИЗМА НЕФТЕИЗВЛЕЧЕНИЯ ИЗ ЗАЛЕЖЕЙ УГЛЕВОДОРОДОВ С НИЗКОПРОНИЦАЕМЫМИ КОЛЛЕКТОРАМИ**KUANGALIEV, Zinon A.^{1*}; DOSKASIYEVA, Gulsin S.²; MARDANOV, Altynbek S.³;^{1,2} Atyrau University of Oil and Gas, Department of Oil and Gas Business, 45A Baimukhanova Str., zip code 060027, Atyrau – Republic of Kazakhstan³ “KMG Engineering” LLP “Caspimunaigas”, 22A Elorda Ave., ZIP code 060006, Atyrau – Republic of Kazakhstan

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RESUMO

A maior parte das reservas de difícil recuperação da Rússia está confinada a reservatórios de baixa permeabilidade e carbonatos 73%, óleos altamente viscosos – 12%, vastas zonas localizadas imediatamente abaixo da tampa de gás de depósitos de petróleo e gás cerca de 15% e formações localizadas em grandes profundidades – 7%. O desenvolvimento de tais reservas usando tecnologias tradicionais é economicamente ineficiente. Requer-se o uso de novas tecnologias para seu desenvolvimento e, fundamentalmente, as novas abordagens para o design, levando em consideração as características da extração de reservas de difícil recuperação. O objetivo deste estudo é encontrar as maneiras de aumentar a eficiência do desenvolvimento de reservas de campos com reservatórios de baixa permeabilidade. Para realizar esta tarefa, o campo petrolífero Novobogatinskoye Yugo-Vostochnoye (Sudeste) foi descrito como um exemplo. Foram destacadas as propriedades necessárias das instalações de produção no campo, além de viabilidade econômica e eficiência tecnológica. As reservas envolvidas no desenvolvimento foram determinadas e, graças ao conhecimento das reservas geológicas de petróleo dos depósitos, o potencial fator de recuperação de petróleo foi calculado com a tecnologia de desenvolvimento existente. Como resultado do estudo, foram desenvolvidas as opções de desenvolvimento com os resultados do cálculo de indicadores de projeto para o campo como um todo. Apresenta-se uma comparação dos gráficos de produção e recuperação de petróleo, bem como os padrões de localização. Três opções para os indicadores tecnológicos de desenvolvimento de campo foram calculadas. As figuras mostram os gráficos de produção de petróleo, bem como os padrões de localização. Os autores do estudo concluem qual das opções de desenvolvimento recomendadas pode ajudar a extrair as reservas máximas de petróleo.

Palavras-chave: *coeficiente de recuperação de petróleo, recuperação de petróleo, pressão de saturação, modelo de fluido, fraturamento hidráulico.*

ABSTRACT

The main part of Russia's hard-to-recover reserves is 73% for low-grade and carbonate reservoirs, 12% for high-viscosity oil, about 15% of extensive sub-gas zones of oil and gas deposits and 7% of reservoirs lying at great depths. The development of such stocks with the usage of traditional technologies is economically inefficient. It requires the application of new technologies for their development and fundamentally new approaches to design, taking into account the features of extraction of hard-to-extract reserves (HtER). The purpose of this research is to find ways to improve the performance of low-permeability reservoirs. To accomplish this task, the Novobogatinsk South-Eastern Oil Field has been taken as an example and described. The necessary properties of production facilities in the field are highlighted, along with economic feasibility and technological efficiency. The reserves involved in the development are determined and, thanks to the knowledge of the geological oil reserves

of the deposits, the potential oil recovery factor is calculated with the existing development technology. As a result of the research, development options were worked out with the results of the calculation of design indicators for the field as a whole. The comparison of oil recovery schedules and ORI, as well as the layout of wells, have been presented. As a result of the study, a description of 3 options for the development of design indicators for the field as a whole is given. The figures show oil production graphs, as well as location patterns. The authors of the study conclude which of the recommended development options can help extract maximum oil reserves.

Keywords: *oil recovery index (ORI), oil recovery, saturation pressure, fluid model, fracturing.*

АННОТАЦИЯ

Основная часть трудноизвлекаемых запасов России приурочены к низкопроницаемым и карбонатным коллекторам 73%, высоковязким нефтям – 12%. обширным подгазовым зонам нефтегазовых залежей около 15% и пластам, залегающим на больших глубинах – 7%. Разработка таких запасов с использованием традиционных технологий экономически неэффективна. Она требует применения новых технологий их освоения и принципиально новых подходов к проектированию, учитывающих особенности извлечения трудноизвлекаемых запасов (ТРИЗ). Целью данного исследования является поиск способов повышения эффективности освоения запасов месторождений с низкопроницаемыми коллекторами. Для выполнения поставленной задачи приведено в пример и описано Новобогатинское Юго-Восточное месторождение нефти. Выделены необходимые свойства эксплуатационных объектов на месторождении, наряду с экономической целесообразностью и технологической эффективностью. Определены вовлечённые в разработку запасы и благодаря знаниям о геологических запасах нефти по залежам, рассчитан потенциальный КИН при существующей технологии разработки. В результате исследования разработаны варианты разработки с результатами расчета проектных показателей по месторождению в целом. Представлено сравнение графиков добычи нефти и КИН, а также схемы расположения скважин. Рассчитаны три варианта технологических показателей разработки месторождения. На рисунках представлены графики добычи нефти, а также схемы расположения скважин. А также авторы исследования приходят к заключению, что, третий рекомендуемый вариант разработки способствует максимальному извлечению запасов нефти.

Ключевые слова: *коэффициент извлечения нефти, нефтеотдача, давление насыщения, флюидальная модель, гидроразрыв пласта.*

1. INTRODUCTION

The peculiarity of the deposits located within the Astrakhan-Aktobe uplift zone is the low permeability, high fragmentation, and heterogeneity of the reservoir (Naderi and Babadagli, 2014; Ren and Wang, 2015; Solaimany-Nazar and Zonnouri, 2011). The following developmental difficulties are associated with these factors:

1. The problem of obtaining industrial inflow from the reservoir, there is no period of gushing, production is mechanized at the beginning, and until the end of development.

2. The problem is related to the preparation of well production. Already in the first months of operation, wells produce water products (20-30%), and this entails additional preparation costs.

3. Difficulties with reaching the project level of oil recovery – the need to use thick wells, drilling the side trunks both in the option of sealing the grid and in the version of HS and surface flooding

systems, GTM in significant volumes, the active introduction of flow-deflection technologies, increasing the injection pressure.

4. Low initial oil saturation, in advance – causes low potential oil recovery.

5. Qualitative opening of the productive horizon during drilling is also necessary, due to the fact that the undersaturated collector begins to be intensively saturated with the moisture of the drilling mud, which leads to a sharp decrease in the phase permeability of the reservoir for oil in the BFZ.

6. Ballast water is recovered in large quantities.

The result is a final ORI of about 0.25-0.3. All these factors lead to an increase in the cost of extracted oil. Examples of these phenomena are traced to the following fields: 1. South-Eastern uplift – sub-cornfield of the Novobogatinsk South-East (SEN); 2. Central uplift – the Central Novobogatinsk field; 3. Western uplift – the Novobogatinsk Western field.

The research of the main features of the development of low-permeability reservoirs and the creation of effective technologies for their development are urgent tasks. This circumstance has predetermined the direction of this work research (Alhuraishawy *et al.*, 2018; Li *et al.*, 2018; Zakirov *et al.*, 2016). All the above fields are similar, have low permeability of reservoirs, the porosity of which varies within 16.7-19.5% (Nazari and Honma, 2017; Shelley *et al.*, 2010; Volpin *et al.*, 2014). The gas content varies from 100-150 m³ / t. The saturation pressure is below the current reservoir pressure by 2-10MPa and averages 5-17MPa. The fluid model of the deposit is characterized by light, low-viscosity, low-sulfur, low-paraffin oil (Kuangaliev and Nakpaev, 2019; Kuangaliev and Nakpaev, 2018b; Wang *et al.*, 2017; Wang *et al.*, 2018). Based on the purpose of this study, we identified the main objectives of the work:

1. Research of the mechanism of oil extraction from hydrocarbons with low-permeability reservoirs in the implementation of various schemes for maintaining reservoir pressure.

2. Substantiation of wells grids, zones of their location, rates of hydrocarbon extraction, and sequence of development of reserves when implementing development systems with and without impact on the formation.

3. Research on the impact of layer-by-layer heterogeneity of low-permeability reservoirs on the efficiency of their development with active influence on the process of oil extraction by hydraulic fracturing (fracturing).

The efficiency of the development of an oil field is determined by the accuracy of the choice of method of impact on the productive layer, aimed at increasing or maintaining the mobility of oil. The choice of impact method is based on the available data on the geological and physical conditions of the oil deposit, composition, structure and petrophysical properties of the rocks, and the characteristics of reservoir fluids, taking into account their compliance with the criteria of applicability.

2. MATERIALS AND METHODS

The most common impact method today is water flooding, which provides 95% of oil production in Kazakhstan, due to the restoration of reservoir pressure and the displacement of the whole oil. The main features of the current state of the oil industry in Kazakhstan are an increase in

the share of hard-to-recover reserves in the structure of oil reserves and a lack of experience in the industrial application of enhanced oil recovery methods. In general, four problems are relevant in the fields of the Atyrau region: the high viscosity of oil; high water cut of products; the problem of utilization of oil gas and associated water; The low permeability of reservoirs.

The territory under consideration is located on the south-western slope of the Novobogatinsk dome, complicated by an overhanging cornice of salt, which is monoclinically immersed in the adjacent mold. Let's take a closer look at the Novobogatinsk South-Eastern field. At the Novobogatinsk South-Easternfield, deposits were discovered from the Permian-Triassic to Quaternary age inclusively, including deposits of the Kungurian stage of the Lower Permian (salt), which are embedded in the Permian as deposits in the form of a cornice.

Exploration and, subsequently, production drilling confirmed the industrial oil content of Permotias in the under-eaves conditions. Seven productive horizons were established in the section of the subcarpathian Permotias: RT-IV, RT-V, RT-VI (square A + B), RT-VII, RT-VIII, RT-IX, RT-X. All deposits by the type of natural reservoir are stratified, vaulted, shielded by tectonic disturbances, and the sole of the salt cornice (Figures 1 and 2). The reservoir strata of productive horizons are lithologically represented by sandstones, siltstones, sand, and Alekvrit, varying degrees of cementation. Siltstone of different colors, fine-grained, clay to varying degrees, slightly carbonate, cemented. Sandstones are gray, dark gray, fine-grained, slightly clayey, non-carbonate, micaceous. Sands are light gray, dark gray, slightly carbonated, slightly clay. The type of collector is porous. The sandiness coefficient varies in the range of 0.32-0.55, the dissection coefficient is in the range of 1-10. The pioneer of the Novobogatinsk South-East oilfield is an exploratory well No 1, which in January 1984 produced an inflow of oil with a flow rate of 2.8 tons/day for a 5 mm nozzle.

According to the results of laboratory tests of the core, the values of porosity vary from 0.142 to 0.202 fractions of a unit, the average value across the horizon is 0.167 fractions of a unit, the coefficient of variation is 0.086. The permeability varies from 1.13 to 31.6 × 10⁻³ μm², and the average permeability is 5.81 × 10⁻³ μm², the coefficient of variation is 0.921. According to the GIS results, the average porosity coefficient is 0.198 fractions of units, varying from 0.136 to 0.315 fractions of units, oil saturation on average

is 0.695 fractions of units, varying from 0.461 to 0.862 fractions of units. According to hydrodynamic studies, the horizontal values of permeability vary from 0.023 to $7.363 \times 10^{-3} \mu\text{m}^2$, the average horizontal value is $1.343 \times 10^{-3} \mu\text{m}^2$, and the coefficient of variation is 1.941. The fluid model is characterized by light, low-viscosity, low-sulfur, low-paraffin oil (Table 1).

In total, the oil reserves of the field in categories B + C1 + C2 have reached: geological – 14253 thousand tons, recoverable – 3439 thousand tons. The choice of the most rational development system for both individual deposits and the field as a whole depends on the correct allocation of production facilities. With the selection of production facilities in the field, along with economic feasibility and technological efficiency, the geological structure comes to the fore. A dedicated development object should have sufficient specific oil reserves per unit area of the reservoir and sufficient productivity in order to ensure high well flow rates over a long period of well operation during an anhydrous period and during flooding. In general, two production facilities were allocated at the field:

- I object – horizons RT-IV, RT-V, RT-VI-a, RT-VI-B;
- II object – horizons RT-VII, RT-VIII, RT-IX, RT-X.

A total of 27 wells were drilled at the Novobogatinsk South-East field, of which the production fund is 17 wells, including 11 operating, six wells inactive. The supervisory fund contains three wells, two wells in conservation after drilling. The liquidated fund is five wells; all wells have been abandoned for geological reasons. In the period 2012-2016, the wells of the field were operated with oil production rates of up to 5 tons/day. The maximum average annual production rate was achieved in 2013-2014 (up to 10 tons/day), then a slight decrease in production rate is noted. The main reason for the decrease in oil production rates is the low permeability of the formation.

In general, two wells are currently highly productive in the field, with oil production rates of up to 10 tons/day. According to these wells, hydraulic fracturing was carried out, which gave a positive result. From 1997 to 2005, there was an increase in oil production, which is associated with the commissioning of wells and their active operation (Figure 3). During this period, the stock of producing wells increased from one to six units. Since 2006, there has been a decrease in oil production with subsequent stabilization at the

level of 5.8-6 thousand tons for three years (2006-2008). From 2009 to 2014, oil production is characterized by an increase. The increase in oil production is associated with the commissioning of new production wells from drilling and the implementation of additional geological and technical measures to intensify oil production. From the dynamics of the technical indicators of development, it can be seen that the maximum level of oil production was reached in 2014 and amounted to 18.5 thousand tons. Then, there is a slight decline in annual production due to lack of drilling, reduction in the number of active wells, and low production rate.

The initial reservoir pressure for the I object is 15.6 MPa. Current reservoir pressure averages 12.7 MPa, varying from 10.4 to 16.5 MPa (Table 2). The current bottom-hole pressure, varying in the range of 6.4-10.7 MPa, averages 9.5 MPa. Saturation pressure averages 4.8 MPa. The initial reservoir pressure for the II facility is 19.3 MPa. Current reservoir pressure averages 15.7 MPa, varying from 13.6 to 16.4 MPa. A more noticeable decrease in reservoir pressure, compared with the I object, is associated with more intensive oil production and a three-fold excess of the existing production fund. The current bottom hole pressure averages 9 MPa. The saturation pressure averages 7.3 MPa.

At the beginning of the development in the field, 172.4 thousand tons of oil were produced. The selection rate from the initial recoverable reserves in the field is 0.5%, the selection rate from the currently recoverable reserves is 0.5%, the development of reserves in the field was 5.4% (Table 3). In general, oil-saturated thicknesses in the field vary from 19-146.5 m. The opening of effective oil-saturated thicknesses overall productive horizons is, on average, 30.8% (Table 4) (Kuangaliev and Nakpaev, 2018a).

To determine the values of oil reserves involved in active development with the currently developed development system and applied production technology, according to the method of V.D. Lysenko, the dependences of the specific monthly oil production per well were built on the accumulated oil production based on actual data. This method allows you to determine the amount of oil reserves involved in each facility. Having determined the reserves involved in the development and, knowing the geological oil reserves of the deposits, the potential oil recovery factor was calculated with the existing development technology (Table 5). Under the existing development system, it is impossible to achieve the approved oil recovery index for any of

the development objects, since the involved reserves are lower than the approved recoverable oil reserves (Lysenko, 2000).

3. RESULTS AND DISCUSSION:

Further, on the basis of the "TatNIPIneft" methodology (author V.D. Lysenko), a forecast of technological indicators for the development of production facilities has been made, which is based on a model of a zonal and layer-by-layer heterogeneous formation. The following assumptions have been made in the methodology:

1. the reservoir consists of permeable layers and impermeable layers separating them;
2. in the area of their distribution layers and interlayers consist of square zones, identical in the area;
3. all layers are of the same thickness;
4. layers differ in average permeability, and the distribution of these average values across the layers is completely chaotic, subordinated only to a statistical regularity in the form of a gamma distribution;
5. per layer, within the zones, the permeability values remain constant and change randomly during the transition from one zone to another;
6. in addition to the zonal permeability heterogeneity, the layers can still have a chaotic spread of area zones with zero permeability (discontinuity).

The methodology allows us to evaluate recoverable oil reserves and calculate the dynamics of technological development indicators during the implementation of various formation stimulation systems. In addition, the technique allows you to take into account the difference in the viscosity ratio of oil and water, the effect of a decrease in productivity as a result of a fall in reservoir pressure below the saturation pressure. The calculation of technical indicators in the methodology is carried out according to the following formulas:

the oil flow rate in the t -year (Equation 1):

here q_0^t – current amplitude rate at the middle of the t -th year, t/year ; Q_i – initial recoverable oil reserves put into development by the middle of the t -year, mln tons; $\sum_{i=1}^{t-1} q^i$ – total oil selection for all previous years.

The fluid flow rate in the t -th year (Equation

2): where Q_i^t – initial recoverable liquid reserves introduced into development by the middle of the year; $\sum_{i=1}^{t-1} q_F^i$ – total estimated fluid selection for all previous years.

To calculate the amplitude flow rate use the formula (Equation 3): where τ – working time of the wells; η_{cp} – the average productivity of the wells; n – total number of wells of the operational fund; P_{ch} – bottom hole pressure of injection wells; P_{c3} – bottom-hole pressure of producing wells; φ – the function of the relative productivity of the wells, taking into account the difference in wells in productivity, the relative placement, and the ratio of production and injection wells, the ratio of the mobilities of the displacing agent and oil; ξ_1, ξ_2 – reliability factors taking into account the increase infiltration resistance and, accordingly, the productivity of the layers due to their discontinuity and zonal heterogeneity, as well as the degree of knowledge of the layers.

Recoverable reserves are determined by the formula (Equation 4): where Q_b – balance oil reserves. The oil recovery index (ORI) is calculated by the formula (Equation 5): Index K_1 is called a grip coefficient and depends on the number of production wells and the distance between them (Equation 6): where S^1 – oil square per well of the design grid, km^2 ; w – the share of the non-collector by the square of distribution of the isolated oil layers, unit fractions; d – the size of the square zones' sides that simulate the zonal heterogeneity of the formations (step of random variation of the effective thickness of oil formations), km.

Index K_2 in, the ORI formula indicates the coefficient of oil extraction. The index K_3 is the coefficient of water flooding and is calculated by the formula (Equation 7): where K_{3H} – the proportion of the selection of mobile reserves for the anhydrous period; K_{3K} – the final share of the selection of mobile stocks; A – estimated marginal water cut, unit fraction.

These parameters are determined by the following formulas (Equations 8-10): where V^2 – the square of the variation coefficient of the estimated heterogeneity of reservoir features of the lay; A_2 – the maximum water cut of the production of wells, unit fraction; μ_0 – coefficient taking into account the difference in physical properties of oil and water in reservoir conditions (Equations 11-12): where ρ_w, ρ_H – the density of water and oil, kg/m^3 ; b_H – volumetric coefficient of oil, unit fraction;

To determine the squared coefficient of variation of the calculated heterogeneity of reservoir properties (V^2), it is necessary to establish the actual layer-by-layer and zonal inhomogeneities (Equation 13): where M – the ratio of the lengths of the neutral (the longest) and main (the shortest) streamlines going from the injection well (or from the aquifer) to the producing well; n – the number of sides of the water approach to production wells; V_1^2 – the square coefficient of variation of the actual layer-by-layer inhomogeneity of reservoir properties; V_{sq}^2 – the square of the coefficient of variation of zonal inhomogeneity of reservoir properties (Economides *et al.*, 1994).

This methodology is based on direct field measurements of good operation: productivity coefficients, oil, and fluid production rates, accumulated oil and fluid production, current and accumulated displacement agent injection rates, bottom-hole, and formation pressure. The methodology is a mutually agreed, fairly mobile, and universal equation of the oil and liquid production process, as well as the well stock of the production facility for almost any development system.

The validity of using the methodology is based on many years of effective application and its continuous improvement, thanks to the use of effective mathematical ideas and methods; design scheme of point-focused filtration resistances; distribution functions of a universal type and methods for their transformation and association; substantiation of the mutual independence of existing factors; characteristics of distribution functions with initial moments of various orders of inhomogeneities, etc. (VNII GOST 39-112-80..., 1981; Moufazalov *et al.*, 2000).

The acceptable applicability of the methodology has also been proved by conducting numerous approbations within the framework of technological schemes, development projects, and estimation of hydrocarbon reserves in Kazakhstan's fields, including the Emba region. Based on this technique, three variants of technological forecasting indicators of field development, including the object I (Unified Rules for the Development..., 1996; The Gas Industry Development Program..., 2010), have been calculated. Below is a description of 3 development options with the results of the calculation of design indicators for the field as a whole. Figure 4 shows a graph of oil production and oil recovery index as well as the layout of the wells (Figures 5-7 – the recommended option).

3.1. The first variant (basic)

It provides for the continuation of the development of production objects for the SEU field.

In order to use the potential of the drilled well stock, to increase the oil recovery factor at production facilities, measures are also planned to involve additional oil reserves in the development by:

- developing in the wells the intervals of productive horizons allocated to one production object that has not been previously developed;
- transferring wells from object to object, as a result of the development of reserves.

3.2. The second variant

Additionally, the introduction of new design wells in the amount of 90 units is provided with hydraulic fracturing and taking into account the new understanding of the geological structure of productive horizons and their productive capabilities. The development of the object is also expected to be in natural mode. The location of the project wells was selected, taking into account new ideas about the geological structure of the field. The main purpose of the option is to assess the effectiveness of previously accepted and unrealized design decisions from the point of view of new ideas about the geological structure and the achievement of the approved ORI values. For the projected period, the production fund will be 101 wells.

3.3. The third variant (recommended)

It is envisaged that 80 production wells will be commissioned from drilling with hydraulic fracturing, as well as with the launch of an ESP. Additionally provided is the input from drilling 31 injection wells in order to maintain reservoir pressure. Carbon dioxide was selected as the working agent for injection. For the projected period, the production fund will be 91 wells. Injection well stock – 31 units.

Thus, the largest amount of oil in the field will be produced during the implementation of the third option, which involves the drilling of new wells with hydraulic fracturing and launching of ESP, as well as the use of an injection system with gas injection. According to calculations, the value of the oil recovery factor by the end of development will be 0.483 units, which is significantly higher than the approved value of 0.258 units. The lowest

oil recovery factor is characterized by option one, which involves the development of an object by existing wells (Table 6).

Economic analysis is a special approach that allows you to assess the possible financial and economic consequences of implementing a development option. This analysis allows you to measure the total costs of the investor and the benefits of implementing a development option using the same unit of measure, usually money. The economic analysis allows you to determine the most profitable option for a company-subsoil user and for the state.

When choosing the recommended development option, the following were analyzed: the projected level of oil production, cumulative oil production for a profitable period, the time to reach the economic limit, the payback period of investments, capital investments, operating costs, net profit, accumulated cash flow, and economic indicators. Based on the technical and economic indicators for each option, analysis, and selection of the recommended option for development were carried out. When comparing development options, the best option has turned out to be the option III, according to which the maximum indicators of the accumulated cash flow are obtained – 1,059.6. Million US dollars, net present value – 250.4 million US dollars and total payments to the state for 2061 – 2,480.2 million US dollars.

According to the main provisions of the development system options, the technical indicators were calculated for operational objects and for the field as a whole in three versions. To assess the achieved ORI values, technological indicators for all productive horizons have been additionally calculated for each counting object (horizon). As a recommended option, the III development option is proposed for implementation during the implementation of which the maximum extraction of oil reserves is achieved. When implementing the recommended third development option, the projected level of oil production in the amount of 375.16 thousand tons will be achieved in 2061, the rate of selection will be 10.2%. The cumulative oil production in the field as a whole by the end of the economically viable development period will be 6814.91 thousand tons, the oil recovery index achieved is 0.478 unit fraction.

4. CONCLUSIONS:

According to the main technical and economic indicators for each variant, the analysis and selection of the recommended variant for development have been carried out. While comparing development options, the best option turns out to be the III, from which the maximum accumulated cash flow – 1,059.6. USD has been obtained, net present value – USD 250.4 million, and total payments to the state for 2061 – USD 2 480.2 million.

According to the basic provisions of the variants of the development systems, the calculations of the technical indicators for the operational objects and the field as a whole in three variants have been made. To evaluate the achieved ORI values, calculations of technological indicators for all productive horizons were additionally carried out for each calculated object (horizon).

As a recommended variant, the third variant of development is proposed for implementation, in the course of which the maximum extraction of oil reserves has been achieved. While implementing the recommended third development variant, the projected level of oil production in the amount of 375.16 thousand t will be reached in 2061, the rate of selection will be 10.2%. The accumulated oil production by the field as a whole by the end of the economically profitable development period will make 6814.91 thousand t, achieved by ORI 0.478 unit fraction.

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$$q^t = \frac{q_0^t}{Q_i^t + \frac{1}{2}q_0^t} [Q_i^t - \sum_{i=1}^{t-1} q^i] \quad (\text{Eq. 1})$$

$$q_F^t = \frac{q_0^t}{Q_{Fi}^t + \frac{1}{2}q_0^t} [Q_{Fi}^t - \sum_{i=1}^{t-1} q_F^i] \quad (\text{Eq. 2})$$

$$q_0 = \tau \cdot \eta_{cp} \cdot n \cdot (P_{ch} - P_{c3}) \cdot \varphi \cdot \xi_1 \cdot \xi_2 \quad (\text{Eq. 3})$$

$$Q_i = Q_b \cdot ORI, \quad (\text{Eq. 4})$$

$$ORI = K_1 \cdot K_2 \cdot K_3. \quad (\text{Eq. 5})$$

$$K_1 = e^{-\alpha \cdot S^1}, \alpha = \frac{w^2}{d^2} \quad (\text{Eq. 6})$$

$$K_3 = K_{3H} + (K_{3K} - K_{3H}) \cdot A \quad (\text{Eq. 7})$$

$$K_{sq} = \frac{1}{1.2+4.2 \cdot V^2}; \quad (\text{Eq. 8})$$

$$K_{sq} = \frac{1}{0.95 + 0.25 \cdot V^2}; \quad (\text{Eq. 9})$$

$$A = \frac{A_2}{(1 - A_2) \cdot \mu_0 + A_2}, \quad (\text{Eq. 10})$$

$$\mu_0 = \frac{1}{2} \cdot (1 + \mu_*) \cdot \frac{\rho_w}{\rho_H} \cdot b_H \quad (\text{Eq. 11})$$

$$\mu_* = \frac{\mu_H}{\mu_w} \cdot K_2^{1.5} \quad (\text{Eq. 12})$$

$$V^2 = (V_1^2 + 1) \cdot \left(\frac{2}{3} \frac{(M-1)^2}{M} \cdot \frac{2\mu_*}{1+\mu_*} + 1 \right) \cdot \left(\frac{V_{sq}^2 + 1}{\frac{V_{sq}^2}{n_*} + 1} + 1 \right) - 1 \quad (\text{Eq. 13})$$

Figure 1. Structural map of the horizon collector roof

Figure 2. Geological and lithological profile

Figure 3. Dynamics of the main technical indicators of field development

Figure 4. Comparison of the project ORI by development options

Figure 5. Layout diagram of drilled and project wells according to option 1

Figure 6. Layout diagram of drilled and project wells according to option 2

Figure 7. Layout diagram of drilled and project wells according to option 3

Table 1. Physical and chemical features of oil under reservoir conditions

Item	Horizons					
	PT-IV	PT-V	PT-VI-A	PT-VII	PT-IX	PT-X
Bubble point pressure, MPa	7.2	4.9	10.7	11.9	9.0	9
Gas oil ratio, m ³ /t	130.1	135.5	137.6	155.7	170.2	189.3
Volume ratio, u.f.	1.306	1.318	1.326	1.397	1.430	1.337
Density, kg/m ³	656.0	692.0	708.0	686.0	687.0	0.777
Viscosity, Mpa. S	0.64	0.70	0.69	0.68	0.6	0.6
Sample test temperature, °C	43.2	44.8	46.5	47.2	45	47

Table 2. Energy characteristic of the Novobogatinsk South-Eastern deposit

Objects	Figures	Pin, MPa	Years						Deviations, MPa	
			2012	2013	2014	2015	2016	Pin, MPa		
									$P_{current} - P_{in}$	$P_{in} - P_{current}$
I	Reservoir pressure, MPa	15.6	14.4	14.2	14.1	13.9	12.7	4.8	7.9	2.9
	Bottom hole pressure, MPa		11.2	8.6	8.5	9.5	9.5			
	Depression ΔP , MPa		3.2	5.6	5.6	4.4	3.2			
II	Reservoir pressure in the selection zone, MPa	19.3	17.6	17.2	16.8	16.4	15.7	7.3	9.0	3.6
	Bottom hole pressure, MPa		11.1	11.6	8.3	9.3	9.0			
	Depression ΔP , MPa		6.5	5.6	8.5	7.1	6.7			

Table 3. Oil production relating to objects and field as a whole

Development object	Initial reserves, thousand tons		Reservoir oil production, thousand tons	Recoverable reserves, thousand tons		ORI, u.f.		Production, %
	geology.	recov.		geolog.	recov.	conf.	cur.	
I object	3492	917	41.3	3450.7	875.7	0.263	0.012	4.5
II object	8867	2275	131.0	8736.0	2144.0	0.257	0.015	5.8
In general, according to the field	12359	3192	172.4	12187	3020	0.258	0.014	5.4

Table 4. The distribution of the opening degree of effective oil-saturated thickness with perforation

Wells' No	Total effective oil-saturated thickness	Total opening of the effective thickness with perforation		Total unopened oil-saturated thickness	
	(m)	(m)	% from general	(m)	% from general
1	146.5	50	34.1	96.5	65.9
2	32.1	29	90.3	3.1	9.7
3	19.9	15.9	79.9	4.0	20.1
4	22.5	8.5	37.8	14.0	62.2
5	34.1	6	17.6	28.1	82.4
7	21.2	0	0.0	21.2	100.0
10	57.7	37.3	64.6	20.4	35.4
11	103.1	16.3	15.8	86.8	84.2
12	78.9	0	0.0	78.9	100.0
13	34.1	13.3	39.0	20.8	61.0
16	144.5	37.6	26.0	106.9	74.0
20	38.3	28.7	74.9	9.6	25.1
21	30.3	5.9	19.5	24.4	80.5
22	89.9	25.5	28.4	64.4	71.6
23	111.4	17.6	15.8	93.8	84.2
24	58	16.6	28.6	41.4	71.4
25	79.1	10.6	13.4	68.5	86.6
26	100.2	22.9	22.9	77.3	77.1
27	78.2	26.1	33.4	52.1	66.6
28	100.2	12	12.0	88.2	88.0
29	40.7	12.9	31.7	27.8	68.3
30	52.2	7.6	14.6	44.6	85.4
31	85.8	57.8	67.4	28.0	32.6
32	74	45.2	61.1	28.8	38.9
Total	1632.9	503	30.8	1129.6	69.2

Table 5. Comparison of the calculation results of the reserves involved

Object	Oil reserves, thousands of tons				ORI, u.f.		
	geol.	produc.	inv.	rest from inv.	appr.	cur.	Potent.
I object	3492	917	100	817	0.263	0.012	0.029
II object	8867	2275	230.5	2044.5	0.257	0.015	0.026

Table 6. ORI per variants

	K1	K2	K3	ORI
Variant 1	0.159	0.56	0.649	0.058
Variant 2	0.854	0.56	0.549	0.263
Variant 3	0.854	0.645	0.874	0.481