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MODELING OF DEVELOPMENT OPTIMIZATION IN BALAKHANI-SABUNCHU-RAMANA FIELD (V HORIZON)

(Представлено членом редакційної колегії д-ром геол. наук, доц. Георгієм ЛІСНИМ)

Background. ***This paper presents the principals of application relevance methods for modeling and optimizing the development process, such as Shewhart control charts. This method provides a guide to a detailed development process that addresses various issues that often arise when implementing waterflooding in both offshore and onshore oil and gas fields, in extraction of fluids from reservoir, challenges in well drilling, in oil recovery etc. Using the Shewhart control charts method, it was possible to obtain an adequate answer to the problem (adjustment of the development process) when studying the issues of optimizing the dynamics of oil production from the field. At the same time, this method is useful both for the analysis of all dynamic series and for individual segments (stages).***

The purpose of constructing control charts is to identify the points at which the process leaves a steady state in order to subsequently determine the causes of the deviations that have arisen and eliminate them. The purpose of constructing Shewhart control charts is to determine the boundaries of the system variability of the process and to predict the behavior of the process in the near future based on past process data.

Methods. ***Development curves have been constructed using geological and field data. This graph allows determining the optimal development regime, recalculating oil and gas reserves, and fully reflecting the effective extraction of hydrocarbons from the field.***

Results. ***Analyzing the relationship among development curves, pressure recovery, oil and gas production growth rates for various development periods adjustment is possible.***

Conclusions. ***As a result of the research conducted using the Shewhart control charts dynamic model, it was possible to control and regulate the development processes of the V horizon of the Balakhany-Sabunchu-Ramana field, which is an exploitation object, as well as to determine the optimality levels of these processes and the effectiveness of using appropriate methods to increase the oil recovery factor.***

This method proved effective in increasing production, can effectively enhance the production performance during the optimization process. This is crucial for implementing refined management of individual horizons, determining the exit beyond of development regulation limits.

Keywords: ***development curves, Shewhart control charts, deviations, regulation, optimal development, exploitation object.***

Background

The correct selection of technologies and methods is an important factor in significantly improving the efficiency of the development and operation of gas and oil fields (Mukhametshin, 2022). The closely interconnected links of the production and consumption chain require the use of integrated systems and programs that can increase oil production and help reduce the total cost of ownership.

The solution of the latest technological issues also allows improving the control and analysis of various processes in gas and oil fields. One of the most important aspects in the process of development and adjustment of fields is the selection of control systems and appropriate methods to increase the oil recovery factor (Chupin, & Moroz, 2020; Urazgaliyeva et al., 2023; Yang, Kim, & Choe, 2017; Zhang et al., 2023).

Material. Geological and field data of SOCAR were used to investigate and analyze the development process of horizon V of the Balakhany-Sabunchu-Ramana field. Surface and Excel programs were used to plot the graphs attached to the work.

Lithological-stratigraphic and tectonic features of the development object. The Balakhany-Sabunchu-Ramana field is located 12 km northeast of Baku. The area of the field resembles a latitudinal lowland. In the west of the lowland, the Bogh-Bogha mud volcano is located in the Balakhani area. The Boyukshor and Ramana lakes are stretched in latitudinal direction, and are located to the south of the Balakhany-Sabunchu-Ramana field (Salmanov et al., 2023).

The Productive series (PS), Aghjagil and Absheron deposits have been exposed in the geological section of the field. In the Bogh-Bogha mud volcano zone located in the relatively elevated part of the fold and to the west of it, deposits of the Fasila and partly Post-Kirmaki Clayey (PKC) and Pre-Kirmaki (PK) suites of the PS have been discovered. Towards the Ramana area, most younger deposits emerge to the Earth's surface.

The PS deposits consist of alternating sand, sandstone and clay. The section of PK suite is sandy. At the intersection of the PS, the Surakhany, Sabunchu, Balakhany, Fasila, PKC, Post-Kirmaki Sandy (PKS), PK suite are separated. The horizon V of the Balakhany–Sabunchu–Ramana field is separated at the intersection of the Balakhany suite (Fig. 1).

The field is associated with a large brachyanticlinal fold extending in the latitudinal direction. The fold has a steep southern (40–70°) and inclined northern (10–15°) limb and a wide crest (Fig. 2, 3).

The structure is complicated by numerous longitudinal faults. Transverse faults have not very large displacement amplitudes (10–40 m) and they decrease with increasing depth.

The industrial oil content of the field is associated with sediment complexes from the Absheron stage to the PK suite of the PS. More than 30 oil-bearing layers are separated at the intersection of these suites (Fig. 3).

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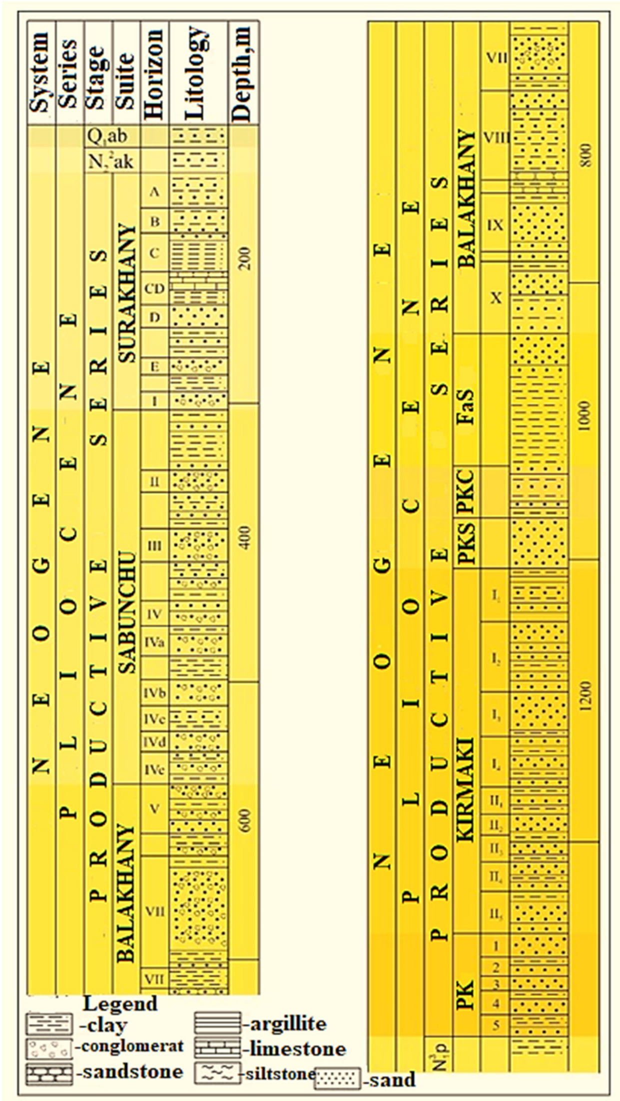

Fig. 1. Balakhany–Sabunchu–Ramana deposit. Generalized geological section

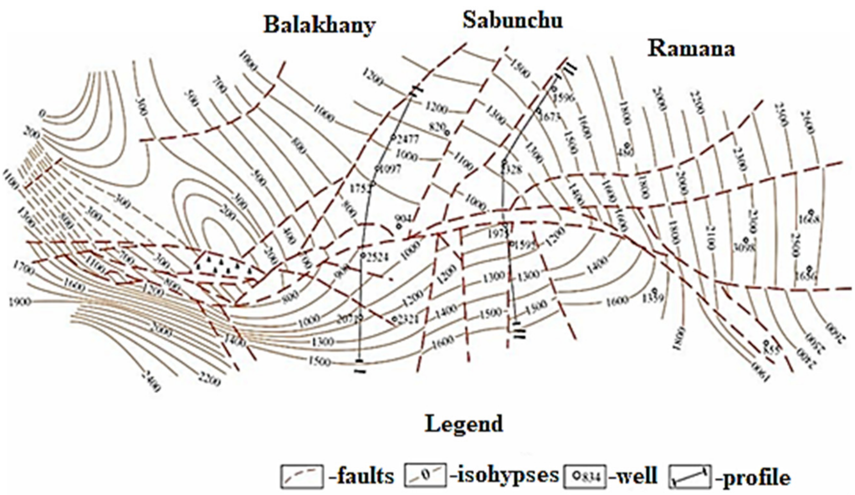

Fig. 2. Balakhany–Sabunchu–Ramana field. Structural map by the top of the KS of the PS

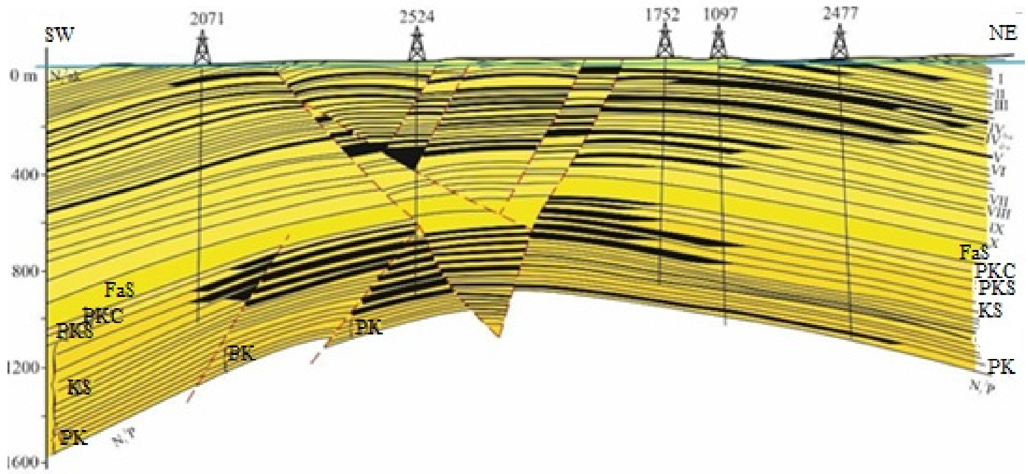

Fig. 3. Balakhany–Sabunchu–Ramana field. Geological profile

The oil deposit in the upper series of the PS covers a large area and the production wells are characterized by high productivity. In the intersection of the upper series, 10 main and a number of intermediate sandstone layers are distinguished. The depth of the productive layers is not very deep, from 140 m to 460 m. The open porosity of the reservoirs along the intersection is 24–27 %, and the permeability is 700×10^{-15} m^2.

The horizon V, which is the object of research, is mainly associated with a tectonic screened trap. The intersection of the horizon is characterized by 23 % clay content and 81 % sandiness. Lithologically, the reservoir rocks are composed of sand and sandstone. The porosity of the rocks is 26 %, the permeability is 364×10^{-3} μm^2, and the carbonate content is 13 %. The viscosity of the oil is 8 mPa x s; the current oil recovery factor is 0.73 %. The current oil-bearing area of the development object is 1090 m^2, the average depth of the reservoir is 390 m, and the effective thickness is 34 m.

Methods

In order to analyze (Aliev, 1983; Salmanov et al., 2023) and predict the development of horizon V of the Balakhany–Sabunchu–Ramana field, development curves were constructed using geological-field data (Fig. 4). This graph fully reflects the determination of the optimal development regime, recalculation of oil and gas reserves, and effective extraction of hydrocarbons from the deposits. The graph reflects the III (1931–1975) and IV (starting from 1975) stages of the development of horizon V. Thus, according to the analysis, the volume of oil extracted from the horizon gradually decreased, from 357.4 thousand tons (1931) to 173 thousand tons (1945). In 1945–1958, there was a certain increase in oil production. Production varies between 188–211 thousand tons. The increase in production in these years was achieved by increasing the number of production wells and increasing the volume of water injected into the horizon. The decline is also observed in gas production. Gas has been produced from the horizon since 1965, and a decline in production has been observed since that year. Between 1965 and 2015, the volume of gas produced decreased from 6.6 m^3/t to 0.11 m^3/t.

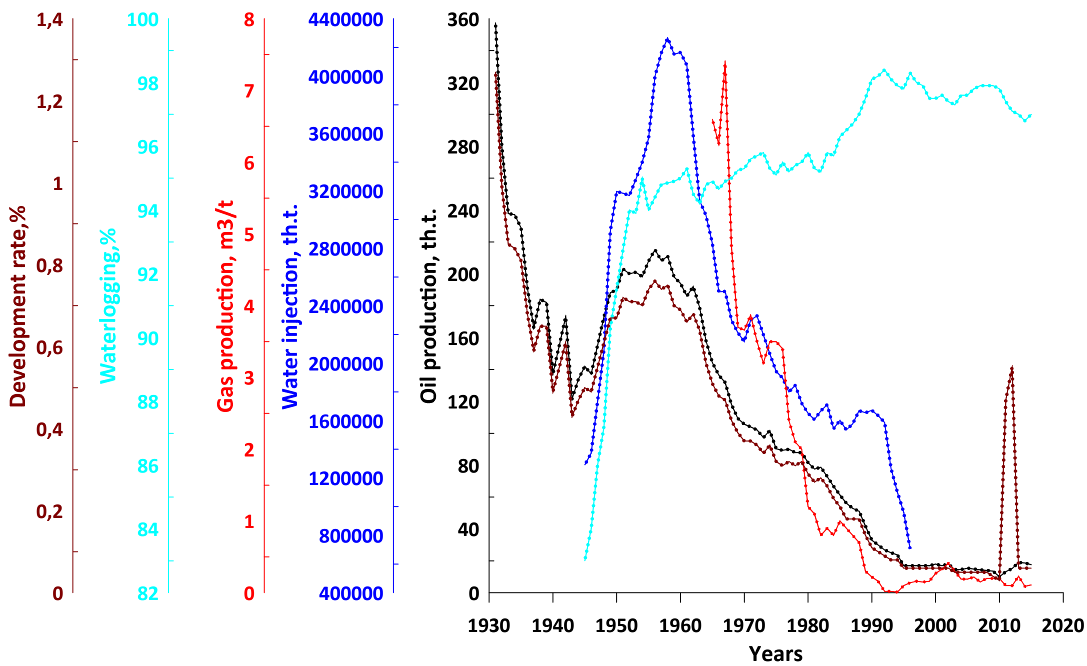

Fig. 4. Development curves of the horizon V of the Balakhany–Sabunchu–Ramana field compiled based on geological-field data

As can be seen from the graph, water injection into the horizon began in 1945. The goal is to overcome the observed declines in production and optimize the level of exploitation. Initially, 1290638 m^3/t of water was injected into the horizon, which slightly increased production. However, as the amount of injected water increased, the level of waterlogging in the formation increased. The maximum amount of water (4265623 m^3/t) was injected into the horizon in 1958, as a result of which 211 thousand tons of oil were extracted from the formation. The water injection process was gradually reduced (706411 m^3/t) and finally stopped. Because the waterlogging in the horizon increased, it increased by 98.3 %. The rate of development of the horizon also decreased in turn. Thus, since 1931, the dynamics of development began to decrease. It decreased from 1.27 % to 0.06 %. The development rate on the horizon increased slightly only in 2012, reaching 0.55 %. Then it sharply decreased to 0.06 % (see Fig. 4).

Results

Crude oil adjustment reflects the combined uncertainty around each of the crude oil data elements and crude oil supply and its disposition. The crude oil balance relationship, which are developed independently, should balance perfectly. In practice, this is rarely the case, because timing differences or other factors that contribute to survey responses may not precisely reflect actual crude oil extraction, storage, and refining activity for the year (Merriam, 2015).

So, engineers need to continuously adjust strategies to maximize oil recovery during development. Then strategy adjustment requires a lot of cost, so it is necessary to select the optimal strategy through production forecasting (Wang et al., 2022; Wang et al., 2023).

In this paper, Shewart control charts, used in the management of oil and gas field development processes, are a visual tool, a graph showing the change in process parameters over time to implement statistical control over the stability of the process. Timely detection of instability in the development allows to obtain a controlled process, without which no improvement is possible in principle. Control charts were first established in 1924 by Walter Shewhart to reduce process variability by eliminating deviations arising in operation from non-systemic causes.

The purpose of constructing control charts is to identify the points at which the process leaves a steady state in order to subsequently determine the causes of the deviation and eliminate them. The purpose of constructing Shewhart control charts is to determine the boundaries of the system variability of the process, and to predict the behavior of the process in the near future based on past process data.

For this reason, Shewhart control charts were constructed in order to optimize and regulate the development of the horizon V. Control maps have been drawn up for optimal regulation of oil and gas production (Fig. 5a, 5b).

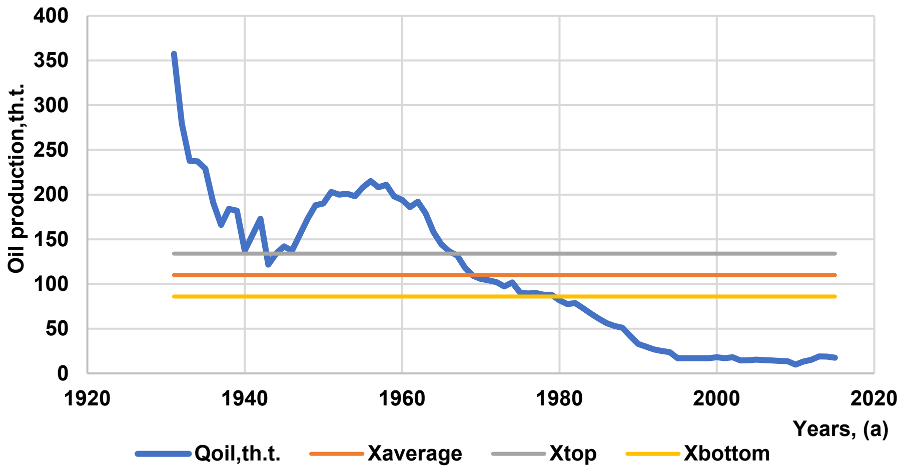

Fig. 5a. Control chart of oil production (horizon V)

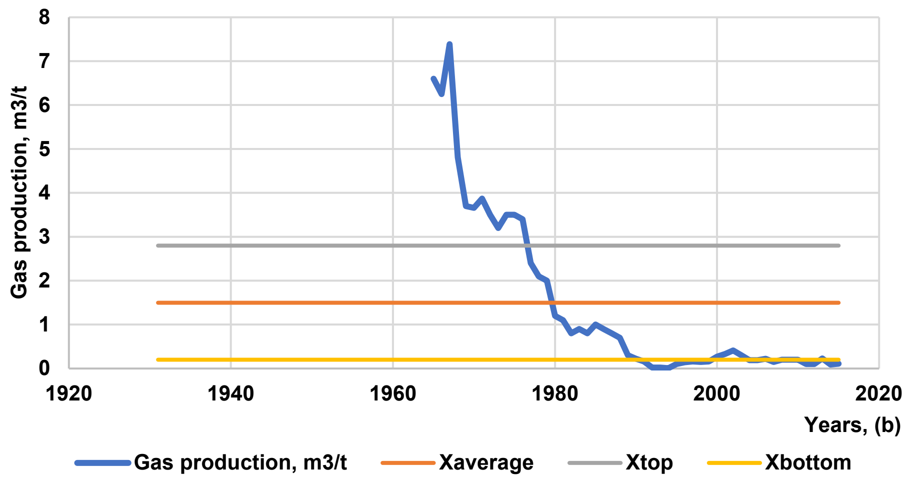

Fig. 5b. Control chart of gas production (horizon V)

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The top, average and bottom limits for the horizon have been determined: for oil- $X_{average}$=110; X_{top}=134; X_{bottom}=86; for gas- $X_{average}$=1.5; X_{top}=2.8; X_{bottom}=0.2. As can be seen from the chart, the adjustment limits established to regulate both oil and gas production are symmetrical with the average limit, but deviations from the top and bottom limits are observed in the development process. It should be noted that from 1971 to 2015, an intensive decrease in oil production was observed. After 2015, the curve deviated from the bottom adjustment limit and fell to 17.6 thousand tons. Gas production on the horizon began in 1965, and there was a gradual decrease in production in that year. The initial production is 6.6 m^3/t. Since 1965, production has decreased from 6.6 m^3/t to 0.11 m^3/t. The maximum production occurred in 1967, which was 7.39 m^3/t. In order to study the reasons characterizing this process, similar charts were compiled for the main production indicators: the number of production wells (Fig. 5c), the volume of water injected into the horizon (Fig. 5d); waterlogging (Fig. 5e) and the development rate of production (Fig. 5f).

The upper, middle and lower limits for well regulation have been determined: $X_{average}$=261.7; X_{top}=316; X_{bottom}=207 (Fig. 5c).

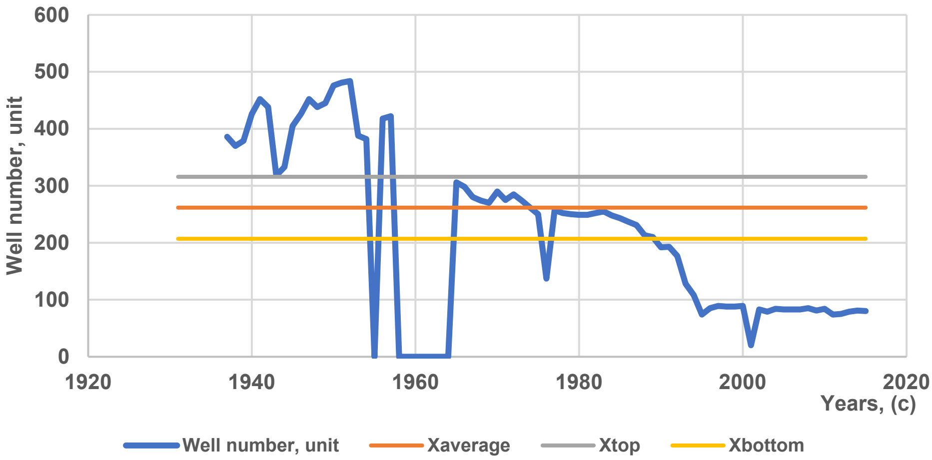

Fig. 5c. Control chart of well number (horizon V)

The control chart of wells drilled along the horizon shows that the top and bottom adjustment limits are relatively symmetrical at the average limit. Based on the analysis, it was determined that in order to maintain the development process at an optimal level, it is advisable to have a maximum of 316 wells and a minimum of 207 wells. However, the decrease in the number of wells drilled since 1990 has had a negative impact on both oil and gas exploitation and development dynamics.

In reservoir development, liquid production rate and water injection rate change according to the human-made policy, leading to an unnatural fluctuation of development process (Wang et al., 2022). To make analysis more accurate, we analyzed the factors of effects on oil production rate. We notice that the oil rate is seriously affected by injected water from the injection wells (Fig. 5d).

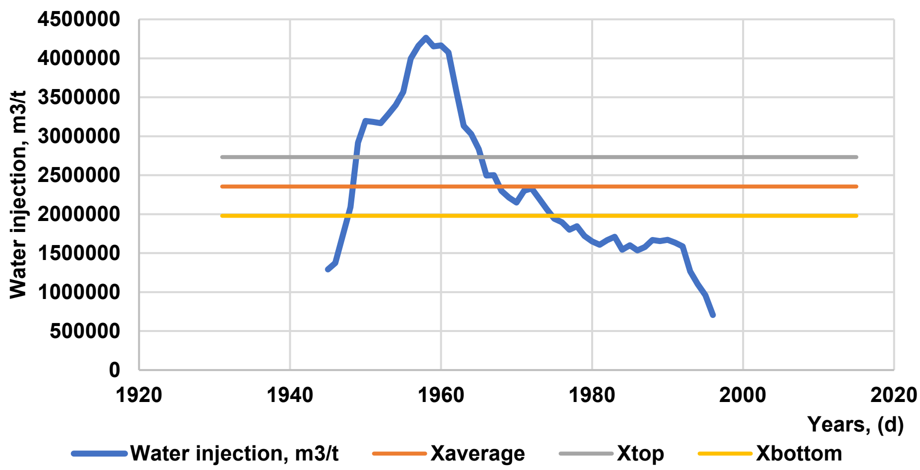

Fig. 5d. Control chart of water injection (horizon V)

There is injection of water into formations in order to increase the permeability of formations, coverage of formations due to waterlogging, regulation of the process of displacement of oil to the bottoms of production wells. However, on the other hand, there are also negative manifestations during water injection. This is the flooding of layers earlier. Because of this, water injection was stopped in our target facility in 1996.

The nature of the waterlogging of the extracted production is influenced by many factors related, on the one hand, to the geological structure and collector properties of the layer, the physical and chemical properties of oil and the displacing liquid, and on the other hand, to the applied well placement system, the technology of their construction, and operating modes. In the conditions of increasing depressions, a large number of wells are flooded due to the breakthrough of water through separate high-permeable areas of the developed object, the violation of the tightness of the underground space, and also due to the pulling of the cones of the bottom water. In addition, many oil fields have hydro-oil zones and wells located in these zones begin to produce watered-down products from the first days of operation. Premature flooding of wells reduces the final oil recovery and causes large non-productive costs for production, transportation of associated water and for combating corrosion of industrial equipment (Bagirov, 2011; Bazhenova et al., 2004, 2012).

The considered horizon, which has been under development for more than 74 years, has large reserves of oil and consists of one productive layer with high-viscosity oil of about 8 mPas. Only 16 % of recoverable oil reserves were selected during the development period. Waterlogging of the product is 97 % (Fig. 5e).

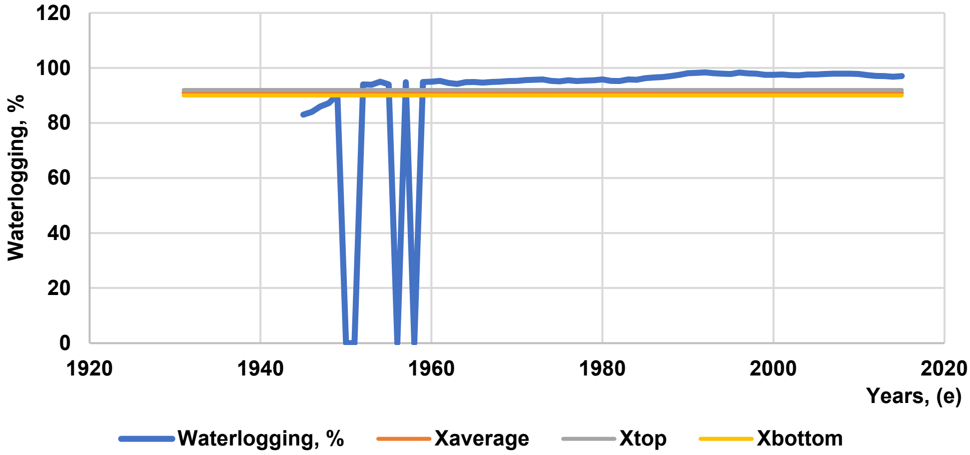

Fig. 5e. Control chart of waterlogging (horizon V)

As can be seen from the chart, the waterlogging level of the horizon is above the adjustment limit; however, there is a danger of losing significant reserves of oil, which were in the "bypassed oil", due to the influence of capillary forces and anisotropic properties of the reservoir.

Therefore, it is necessary to find solutions as soon as possible, to test new technologies at the horizon and to apply them on an industrial scale, in order to achieve the final approved ORF and high economic efficiency of the enterprise. An additional reason for the early waterlogging of the products of production wells is a violation of the integrity of annular space. Maintenance of high rates of oil production is achieved by the introduction of new oil production from drilling wells, while the majority of wells that have been watered down are out of operation, and have not exhausted their potential. Conducting regular measures to control development allows timely identification of the causes of backflows (Chupin, & Moroz, 2020; Kuangaliev, Doskaziyeva, & Mardanov, 2019; Law of the Republic of Kazakhstan, 2010; Lysenko, 2003; Maharramov, Karimov, & Sharifov, 2022; Maisel, 2020; Saptarini, & Nainggolan, 2022; Schiozer et al., 2019).

During the development of reservoirs, the most different values of the maximum rate of oil production are reached. The maximum extraction rate is inversely proportional to the time of its achievement and depends on the type of law of entering wells, that is, from the general organization of oil production, the slower the wells are entered, the lower the rate of production is (Boyce et al., 2011; Kuvanyshev, & Kuvanysheva, 2010).

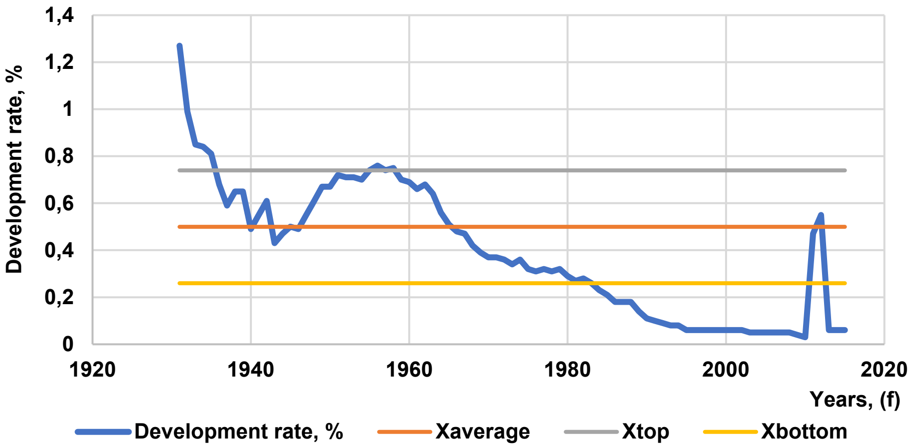

Fig. 5f. Control chart of development rate (horizon V)

As is known, the studied horizon is in the last stage of exploitation. According to the mining data, the development rate since the beginning of development was 1.27 %. On the eve of the process, a decrease in the development rate is observed starting from 1931. The rate decreased from 1.27 % (1931) to 0.06 % (2015). As can be seen from the control chart, this indicator is marked much below the adjustment limit (with the top limit being 0.74 % and the bottom limit being 0.26 %).

Discussion and conclusion

A comprehensive analysis of the Shewhart control charts constructed on the development indicators of the horizon V allows us to identify the reasons for the change in annual oil and gas production throughout the entire development period.

• At the initial stage, a large number of production wells were put into operation: from 1931 to 1942, their number increased from 386 to 438, although the optimal control zone for this indicator should be between 316 and 207 units (Fig. 5c).

• The amount of water injected from 1951 to 1959, in order to maintain the development process at an optimal level. It was advisable to inject a maximum of 2732743 m^3/t, an average of 2356180 m^3/t, and a minimum of 1979617 m^3/t of water, the amount of water injected was increased from 31960000 m^3/t to 4152060 m^3/t (Fig. 5d). During the development period, the volume of water injected in 1949–1966 was outside the top limit of adjustment. Since 1976, it has been outside the bottom limit. In this case, a decrease in the number of water-injecting wells is noted. Despite the decrease in the amount of water injected into the horizon, it had a significant impact on both the oil production process and the rapid waterlogging of the horizon. In this regard, the process of water injection into the horizon was stopped in 1996.

• The waterlogging of the horizon was below the bottom optimal adjustment limit in 1949, 1953, 1956, 1958, 1960 and amounted to 90 %. From 1960 to 2015 it was outside the top limit, increasing from 90 % to 97 % (Fig. 5d).

• From 1931 to 1936 the rate of development was outside the top limit of adjustment (Fig. 5e). While the top 0.75%, the average 0.5%, and the bottom 0.29 % were required, it was noted outside the bottom adjustment limit in 1984, 2011, 2013–2015.

Thus, as can be seen from the above figures, it was possible to obtain an adequate answer to the problem posed when studying the issues of optimizing the dynamics of oil production from the field (adjustment of the development process) using the Shewhart control chart method. At the same time, this method is useful both for the analysis of all dynamic series and for individual segments (stages). As a result of the research conducted using the Shewhart control chart dynamic model, it was possible to control and regulate the development processes of the horizon V of the Balakhany–Sabunchu–Ramana field, which is an exploitation object, as well as to determine the optimality levels of these processes and to determine the effectiveness of the use of appropriate methods for increasing the oil recovery factor.

Thus, knowing that the viscosity of the horizon's oil is 8 mPaxs., its permeability is 364×10^{-3} μkm^2, the average depth of the reservoir is 390 m, and that 16% of the geological reserve is used, it was determined that the use of SAM, alkaline and micellar substances injection methods into the layers is effective in increasing the oil recovery factor (according to B.A. Bagirov's "tree" method) (Bagirov, 2011; Ivanova, Cholovsky, & Bragin, 2000; Karimov, Sharifov, & Zeynalova, 2023).

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МОДЕЛЮВАННЯ ОПТИМІЗАЦІЇ РОЗРОБКИ НА РОДОВИЩІ БАЛАХАНИ-САБУНЧУ-РАМАНА (V ГОРИЗОНТ)

Вступ. ***У статті представлено принципи застосування методів релевантності для моделювання та оптимізації процесу розробки, таких як контрольні карти Шухарта. Цей метод надає керівництво для детального процесу розробки, який враховує різні питання, що часто виникають під час впровадження заводнення як на морських, так і наземних нафтогазових родовищах, під час видобутку рідин із пласта, проблеми під час буріння свердловин, під час видобутку нафти тощо. Використовуючи метод контрольних карт Шухарта, вдалося отримати адекватну відповідь на проблему (коригування процесу розробки) при вивченні питань оптимізації динаміки видобутку нафти з родовища. Водночас цей метод корисний як для аналізу всіх динамічних рядів, так і для окремих сегментів (етапів).***

Метою побудови контрольних карт є визначення точок, у яких процес виходить зі стаціонарного стану, щоб згодом визначити причини виниклих відхилень та усунути їх. Метою побудови контрольних карт Шухарта є визначення меж системної мінливості процесу та прогнозування поведінки процесу в найближчому майбутньому на основі даних минулого процесу.

Методи. ***Криві розробки було побудовано з використанням геологічних і промислових даних. Цей графік дає змогу визначити оптимальний режим розробки, перерахувати запаси нафти і газу та повно відобразити ефективний видобуток вуглеводнів з родовища.***

Результати. ***Аналізуючи взаємозв'язок між кривими розробки, відновленням тиску, темпами зростання видобутку нафти і газу для різних періодів розробки, можливе коригування.***

Висновки. ***В результаті дослідження, проведеного з використанням динамічної моделі контрольних карт Шухарта, стало можливим контролювати та регулювати процеси розробки V горизонту родовища Балахани–Сабунчу–Рамана, яке є об'єктом експлуатації, а також визначати рівні оптимальності цих процесів та ефективність використання відповідних методів підвищення коефіцієнта вилучення нафти.***

Цей метод виявився ефективним у збільшенні видобутку, може ефективно підвищити виробничі показники під час процесу оптимізації, що має вирішальне значення для впровадження уточненого управління окремими горизонтами, визначення виходу за межі регулювання розробки.

Ключові слова: *криві розробки, контрольні карти Шухарта, відхилення, регулювання, оптимальна розробка, об'єкт експлуатації.*

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