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SCIENTIFIC & PRACTICAL FUNDAMENTALS FOR DEVELOPMENT OF NEW METHODS OF DIAGNOSTICS OF OIL FORMATIONS TO SELECT EFFECTIVE EOR (ENHANCED OIL RECOVERY) TECHNIQUE

Speciality: 2526.01 – Offshore development of mineral deposits
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THESIS ABSTRACT
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ELMİ KATİB

GENERAL DESCRIPTION OF WORK

The topicality and development degree of the subject.

Seeking for new solutions which are applied in an effort to most completely recover hydrocarbons is one of the major tasks of the sectoral science of oil and gas complex. In line with reliable estimates, under the current conditions for the development of oil fields (about 4 billion tons annually), the hydrocarbon reserves, which make it possible to recover more than 40% of the world's geological resources on average, will be depleted by the end of the 21st century. At the same time, the modern development of fundamental and applied science allows predicting an increase in the oil recovery factor (ORF) by an average of 8%. For fields in Azerbaijan that are in long-term development, the effect of an increase in oil recovery factor by 1% is comparable to the commissioning of a new large field. Therefore, the growth of oil production at fields under long-term developmet, by increasing the effectiveness due to stimulation of productive formations, is one of the priority areas on the way of innovative development chosen by State Oil Company of Azerbaijan Republic (SOCAR).

The mechanism of devising an innovative approach to the development of oil and gas complex (O&GC) is based on the wealth of experience accumulated in the field of oil and gas production. However, at this stage of the development of the oil industry, the possibilities of enhancing oil recovery (EOR) are significantly limited by the lack of information about the dynamics of the current state of reservoir processes.

An oil field at a mature stage of development at the current level of its informatization is a poorly managed system. Data on physical and chemical processes occurring in the layer system are not reliable enough and are fragmentary in nature. Multilevel connections of reservoir system objects - wells and reservoirs, combining into a single complex organism, lead to the appearance of new properties and regularities. Changing the mode of operation of a limited set of mutually interacting production and injection wells affects the work of all others. The absence of an organically built-in complex information system in the oil industry, which includes computerized collection and comprehensive analysis of information on the oil layer, does not allow to increase the efficiency of the oil production process to a modern level. The methodology of processing qualitative and quantitative information about extracted production, core material, the effectiveness of technological measures used for the intensification of oil production, allowing to optimize the choice of technique and technological impact on productive layers, could become the basis of this system. Using the proposed approach when collecting and systematizing industrial information allows you to form a unified vision of the field development process.

The lack of design and management solutions with dynamic information about the actual state of the researched processes contradicts the interests of the rational solution of development tasks. The creation of a methodology for diagnosing the reservoir system based on the processing of industrial and laboratory-experimental information in order to increase the reliability and completeness of the data about the state of the productive layers of the field acquires special relevance. The research direction developed has special relevance for offshore fields. According to experts, the estimated geological oil reserves located in the sedimentary rocks of the seas reach 70% of the total world volume and can amount to hundreds of billions of tons. Currently, about 20 offshore fields are being developed in Azerbaijan, a quarter of them are deep-water. Oil production is carried out on such deposits, as a rule, at a depth of 50 meters or more. Oil production in offshore areas is associated with high costs and technical difficulties, as well as with a number of external adverse factors. The costs of researching the state of the layer system in the development of offshore fields are significantly higher than those onshore. Obstacles to conducting diagnostic studies, which allow identifying the necessary conditions for effective results of offshore oil production, are often a high indicator of natural factors and large well depths, as well as the lack of sufficient reserves for placing equipment and conducting research in the conditions of marine hydrostructures, as costs increase in proportion to the depth and area used for placing the necessary equipment. The level of operational expenses increases as the recovery depth, hardness and thickness of the rock increases, as well as the distance of the industry from the coast and the complexity of the relief of the bottom between the production zone and the shore.

From the above, it follows that in the current conditions of Azerbaijan, the innovative transformation of the oil and gas complex cannot be instantaneous and widespread, and therefore it should be based on the creation of so-called oil production growth zones at various fields. Zonal reservoir stimulation, carried out in order to increase oil production in certain areas, can become the starting point in solving the general issue of boosting oil production at fields, allowing this process to move from a quantitative level to a qualitative stage over time. The advantage of zonal stimulation on productive formations is the availability of wide opportunities for the use of technological solutions and methodology for analyzing the effectiveness of ongoing activities, without attracting significant investments and expensive software systems.

To purposefully increase oil recovery factor by stimulating the formation, a preliminary analysis of the current state of the object of study, trends in the development of the treatment process, potential resources of the reservoir system and the expected timing of achieving the goal is necessary. This information makes it possible to evaluate the expected effect and possible consequences of the measures to enhance oil recovery.

This paper proposes a methodology for diagnosing the current state of the field and its individual zones in order to select effective reservoir stimulation. The use of the proposed methodology makes it possible to increase the efficiency of the oil production process by providing control over the technological processes for the impact on the reservoir used in oil production and optimizing the operating mode of production wells and the operation of injection wells. In accordance with the proposed methodology, the adoption of technological decisions is carried out with the involvement of an express analysis of field data and visualization of the information received, carried out using specially developed software tools. This allows to reduce the level of uncertainty of knowledge about the current state of the object of influence.

The above confirms that the scientific directions studied in the dissertation work are among the actual issues in the more efficient development of the oilfields. Providing solutions to these scientific issues is of vital importance in working out the rational processing methods of deposits and enhancing hydrocarbon recovery. Consideration of the above issues is very relevant and has important scientific and practical significance.

The object and subject of the research – techniques for diagnosing the current state of the subject of diagnosis, trends in its development in the process of artificial conditions and evaluation of potential resources. The subject of diagnosis can be both the field as a whole - a complex, highly organized dynamic system, and its individual components - zones of the productive horizon around a block, a group of wells or individual wells. Individual elements of the system, for example, rocks, fluids, processes of interaction between them, production functions, resources and organizational structure of oil and gas producing enterprises, the cost of technological operations, etc., can be considered as diagnostic objects.

Purpose and objectives of research.

The major purpose of the research in the dissertation work is to develop a new methodology for analyzing the state of the field and well productivity, which allows you to quickly identify current changes in the operation of the reservoir system. Decisions on reservoir stimulation made on the basis of diagnostics of the current state of productive horizons are used to form zones of production growth in oil and gas fields. To this end, the following tasks were solved in the work:

1. Studying the possibilities of boosting oil production in the offshore and onshore fields of Azerbaijan. Determination of a set of problems associated with the genesis of the zonal approach to the

problem of increasing oil production at fields during their long-term development;

2. Diagnosis of a productive reservoir based on the development of new and improvement of existing methods for assessing and visualizing changes in the current filtration state of the reservoir system in a selected area of the field, intended for carrying out measures to increase oil recovery;

3. Prospective assessment of the effectiveness of the planned stimulation on the reservoir based on the dynamics of standard field information;

4. Making decisions on the choice of a strategy for influencing productive strata in order to increase oil recovery according to the data of normal operation of wells in oil and gas fields onshore and offshore.

5. Analyzing the relationship between CO_2 content in dissolved gas and well productivity, assessing the impact of this factor on the state of the reservoir system in the vicinity of producing wells and on development indicators. Study of the possibilities of using this factor for the purpose of the current diagnostics of productive horizons and enhanced oil recovery.

Research methods. The tasks were set off by applying the methods of mathematical modeling and mathematical physics, information theory, programming, probabilistic-statistical and laboratory-experimental data analysis and field research.

Provisions for defence

1. A method for assessing the current state of the reservoir system according to well productivity data in the considered section of the field, which is at a mature stage of development, using the methods of function theory of a complex variable;
2. A method for assessing the state of oil field development and determining the spatio-temporal boundaries of the oil-water contact screen in the reservoir using the methods of fractal and multifractal analysis and the theory of wavelet transforms.
3. Combined methods of scientific substantiation of measures taken to enhance oil recovery.

4. Methods for using data describing the dynamics of the CO_2 content in the composition of the gas dissolved in the recovered product to assess and interpret the state of the reservoir.

5. A method for extracting responses to transient processes occurring in a reservoir in the dynamics of normal well operation data based on the calculation of information and fractal indicators.

Scientific novelty of the research

1. A science-based methodology for diagnosing a reservoir system is proposed when choosing methods for stimulating the reservoir in order to boost oil recovery.

2. A software package is proposed that is used for operational and long-term assessment of both the zonal and the general state of the reservoir system, in order to conduct and preliminary evaluate the effectiveness of planned measures to enhance oil recovery of productive reservoirs and select a strategy for artificial conditions on a reservoir;

3. Express methods for assessing the current distribution of the filtration characteristics of the movement of reservoir fluids in the productive reservoir of a zonal area are proposed, taking into account the interference of wells. The techniques are also applicable for processing laboratory and experimental results of studying the oil displacement process on a multi-point reservoir model;

4. Methods have been developed for analyzing the process of developing oil reserves from a reservoir using a spectrum of generalized fractal dimensions of drained reserves, Fisher and Shannon information indicators, wavelet theory, and diagnostics of the space-time boundaries of the oil-water contact front in the reservoir.

5. For the first time, it was proposed to use data on the content of CO_2 in the recovered production as an indicator of the state of the productive formation and the drained zone around the wellbore.

6. The use of the proposed methodology makes it possible to solve a number of field problems of practical importance. Among them:

– Obtaining information on the distribution of filtration flows in the reservoir system by calculation, without conducting tracer studies in field conditions;

– Determining the optimal amount of the agent required for treating water injected into the reservoir, taking into account the coverage of the productive reservoir by the impact on the selected area;

– Calculation of reservoir pressure redistribution caused by start-up, shutdown, or change in fluid production from wells, under the influence of measures taken to influence the reservoir under artificial conditions.

– Calculation and visualization of the distribution of phase permeabilities for liquid and gas in the studied zone of the productive formation according to well productivity data;

– Determining the localization of stagnant and active filtration zones during oil displacement from the formation and associated complications in the near-wellbore and drainage zone of wells;

– Calculation and visualization of the distribution of the current values of the stream functions, potential functions, their gradients and filtration rate, characterizing the filtration state of the productive formation when oil is displaced in a selected area with a group of operating wells;

– Quantitative assessment of the correspondence between the volume of injected water and the volume of recovered production for a group of wells, between which there is interference, in order to localize the water-cut.

– A new approach has been proposed for conducting detailed screening when choosing reservoir stimulation methods in order to increase oil recovery in accordance with the current state of the productive reservoir in the selected area.

– All of the above tasks were settled off with the help of the proposed software package on the example of field data of Azerbaijan fields, both onshore and offshore.

Theoretical and practical significance of the research. The theoretical and practical value of the performed research lies in the development of scientific and methodological foundations for diagnosing the current state of oil and gas field development. Qualitative and quantitative analysis, based on the results of the implementation of the calculation schemes proposed in this paper, can improve the technological level of decision-making to improve the efficiency of the oil and gas production process, both in the field as a whole and in limited zones of reservoir stimulation. A reasonable choice of methods for artificial conditions on a reservoir and the depression zone of wells is provided by quantitative assessment of the filtration characteristics of the movement of reservoir fluids in the productive reservoir of the zonal area, taking into account the interference of wells and visualization of their current distribution. The reservoir stimulation strategy, chosen based on the analysis of time series of development history data using fractal analysis methods, wavelet theory and information processing theory, makes it possible to operate the field not only on the principles of reservoir pressure maintenance, but also take into account the process of system self-organization.

In this sense, the results provided in the dissertation are of high importance. The methods and results proposed in the dissertation have been successfully used in the scientific-research works carried out at SOCAR "OilGasScientificResearchProject" Institute, and the results have been applied in production.

The outcomes of calculations and analysis carried out in accordance with the proposed methodology have been repeatedly used to study the dynamics of changes in the current state of the reservoir before and after the intervention to stimulate the reservoir in order to enhance oil recovery in the fields of Azerbaijan onshore and offshore and in Kazakhstan. Among them: onshore - Balakhany-Sabunchu-Ramana, Pirallahi, Zhetebay (Kazakhstan) fields, offshore - the Gunashli, Neft Dashlari, West Absheron fields. Based on the results of the generalization of the experience gained, the methodology for processing the results, diagnosing and predicting the processes under study was improved.

Approbation and application of work.

The main provisions on the content of the dissertation were discussed at the following international scientific conferences and forums:

– International conferences "Khazarheftgazyatag", 2002, 2004, 2006, 2008, Baku, Azerbaijan;

– "Natural cataclysms and global problems of the modern civilization" Special edition of Transactions of the International Academy of Science H&E 2007, Baku-Innsbruck,

– 10th International Congress on "Energy, Ecology, Economy", 2009, Baku, Azerbaijan;

– Russian oil and gas technical conference and exhibition, 2010, Moscow, Russia;

– II International scientific-practical conference "New technologies in oil production", 2012, Baku;

– International scientific conference "Non-Newtonian systems in oil and gas industry", 2013, Baku;

– Scientific workshops: subdivisions of oil and gas production of NIPI "Neftegaz", Research Institute "Geotechnological Problems of Oil, Gas and Chemistry", AGNA, Research Institute of Applied Mathematics of Baku State University Baku, Azerbaijan;

– SPE Annual Caspian Technical Conference and Exhibition, 2015, 2017, 2021, Baku, Azerbaijan;

– X Azerbaijan international geophysical conference "Assessment of the hydrocarbon potential of the South Caspian and similar depressions by geophysical research", Baku, Azerbaijan;

– 6-8th International Conference on Control and Optimization with Industrial Applications (COIA-2018, COIA-2020, COIA-2022). 2018, 2020, 2022 in Baku, Azerbaijan;

– "Bulatov Readings" Proceedings of the International Scientific and Practical Conference, 2018, 2020, 2022, Krasnodar, Russia;

– International Conference Dedicated to the 90th Anniversary of Academician Azad Mirzajartzadeh December 13-14, 2018, Baku, Azerbaijan.

– International scientific and practical conference "Technological innovations in modern world", November 28, 2019, Ufa.

63 scientific papers have been published on the topic of the dissertation, including 36 articles in journals recommended by the Higher Attestation Commission of Azerbaijan, 27 reports in collections of international and domestic scientific conferences.

The organization where the dissertation work was performed. "OilGasScientificResearchProject" Institute, SOCAR.

The total volume of the dissertation with a sign, indicating the volume of the structural units of the dissertation separately.

The dissertation work consists of an introduction, six chapters, 31 paragraphs, 11 conclusions and recommendations, a list of references presented by 339 titles and appendices. The amount of work, including 111 graphics and figures and 19 tables, is 367 pages of printed text. The volume of the dissertation work: introduction 11112 symbols, Chapter I 111932 symbols, Chapter II 58979 symbols, Chapter III 450557 symbols, Chapter IV 72346 symbols, Chapter V 56147 symbols, Chapter VI 30467 symbols. The total volume of the dissertation is 791540 characters.

Personal contribution of the author. The author directly participated in the planning of the scientific research presented in the dissertation, in defining the questions, choosing the research methods, creating the experimental apparatus and conducting the laboratory research. He led the selection of topics of all published scientific works and reports on the subject of the dissertation, the justification, the creation of the research methodology, the summaries of scientific literature and the analysis of the results.

The author was also the responsible executor of the scientific research works carried out at the SOCAR Institute "Oil and Gas Research Project", which formed the content of the dissertation.

The author remembers with deep gratitude the late academician A.Kh.Mirzajanzade, who supported and guided him at all stages of the work.
The author is grateful to Professor B.A.Suleimanov, his scientific adviser, corresponding member of ANAS, who helped a lot in the completion of the work.
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MAIN CONTENT OF THE DISSERTATION

The introduction gives reasons for the relevance of the conducted research, outlines the purpose and main tasks, the methods of solving the issues, the main provisions defended, shows the scientific novelty and practical significance of the results obtained, approval and application, the structure and scope of the work are reflected.

The first chapter covers the classification and system analysis of modern methods and tools for diagnosing the state of oil reservoirs. A scientific and practical substantiation of the chosen areas of research and prospects for their development was carried out. The chapter consists of seven paragraphs.

The first paragraph defines the goals and tasks facing the diagnosis of productive formations when choosing methods of stimulation to enhance oil recovery and the requirements for the initial information. It is considered how the general principles of allocation of objects of diagnostics correlate with the tasks of diagnostics. An assessment was made of general modern ideas about methods for diagnosing the structural and functional state of the system in the light of the choice of parameters for managing oil recovery of a productive formation during the development and operation of oil and gas fields.

In the second paragraph, based on the history of the formation of diagnostics, as an integral part of oilfield science, the main stages in the development of methods for diagnosing a reservoir system were identified, the principles for choosing EOR and assessing the boundaries of their applicability were considered. The place of zonal impact on the formation in the general theory of the formation of an innovative approach to the development of oil and gas complex is determined[1].

It is proposed to consider the zonal impact on the reservoir as a systemic factor, the purpose of which is to maintain and boost oil recovery, irrespective of the method chosen for application. The result of the impact, which determines the success of the measures taken, as well as a sign indicating the need and expediency of applying the impact, can be considered compensatory reactions of the reservoir system. Based on the assessment of the state of the reservoir in different areas of the fields, it is proposed to identify zones that have sufficient potential for additional development and need to be stimulated. An effective impact is selected in case of undesirable changes in the reservoir characteristics, in accordance with the criteria compiled on the basis of scientific and practical knowledge and the proposed methodological approach. Monitoring of the responses of the reservoir system to the intervention made it possible to classify the impacts on the reservoir not by type, but by timeliness, necessity, expediency and sufficiency. Using the proposed diagnostic approach and existing methods to improve the efficiency of oil production, it is possible to influence productive formations in local areas of the field, thereby transforming zones with a low oil recovery factor into zones of oil production ramp-up.

This allows you to save and enhance the oil recovery of productive layers, to prevent premature transition of the field to the next stage of development.

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[1] Гусейнова Н.И. О преимуществах зонального подхода при моделировании гидродинамических процессов в пластах нефтяных месторождений на поздней стадии разработки. Строительство нефтяных и газовых скважин на суше и на море. ISSN 0130-3872, 2017, №8, с.37-39

The first chapter also back up with facts the accuracy of the proposed methods for modeling reservoir processes with zonal stimulation of the reservoir, using which it is possible to purposefully group areas according to a selected attribute and develop strategies for converting various types of limited impact zones into areas of oil production growth.

The third and fourth paragraphs discuss modern methods and tools for obtaining and storing information arrays used to diagnose the state of productive formations in the development of oil fields, as well as the use of mathematical modeling methods, software calculation and visualization tools for diagnostic processing and interpretation of field data. One of the means to justify the effectiveness of ongoing measures to enhance oil recovery is the use of digitalization of the processes occurring in the reservoir.

The fifth paragraph is devoted to methods for diagnosing the reservoir system using new approaches to modeling field development and interpretation of field data in order to enhance oil recovery. An assessment was made of the merits and demerits of diagnosing the current state of the field based on the globalized and zonal approach when choosing a development strategy. Insufficient interest in the methodology of zonal reservoir stimulation, technical and socio-economic difficulties associated with the collection and storage of field data, the use of a globalized approach in hydrodynamic modeling of reservoir processes, covering the entire field as a whole, hinder the development and use of zonal digitalization in an oil field. Development of a methodology for zonal stimulation of the reservoir based on the creation of new and improvement of already known methods for assessing and visualizing changes in the filtration state of the reservoir system in a selected area of the field, the creation of corporate data banks on the effectiveness of methods of zonal stimulation of the reservoir, along with a general system for collecting and systematizing reliable field information solves the above problems.

The possibilities of monitoring and detailed statistics of the field development process in order to identify critical states of the reservoir system are considered. Regular visualized analysis of changes in hydrodynamic and geomechanical characteristics contributes to the control and management of the development of oil and gas fields. To solve the tasks set, it is proposed to use the methods of fractal and multifractal data analysis using the theory of wavelets, elements of the theory of signal processing, etc. The implementation of computational methods based on advanced scientific research is proposed to be carried out by using software modules presented in the form of additional software patches (program patch), and the choice of parameters for controlling the state of the reservoir system during field development is proposed from the standpoint of structural, functional and model diagnostics.

The sixth and seventh paragraphs of the first chapter are devoted to this question.

Thus, in the first chapter, it is proposed to consider the development of new methods for diagnosing the reservoir system as an integral part of solving the general problems of increasing oil production in the fields. This provides a real way out to the management of reservoir processes, which allows to achieve the advanced development of the entire industry, which is the central strategic task facing SOCAR.

On the basis of the conducted research, the following conclusions were drawn:

– On the way of scientifically substantiated choice of the most effective technologies for influencing reservoirs in order to enhance oil recovery, there is a need to solve problems to improve diagnostic methods and criteria for assessing the state of the reservoir system and the timeliness of reservoir stimulation. At the same time, both theoretical and practical aspects of this task are equally important.

– It is necessary to search for alternative ways to increase the efficiency of diagnostic methods that allow making decisions on optimizing the operation of the well system, which is different from the traditional optimization of the operation mode of each well separately.

– New diagnostic methods should organically fit into the system of digitalization of technological processes, automated collection, processing and analysis of data and take into account the fact of mutual influence of well operation among themselves. This will make it possible to analyze the synergistic interaction of reservoir processes that ensure the behavior of hydro- and gas-dynamic filtration flows, both in the drained zone of the wells and in the crosshole space of the productive reservoir.

– There is a demand for methods of diagnostic analysis of the current state of development and its compliance with the laws of self-organization of reservoir processes when planning a general strategy for field development. The availability of methods that make it possible to discard noise distortions in the information flow and to identify patterns of internal order in the general deterministic chaos of reservoir processes make it possible to control it, while the noise chaos becomes uncontrollable.

– Reducing the level of uncertainty when choosing a method of stimulation of the formation provides an opportunity to refrain from the use of expensive and energy-intensive technologies and use the natural energy capacity of the productive formation. Increasing the flexibility of managing the development process creates conditions for the formation of a well-thought-out tactics and strategy for the development of the field.

– Since the reservoir is a heterophase metastable self-organizing system, the combined use of diagnostic methods of analysis has a high potential, when the results of one study are the object of study of other methods. This approach allows you to more reasonably allocate the parameters of the development process management[2].

The second chapter provides justification of and scientific background for the development of a method for carrying out express

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[2] Сулейманов Б.А., Гусейнова Н.И. Прогнозирование нефтедобычи от планируемого мероприятия, с учетом интерференции скважин. // Proceedings 2014, №1, с. 31-38.

monitoring of the current hydrodynamic state of the productive strata of oil fields, taking into account the interference of wells under zonal stimulation in order to increase oil recovery[3]. It should be noted that the developed approach for assessing the state of the reservoir system has great prospects for application in offshore fields, since it is based on mathematical processing of standard measured data from normal well operation and does not require special equipment or additional measurements of any indicators. The method for diagnosing the hydrodynamic state of the reservoir system in the studied area of the productive horizon was developed on the basis of the application of methods of the theory of complex potential functions. The chapter consists of three paragraphs. The first paragraph provides the necessary information from subsurface hydrodynamics, the theory of complex-variable function, outlines the principles and algorithms underlying the hydrodynamic express monitoring of zonal impact on productive strata of oil fields, taking into account well interference, and the feasibility of the outcomes obtained are validated by mathematical calculations. The results of the research are formulas that allow calculating for each cell of the grid superimposed on the studied zone of the field, the values of the stream functions and potentials F_1 and F_2, the characteristic function of the flow or the complex potential F, the modulus of the filtration rate W, the gradient of the function $F(x, y)$.

İnjecting wells are taken as sources (*debit* < *0*), and production wells are taken as sinks *(debit > 0)*. The task is solved in the Cartesian (x_k, y_k) and polar coordinate (r,φ) systems::

$$z_k = x_k + i \cdot y_k = r_K \cdot e^{i \cdot \phi k} \tag{1}$$

Complex potential:

$$F = F_1 + i \cdot F_2 \tag{2}$$

[3] Гусейнова Н.И. Гидродинамический экспресс-мониторинг зонального воздействия на продуктивные пласты нефтяных месторождений с учетом интерференции скважин. // Нефтегазовое дело, Уфа, 2017, т.15, №3, с. 41-47.

According to the principle of superposition applied to the source and flow points operating at the same time in the layer:

$$F_1 = \sum_{i}^{n}\sum_{k=1}^{K}\sum_{j=1}^{J}\frac{q_i}{2\cdot\pi}\ln(r_i(\mathrm{k},\mathrm{j})) \qquad F_2 = \sum_{i}^{n}\sum_{k=1}^{K}\sum_{j=1}^{J}\frac{q_i}{2\cdot\pi}\cdot\varphi_{i,j} \qquad (3)$$

Modulus of filtration rate:

$$W = \left|\frac{dF}{dz}\right| = \sum_{i}^{n}\sum_{k=1}^{K}\sum_{j=1}^{J}\frac{q_i}{\pi\, r_i(\mathrm{k},\mathrm{j})} \qquad (4)$$

The gradient of the function $F(x,y)$:

$$grad(F)= (dF(x,y)/dx)\cdot i_v+(dF(x,y)/dy)\cdot j_v \qquad (5)$$

Where: z_k, x_k, y_k –the coordinates of well number к expressed in complex and real numbers, respectively;
r_κ , φ_κ – the distance and polar angle from well number к to the starting point of the coordinate system, respectively; $\kappa =1, \ldots n$ - the number of wells in the field of application, i – imaginary unit, q_κ, F_1, F_2 – flow rate of the kth well, the potential of the filtration rate and the liquid flow per unit (i.e. per 1 metr of filter), respectively;

The above hydrodynamic characteristics are determined in accordance with the principle of superposition to the sources and sinks simultaneously operating in the reservoir. As initial data for calculations, the values of the current flow rate of production wells and the wells injectivity, the coordinates (xi, yi) of each of the n wells operating in this area from the considered horizon are required. The well coordinates are necessary to determine the distance between any grid cell with index k, j to the i well and the polar angle that determines the position of the radius vector in relation to the unit basis vectors i_v, j_v.

Based on the existence of interference between wells, which are taken as sources and sinks, a system of methods for diagnosing the current filtration state of a productive formation in the area where the wells are located has been developed. Digital visualization of streamlines and equipotentials, reservoir flow rate and their gradient vectors, pressure change areas and other characteristics of the reservoir system are carried out, using the color scale.

On the figure 1 it is showed the results of the visualization of the hydrodynamic properties distribution of the KS_v productive layer filtration state in the pilot area of the Pirallahi oilfield.

The position of these geometric objects relative to each other, both on the plane and in space, makes it possible to identify the main directions of fluid movement in the reservoir, to identify active and passive filtration areas due to well operation in interference conditions and the geological and physical properties of the reservoir system. At the same time, visualization is carried out directly for the planned impact zone, without involving a simulation hydrodynamic model of the entire field as a whole.

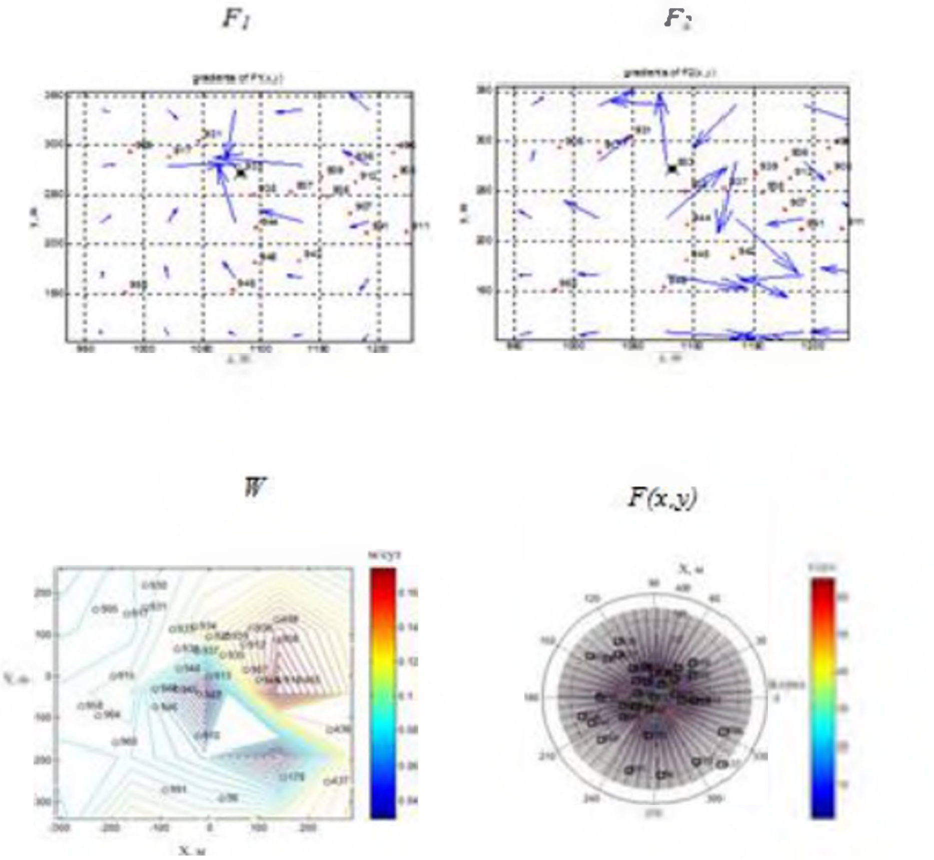

Figure1. The visualization of the of the hydrodynamic properties distribution of the KS_v productive layer filtration state in the pilot area of the Pirallahi oilfield.

The performed calculations are accompanied by an explanation of the ways of interpreting the results obtained. The second and third paragraphs provide information on the progress of research work to identify the reliability of the results obtained. The proposed method was previously tested in laboratory and experimental conditions during the analysis of data obtained in the course of research work on oil displacement from a five-spot reservoir model. The approbation results are compared with the results of preliminary calculations. The reliability of the results obtained during the diagnostics of the reservoir system using the proposed approach is confirmed by the outcomes of tracer studies carried out at Oil Rocks field[4]. The research outcomes are provided in the third paragraph. Approbation of the proposed method in the course of zonal impact on productive formations in order to increase oil recovery in such fields onshore and offshore as Balakhani-Sabunchu-Ramana, Pirallahi, Oil Rocks, Gunashli (Azerbaijan), Zhetybai (Kazakhstan) made it possible to develop the principles and the procedure for interpreting the obtained calculated and visualization information[5].

– The use of the developed method of data analysis, taking into account well interference, rationalizes the zonal impact on the reservoirs, visualizing the response of the reservoir system to the planned event. Regular analysis of the dynamics of changes in the above filtration characteristics, visualized using the proposed method, contributes to the control and management of the

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[4] Ибрагимов Х.М., Гусейнова Н.И., Гаджиев А.А. Разработка новых методов контроля над воздействием на продуктивные пласты на примере месторождения "Нефт Дашлары"//«Scientific Petroleum» , 2021, с. 37- 42.

[5] Suleimanov Baghir, Huseynova N.İ. , Rzayeva Sabina & Tulesheva Gulnar Results of Acidizing Injection Wells on the Zhetybai Field (Kazakhstan) //Journal: Petroleum Science and Technology Petroleum Science and Technology,Volume 36, 2018 - Issue 3 Pages 193-199.

development of oil and gas fields. The research results led to the following conclusions:

– The developed and tested technique for express-monitoring of the reservoir system, taking into account well interference, can be used to diagnose the hydrodynamic state of productive reservoirs of oil fields that are at a mature and late stage of development, with zonal stimulation of the reservoir in order to increase oil recovery.

– The technique is based on the application of methods of the theory of complex potentials. Both before and after the impact on the formation, the calculation and visualization of the distribution of the hydrodynamic characteristics of fluid movement in the rocks of the productive formation is carried out - the functions of the current and potentials, and their gradients, filtration rate. The filtration situation in the reservoir is estimated and compared with a system of interacting wells operating from a given horizon.

– The method includes the procedure for automating the calculation and visualization of the main characteristics of the distribution of the soakaway, implemented in the interactive environment of the "Matlab" program. The entire analysis process from collecting information about the site to generating a report with the interpretation of analytical results lasts 1 to 3 days. The calculation procedure takes about 30 minutes.

– The obtained results are confirmed by the data obtained during laboratory and experimental studies of oil displacement on the physical reservoir model and field conditions with tracer studies, which are confirmed by the test report[6]. One-time cost savings for obtaining results that replace tracer studies amounted to 62.9 thousand manats.

– The possibility of promptly conducting a diagnostic study of the current filtration state of the reservoir, based on the processing of

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[6] Гасымлы А.М., Гусейнова Н.И., Мусаева Ш.Ф. Анализ распределения фильтрационного потока, созданного в физической модели пласта. / Ученые записки НИИ «Геотехнологические проблемы нефти и газа и химия», 2012, XIII том, с. 100-113.

systematically measured indicators of the productivity of injection and production wells in a selected area of the field, has been confirmed by many years of practice using this method in the oil fields of Azerbaijan with zonal impact on productive formations in order to increase oil recovery.

The method makes it possible to use more accurate information to select the best scheme for influencing the reservoir and to improve the methods used for stimulating the productive formation in order to increase their oil recovery.

The third chapter gives insight into the development of a method for estimating the pressure gradient required to stimulate the reservoir in order to control its leak-off capacity. The change in the stress-strain state (SSS) of the reservoir, due to the redistribution of its filtration characteristics, is estimated taking into account the interference of wells in the area selected for the stimulation[7]. The deformation of the near-wellbore zone of operated wells, in turn, leads to a non-uniform redistribution of reservoir properties in certain areas of the field. Accordingly, the quality and quantity of products produced at the wells are changing. Therefore, the paper proposes, when carrying out measures aimed at increasing oil recovery, to assess the impact on the reservoir, taking into account not only filtration, but also its geomechanical properties that change during the operation of the field. The chapter consists of six paragraphs. The first two sections present the problem statement, information from the theory of continuums necessary for its solution, and mathematical calculations.

The third chapter is devoted to the problem of determining the stress and reservoir pressure during fluid filtration in a disturbed zone around a cylindrical working in a medium whose behavior has an elastic and viscoelastic character. The proposed estimation

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[7] Гусейнова Н.И. Оценка градиента давления при воздействии на пласт с учетом влияния интерференции скважин на деформационные и фильтрационные процессы на выделенном участке месторождения.// SOCAR Proceedings No.1 (2017) 070-82.

method is based on determining the pressure gradient, the value of which depends on the change in the components of the average normal stress of the reservoir rocks, which change over time under the influence of filtration processes in the reservoir environment:

$$\boldsymbol{\sigma} = \boldsymbol{\sigma}^{n} + \boldsymbol{\sigma}^{t} \quad (6)$$

Where: σ^n, σ^t, - average normal stresses around the well at the initial and current time.

As a result of the studies, an analytical expression was obtained that reflects the change in stress values around the wellbore in the horizon dominated by sands, sandstones, basalts, that is, rocks whose behavior is described using an elastic model. The values of physical-mechanical and rheophysical indicators characterizing the "well-formation" system are used as initial data when calculating stresses. If $t=0, \Delta p = 0$ then $\sigma^t = 0$. σ^t is determined at a fixed pressure $\Delta p = const$, Δp - chancing of pressure between the formation and the well, Pa.

At the same time, the value of the initial stress σ^n at the inner boundary of the stress-strain state change zone balances with the hydrostatic pressure in the wellbore, and at the outer boundary with the sidewall pressure of the formation:

$$\sigma_{rr}^{n} = \begin{cases} -j_m h, & r = r_0 \\ -j_s \xi h, & r = r_1 \end{cases} \quad (7)$$

Where:

j_m, j_s – density of liquid and rocks, respectively, kg/m^3;

$h = h_2 - h_1$ - layer thickness;

h_1 h_2 – upper and lower contacts of the productive horizon, respectively, m;

H – vertical depth of the well;

P_h – hydrostatic pressure in the well, Pa;

Py —side mountain pressure, Pa;

The radial component of the current stress under the influence of constant external forces σt becomes zero at the boundaries of the disturbed zone:

$$\sigma'_{rr} = \begin{cases} 0, & r = r_0 \\ 0, & r = r_1 \end{cases} \tag{8}$$

In the disturbed zone of the initial stress-strain state of the layer, the rocks are deformed and the radius r of the disturbed zone increases u $(u > 0)$. The strain components ε_{rr} and $\varepsilon_{\varphi\varphi}$ are expressed by u as follows:

$$\varepsilon_{rr} = \frac{\partial u}{\partial r} \text{ и } \varepsilon_{\varphi\varphi} = \frac{u}{r} \tag{9}$$

Where:

ε- deformation;

ε_{xy} - component of the strain tensor

u – displacement vector, increase of the radius r during the deformation of the medium in the disturbed zone, m;

From the inverse form of the generalized Hooke's law, it is known that the initial stress state corresponding to the solution of the axisymmetric problem and the condition $\varepsilon_{zz}=0$ is described as follows:

$$\begin{cases} \sigma^{\text{н}}_{rr} = \dfrac{2G}{1-2\mu}\left[(1-\mu)\dfrac{\partial u}{\partial r} + \mu\dfrac{u}{r}\right] \\ \sigma^{\text{н}}_{\varphi\varphi} = \dfrac{2G}{1-2\mu}\left[\mu\dfrac{\partial u}{\partial r} + (1-\mu)\dfrac{u}{r}\right] \\ \sigma^{\text{н}}_{zz} = \dfrac{2G}{1-2\mu}\left[\dfrac{\partial u}{\partial r} + \dfrac{u}{r}\right] \end{cases} \tag{10}$$

Where:

G – shear modulus in the rock matrix, Pa;

μ - Poisson’s ratio.

For the deformations caused by creep processes, the general forms of the relationship between stresses σ and strains ε determined for a two-phase medium are used:

$$\begin{cases} \boldsymbol{\sigma}_{rr}^{t} = \dfrac{2G}{1-2\mu}\left[(1-\mu)\dfrac{\partial \boldsymbol{u}}{\partial \boldsymbol{r}} + \mu\dfrac{\boldsymbol{u}}{\boldsymbol{r}}\right] - k\Delta p \\ \boldsymbol{\sigma}_{\varphi\varphi}^{t} = \dfrac{2G}{1-2\mu}\left[\mu\dfrac{\partial \boldsymbol{u}}{\partial \boldsymbol{r}} + (1-\mu)\dfrac{\boldsymbol{u}}{\boldsymbol{r}}\right] - k\Delta p \\ \boldsymbol{\sigma}_{zz}^{t} = \dfrac{2G}{1-2\mu}\left[\dfrac{\partial \boldsymbol{u}}{\partial \boldsymbol{r}} + \dfrac{\boldsymbol{u}}{\boldsymbol{r}}\right] - k\Delta p \end{cases} \qquad (11)$$

Where:

$k = \dfrac{k_s \alpha_m \beta}{3\gamma_s} B$ - coefficient of deformation caused by filtration processes in rocks, , s^{-1};

κ_s – coefficient of filtrasion, m/s;

α_s, α_m – volume compressive modulus of the rock and the fluid saturating it, respectively;

Δp – pressure difference between the layer and the well, Pa.

The general solution of system (10) is found using the equilibrium equation:

$$\frac{\partial \boldsymbol{\sigma}_{rr}}{\partial \boldsymbol{r}} + \frac{\boldsymbol{\sigma}_{rr} - \boldsymbol{\sigma}_{\varphi\varphi}}{\boldsymbol{r}} = 0 \qquad (12)$$

Boundary and initial conditions and the principle of superposition allow obtaining the dependence of stress components on the properties of the medium:

$$\begin{cases} \sigma_{rr} = A_1 + \frac{(2\mu - 1)}{1-\mu} \cdot C_1 \\ \sigma_{\varphi\varphi} = A_2 - \frac{(2\mu\text{-}1)}{1-\mu} C_2 \\ \sigma_{zz} = A_3 + \frac{(2\mu - 1)C_3}{1-\mu} + \frac{\mu}{1-\mu} \Delta pk \end{cases} \quad (13)$$

Where:
ξ – is coefficient of horizontal stress;
A1, A2, A3, C1, C2, C3 –is coefficients calculated based on the rheo-physical parameters of the reservoir system, Pa;

An analytical expression was also obtained to calculate the stress values in the disturbed zone around the wellbore, the crust is dominated by rocks containing clay, as well as salt-bearing deposits and gypsum, the behavior of which is described using a viscoelastic model. Using the obtained expressions, the change in the stress values around the wellbore in the depression zone of the wells is determined, depending on the physical-mechanical and rheophysical indicators that change over time, characterizing the "well-formation" system. The calculation takes into account that the deformation processes around the well take place from the beginning of drilling and continue until the current date of the well operation period. To take into account the creep factor of rocks, the Laplace transform was applied. The solution for a viscoelastic medium was obtained as a result of the inverse transformation of the expressions obtained to determine the values of the stress component elements, having previously replaced the elastic constants with viscoelasticity operators. To determine the dynamics of changes in the stress components in a medium whose behavior has a viscoelastic nature, the expansion theorem was also used. In accordance with the table of originals and images of functions, the transition from images to originals was carried out:

$$\begin{cases} \sigma_{rr}^{v.e}(S) = (\sigma_{rr})/S \\ \sigma_{\varphi\varphi}^{v.e.} = (\sigma_{\varphi\varphi})/S \\ \sigma_{zz}^{v.e} = (\sigma_{zz})/S \end{cases} \qquad (14):$$

Where:

S- variable conversion;

$v.e.$ – the stress-deformation state of the medium is described with the help of a viscoelastic model when it is viscoelastic;

The solution of the problem for the viscoelastic medium can be obtained by first replacing the elastic constants in the equations of the system (13) with the viscoelasticity operators and then applying the inversion of the expressions $\sigma_{rr}^{v.e}(S), \sigma_{\varphi\varphi}^{v.e}(S), \sigma_{zz}^{v.e}(S)$.

As a result of the research, an analytical expression was obtained that reflects the change in stress values around the wellbore in the horizon dominated by sands, sandstones, basalts, that is, rocks whose behavior is described using an elastic model:

$$\sigma = \frac{A_1 + A_2 + A_3}{3} + \frac{(2\mu - 1)}{3(1-\mu)}\left(C_1 - C_2 + C_3\right) + \frac{\mu}{3(1-\mu)}\Delta pk \qquad (15)$$

The values of the physical-mechanical and rheophysical indicators characterizing the "well-reservoir" system are used as primary data during stress calculation.

An analytical expression was also obtained for the calculation of stress values in the disturbed zone around the wellbore, dominated by clay-bearing rocks, as well as saline sediments and gypsum, whose behavior is described by a visco-elastic model:

$$\sigma^{e.v}(t) = \frac{(A_1 + A_2 + A_3)}{3} + \frac{(2\mu - 1)}{3(1-\mu)}(C_1 - C_2 + C_3)e^{-\theta t} + \frac{(1-\mu)^2}{\mu^2}\Delta pk\left[\frac{(2\mu-1)}{G(1+\mu)}\eta(e^{-\theta t} - 1) + 1\right]$$

(16)

Also in the paper, dependence is derived that reflects the change in reservoir pressure P in the depression zone of the well over time for the case of fluid filtration in a deformable porous medium. The expression used to determine the change in pressure contains the expansion coefficients $T_{m,n}(t)$, cylindrical Bessel functions of the imaginary argument, zeros of the Bessel function $K_0(\mu_r)$ μ_m, the value of which, in turn, is determined using the data characterizing the system "well-formation". Among them, the pressure in the reservoir that exists before the application of deformation loads on the rock p_0, the current reservoir pressure at the inner and outer boundaries of the disturbed zone p_1, p_2, the pore pressure coefficient β, the coefficient characterizing the volumetric properties of the rock saturated with fluid B, the porosity of the rock m, the volume water weight αп, coordinates of the well in a cylindrical system (r, φ, z), total number of production and injection wells $(i=1,...n)$ in the area under consideration, constants characterizing the creep of the medium λ, a. Also, when calculating the components of the average normal stress around the well, data characterizing the profile and trajectory of the well are taken into account, such as the deviation of the well from the vertical l, the angle of deviation of the well from the vertical α, coefficients depending on the values of the zenith angle, azimuth and angle of rotation of the well radius α_1, α_2, α_3, α_4, α_5, well filter length d, wellbore and vertical depth.

A formula is also proposed for determining the rock fracture gradient, the value of which depends both on the values of the mean normal stress components and the tensile strength of the rocks in the vicinity of the considered well T_j and the number of injection wells s and production wells $n-s$ in the area under consideration:

$$\boldsymbol{F}_j = 3\boldsymbol{\sigma}_{jrr} - \boldsymbol{\sigma}_{j\varphi\varphi}\cos(\alpha) + \boldsymbol{\sigma}_{jzz}\sin(\alpha) + T_j + P_j \qquad (17)$$

Where:

T_j - tensile strength of the rock, Pa;

P_j – formation pressure, Pa;

α - the angle of deviation of the well from the vertical,degrees;

–Methods for assessing the distribution of the stress zone in the study area, taking into account the interference of wells and determining the pressure gradient necessary to provide effective impact on the formation, are proposed in the fourth and fifth paragraphs.

–In the sixth paragraph, the results of the numerical implementation of the developed methods are presented on the example of these Gunashli fields. Using the methodology for calculating the change in stress and reservoir pressure drop for one of the blocks of the field, where water has never been injected into the reservoir, a preliminary quantitative assessment of the expected oil production for the period of the planned future injection was made. An assessment was made of the pressure gradient necessary to influence the reservoir in order to control its throughput. Diagnosis of the current state of the reservoir system based on the redistribution of the characteristics of the soakaway, due to changes in the stress-strain state of the reservoir, taking into account the interference of wells operating in the area allocated for the stimulation, makes it possible to justify the interventions on the reservoir aimed at increasing oil recovery. The following results were obtained during the research:

– It is proposed to control the leak-off capacity of the reservoir based on the method of assessing the pressure gradient required to influence the reservoir.

– An algorithm and a software module for calculating the stress and pressure in the reservoir system were developed, taking into account the interference of wells operating in the selected area of the field, implemented in the interactive environment of the "Matlab" program.

– The change in the stress-strain state in the "well-formation" system is estimated by calculating the average normal stresses, both for elastic and viscous-elastic media.

Diagnosis of the current state of the reservoir system based on the redistribution of the characteristics of the soakaway, due to changes in the stress-strain state of the reservoir, taking into account the interference of wells operating in the area allocated for the stimulation, makes it possible to justify the interventions on the reservoir aimed at increasing oil recovery.

The fourth chapter carries on an investigation to study the development of technology for using data on the content of reservoir carbon dioxide in the gas dissolved in the produced gas to diagnose the state of the reservoir system and solve problems related to enhanced oil recovery, implemented in the interactive environment of the "Matlab" program. The chapter consists of six paragraphs. The necessity of a common system for analyzing development indicators for monitoring and controlling the formation of CO_2 in the reservoir is substantiated. On the example of development indicators at Gunashli field, the patterns of formation and changes in the concentration of CO_2 in the reservoir, the relationship between the salinity of formation water and development indicators were revealed.

To diagnose the state of productive formations and analyze development indicators in a limited area of an oil field, various methods are developed and applied based on determining the parameters of the "well-formation" system using fixed input and output signals. In the conditions of elastic mode, after starting and stopping the well, in the vicinity of the bottomhole of the wells of the studied area, the processes of pressure redistribution proceed for some time. Changes in bottomhole and reservoir pressure lead to a shift in chemical equilibria in the reservoir fluid, which cause phase transitions between liquid and gas. This changes the quantitative and qualitative composition of the formation fluid and the gas dissolved in it, which also depends on the lithological composition of the rocks they saturate.

The change in the physical and mechanical parameters of the reservoir system directly depends on the processes occurring in the reservoir. Among them are chemical reactions that react almost instantly to changes in reservoir equilibrium. The time it takes to change the physical and mechanical parameters of the reservoir system is often much longer than the time of chemical reactions between the elements that make up reservoir rocks and fluids. Therefore, the results of measuring the concentration of any products of chemical reactions occurring both in the near-wellbore zone of the reservoir and in the wellbore, for example, carbon dioxide (CO_2), make it possible to assess the state of the reservoir zone using the constructed concentration change curves.

Measurements of the concentration of CO_2 in the composition of the dissolved gas and the concentration of carbonic acid ions in the formation water at the wellhead can be used as a kind of indicator that reacts both to pressure changes at the bottomhole and in the wellbottom zone of the formation, and to the state of permeability in the well drainage zone (skin factor).

This conclusion was made on the basis of the identified patterns between the formation and change in the concentration of CO_2 in the reservoir and changes in the parameters characterizing the "well-reservoir" system, the presence of significant correlations between them[8].

– A high concentration of carbon dioxide is characteristic of many fields in Azerbaijan. In the productive horizons of the Guneshli field, a gradual increase in the concentration of carbon dioxide in the dissolved gas is observed. At Oil Rocks field, the amount of carbonic acid ions in the produced water has increased at some horizons. For all fields of Absheron, a pattern of changes in the chemical composition of produced water was noted, namely, an increase in the concentration of carbonic acid ions HCO^{3-}.

– Limits of change of CO_2 concentration in the composition of the dissolved gas are different for different productive horizons. The amount of carbonic acid ions in formation water also increases with time.

– Chemical processes, as a result of interaction of which there is a change in the composition of fluids in the formation, including the formation of CO_2, occur over a period of about several days. Therefore, the content of CO_2 in well production can be used as a diagnostic indicator of changes in the state of the reservoir system.

– There is an inverse correlation between the concentration of CO_2 and the content of methane (CH_4) and its homologues in the

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[8] Гусейнова Н.И. Анализ возможности управления концентрацией углекислого газа в пласте. // АНХ, 2007, №2, с. 26-30.

composition of the dissolved gas at Gunashli and Oil Rocks fields. The formation of CO_2 in the reservoir is facilitated by the oxidation of naphthenic acids. The concentration of CO_2 in the composition of the dissolved gas is not a constant value for a given well and varies over a wide range.

– The periodicity of the correlation between the change in the values of CO_2 concentration and the time between measurements was revealed. In the bottomhole zone of the well, a gradual accumulation of carbon dioxide occurs, which reaches a certain critical value over a certain period of time (from 1.5 to 3 months). The value of the critical concentration depends on the physical-mechanical, chemical, deformation and thermal properties of the formation in the bottomhole zone of the well. Due to the fact that these properties change over time and are different for several wells, the value of the critical concentration of CO_2 in different periods of time will also be different.

– CO_2 migrates through the reservoir with different advance rates. The outflow rate of carbon dioxide with a specific gravity of 1.52 is almost 8 times less than the outflow rate of the hydrocarbon part of the gas with a specific gravity of 0.580. Consequently, the content of CO_2 in the reservoir gas increases.

– The increase in the concentration of CO_2 in the composition of the dissolved gas is associated with a decrease in reservoir pressure in the productive horizon.

– A correlation has been established between the CO_2 concentration and the location of the oil-water contact.

– There is a significant correlation between water flow rates and CO_2 concentration.

– At many fields in Azerbaijan, the temperature and pressure in reservoir conditions are above the critical values for CO_2. Therefore, in the reservoir it is in supercritical conditions. To this end, it is almost completely soluble in water. CO_2 can be present in formation water in various forms: in the form of free carbon dioxide H_2CO_3 and in the form of HCO^{3-}, CO_3^{-2} ions.

– Concentration of ions in formation water depends on salinity (ionic strength) and alkalinity of water (pH).

– Between the content of the first carbonic acid ion HCO^{3-}, a direct relationship was found with the ionic strength of water, the content of CO_3^{-2} ions, salts of naphthenic acids, Na-, K-. From the characteristics of Palmer, a direct relationship is observed with primary alkalinity. An inverse relationship is observed between the content of the first carbonic acid ion HCO^{3-} and the content of Ca^{+2} and Mg^{+2} ions and other Palmer characteristics - primary and secondary salinity, secondary alkalinity.

– Between the content of the second ion of carbonic acid CO_3^{-2}, a direct relationship was found with the content of HCO^{3-} ions, salts of naphthenic acids. From the characteristics of Palmer, a direct relationship is observed with primary alkalinity. An inverse relationship is observed with the content of Ca^{+2} and Mg^{+2} ions and other Palmer characteristics - primary and secondary salinity, secondary alkalinity. The presence of these relationships can be used in the development of reservoir stimulation methods.

– Based on the application of the Debye-Hückel theory of ionic equilibrium to the results of chemical analysis of formation water, a calculation procedure has been developed for determining the percentage of various forms of CO_2 both in reservoir and under standard conditions.

– Methodological bases for calculating the pH of formation water, both in formation and under standard conditions, have been developed based on the results of studying the relationship between the concentration of CO_2 in dissolved gas and the pH of formation water, its ionic strength and the content of bicarbonate ions in it.

– The content of carbon dioxide in formation water is interconnected with the concentration of Ca^{+2} ions. Based on the results of calculating the amount of free carbon dioxide and the concentration of calcium ions in the formation water, the value of the carbon dioxide concentration at which the dissolution of carbonate rocks occurs is determined[9].

The fifth chapter consists of three paragraphs and looks into the development of a method for determining the state of the reservoir system of a productive reservoir, based on the calculation of Fisher, Shannon entropies and other information indicators for time series compiled by volumes of produced and injected products. Based on their dynamics, early diagnostics of the time boundaries of the stage evolution of the field and its individual zones is carried out, as well as an assessment of the compliance of the state of oil production with the planned impact on the reservoir The problem is solved on the example of field data of the oil field Fortis (Fortis) for *27* years (*n=324*).

The first two paragraphs present the formulation of the problem, as well as the necessary background from information theory and mathematical calculations. In the second paragraph, the development of an algorithm for solving the problem is carried out using real data as an example. The standard verification procedure determines the distribution of given time series. The values in the presented series are a discrete representation of a signal of a continuous nature and have different probability of occurrence, which significantly affects the entropy estimate[10]. Therefore, formulas with a probability density distribution function are used for calculations. For each of the time series, the following calculations are performed:

After normalization, as a result of which the distribution function F is obtained for each time series, a polynomial approximation of the distribution in time is carried out. For each time series, the mathematical expectation and variance are calculated. Further, according to the corresponding formulas, for each time series

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[9] Гусейнова Н.И. Изменение концентрации CO_2 в нефтесодержащих пластах и влияние этого фактора на показатели разработки месторождения. // АНХ, 2006, №12

[10] Сулейманов Б.А. Гусейнова Н.И. Анализ состояния разработки месторождения на основе информационных показателей Фишера и Шеннона.// «Автоматика и телемеханика», 2019, No. 5, pp. 118-185.

information characteristics are determined according to Fisher *FIM* and Shannon *H*, entropy power *N* and the amount of information according to Fisher I_f and Shannon I_{sh}, Entropy change rate, respectively, according to Fisher and Shannon DI_f, DI_{sh}. To obtain the corresponding results, preliminary calculation of such indicators as the sample contribution function U_t, the log-likelihood function *L*, respectively, is carried out in the cases of a continuous general population with a distribution $f_X(x,\theta)$ density function and a discrete general population with a probability distribution $P(x,\theta)$ ($\sum_x P(x,\theta)=1$). For each distribution F, a distribution parameter $\theta=(\theta_1,...,\theta_k)\in\Theta$ is determined - a random real value *X*. Any numerical characteristic of this random variable (mathematical expectation *a*, variance σ, etc.) or any constant explicitly included in the distribution expression can be considered as a parameter θ. The definition of the above functions is carried out taking into account time. To take into account the time factor, it is proposed to use a polynomial dependence. The degree of the polynomial m is chosen so that the dependence is described with the least error. The rate of entropy change, respectively, according to Fisher and Shannon DI_f, DI_{sh} is used to analyze the heterogeneity of the distribution of time series information and is defined as the ratio of the entropy increment to the time increment. Based on the data obtained, a Fisher-Shannon plan is being built. Based on the following principles, which are valid for any time series, the results obtained are interpreted:

a. If, *H=0* and *FIM=0*, then the state of the reservoir system of the field does not change. The fewer uncertainties in the system under consideration, the fewer states it is able to realize (*H* decreases). The more uncertainty in the system, the more states it is able to realize (H increases). Entropy takes on the maximum possible value when all possible states are equally probable.

b. *FIM* characterizes the change in the function variance of the contribution of the sample of the time series; therefore, it is interpreted as a measure of the deviation uncertainty of the values of the series from the average at each new stage of the development of the field. The presence of extrema of the function of different amplitudes (jumps), successively following one after another, makes it possible to recognize the conditions for a possible transition of the reservoir system to the next stage of development.

c. The Fisher-Shannon plan shows how a change in the internal state of the system, manifested in a quantitative change in indicators, characterizes the conditions for the transition of the system from one stage of development to another. This relationship has a stepwise character. Each stage corresponds to the period of action of the system development stage.

d. The presence of extrema in the I_f (I_{sh}) dependence is interpreted as the onset of a pre-transitional state leading to a change in the field development stage. Moreover, the beginning of this period coincides in time with the change in D_{If}. Of great importance is the sign, magnitude and nature of the change in DI_f and DI_{sh}, which can be used to judge the rate, phase and direction of evolution of the reservoir system at the current moment. If the values taken by these functions increase with time, then the system tends to its most probable state with an increase in entropy - relaxation processes occur in the reservoir. If the values of DI_f and DI_{sh} decrease, then the system enters the phase of self-organization, and some new order arises and develops in it. If DI_f and DI_{sh} do not change in time, then the system is in the stagnation phase.

e. A more detailed analysis of the pre-transition period of the development stage allows the use of semi-logarithmic coordinates. With such a graphical representation of the time series, the slightest changes in the mode of information receipt are highlighted and patterns are revealed that the Cartesian coordinate system does not allow to detect. Thus, the dynamics of $I_f(T)$, presented in semi-logarithmic coordinates, allows not only to recognize the transition to a new stage directly from the development data, but also to identify pre-transition periods. The dynamics of $I_{sh}(T)$ in semi-logarithmic coordinates shows that all values are divided into 4 groups, each of which characterizes the state of the system and has its own regular occurrence frequency. The most common are values of the upper amplitude. This makes it possible to predict the dynamics of the system's uncertainty and identify what states it is capable of realizing. Graphic dependences $I_f(T)$ on $I_{sh}(T)$ in semi-logarithmic coordinates show how the state of the system corresponds to one stage or another. The mass accumulation of points highlights the time intervals when the state of the reservoir system changes within one stage. Based on the results of the calculation carried out on the basis of the accumulated history of the development of the field, the time boundaries of the past stages of the development of the field are distinguished. By changing the function, a time period is selected for a more detailed analysis of the state of field development. This makes it possible to clarify the situation in the reservoir in order to make decisions for influencing the reservoir, which is relevant specifically for the considered time period and the state of the reservoir system. The entire time period is divided into local time sections, for which the calculations of the above information characteristics are repeated.

The analysis of the obtained results showed that the depletion of the field without taking into account the dynamics of information indicators leads to a decrease in oil production, an increase in the water cut of the product, and an irrational mode of stimulation of the formation. The following results were obtained during the research:

– A method for analyzing the state of field development is proposed, based on the calculation of the Fisher and Shannon entropy and other information indicators for time series compiled from data on the volumes of produced and injected fluids.

– A joint analysis of the dynamics of information indicators calculated from the data of time series of oil and water production rates and the volume of injected water allows for early diagnosis of the time boundaries of the stage evolution of both the field as a whole and its individual zones, to assess the compliance of the impact on the reservoir with the state of field development. The analysis does not require information about changes in the physical-mechanical and lithological properties of rocks and fluids saturating them.[11]

– Analysis of the development of the Fortis field using the proposed information method showed that the depletion of the field without taking into account the dynamics of information indicators lead to a decrease in oil production, an increase in water cut and an irrational reservoir stimulation mode.

The chapter studies the reservoir system diagnostics using fractal dimension analysis methods and wavelet transform technology. A technique is proposed for studying the process of developing oil reserves from a deposit by computerized calculation and quantitative visualization of the fractal characteristics of the drained reserves of the deposit and its individual areas of oil production growth. The chapter consists of four paragraphs. The first two sections present the problem statement, information from the theory of fractal dimensions and wavelets[12], and mathematical calculations necessary for its solution. The second chapter is devoted to the allocation of the spatio-temporal structure in the dynamics of reservoir processes by calculating the indicators of fractal dimensions that characterize the development of the field[13]. The monofractal Hausdorff-Besikovich dimensions were obtained by the box method, and the generalized Rényi fractal dimensions were obtained using the method of

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[11] Suleimanov Baghir, Huseynova N.İ., Rzayeva Sabina & Tulesheva Gulnar. Results of Acidizing Injection Wells on the Zhetybai Field (Kazakhstan) //Journal: Petroleum Science and Technology Petroleum Science and Technology,Volume 36, 2018 - Issue 3 Pages 193-199.

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[13] Сулейманов Б.А., Дышин О.А., Гусейнова Н.И. Определение фрактальной размерности фронта вытеснения нефти водой на основе данных нормальной эксплуатации скважин. // «Нефтяное хозяйство», 2011, №12, с.111-114.

multifractal fluctuation analysis. To calculate fractal characteristics in order to identify the spatial structure of the oil-water contact front, a new method of scaling the reservoir system of the productive horizon is proposed, which can be applied both to the productive horizon as a whole and to a specific zone of the productive reservoir. The method is developed based on the application of the wavelet transform method. When identifying the spatial structure of the oil-water contact front, a monofractal approach is used. Representation of the oil-water contact front on different scales makes it possible to carry out the procedure for identifying its characteristic features at the current time.

The proposed scheme for evaluating the development process consists of the following main stages:

- Algorithmic calculation of the multifractal dimension of the time series of oil and water production rates and the volume of the injected agent.
- The characteristic features of the time distribution of the obtained multifractal dimensions are highlighted.
- In accordance with the proposed methodology, the obtained results are interpreted for the diagnostic assessment of the state of the reservoir, which makes it possible to make changes to the strategy and tactics of the field development based on the current diagnostics of the reservoir system.
- The solution of the problem of control and management of the advancement of the front of injected water based on the determination of the monofractal dimension of the front of oil displacement by water or other agents consists of the following main stages:
- Based on the algorithm for calculating and visualizing hydrodynamic indicators, a geometric scheme and an algorithm for obtaining a visual image of the front of the advance of injected water are being developed in the section of the productive horizon allocated for impact in order to carry out subsequent automation of calculations and the visualization process.

– A scheme for scaling the studied zone of the productive formation is being developed, which allows visualizing the localization of the front line in relation to the location of production and injection wells operating from the studied productive horizon.

– Algorithmic calculation of the monofractal dimension of the front of the injected fluid at different scales.

– Based on the studies carried out to develop the algorithm, a software module was created for calculating monofractal and multifractal dimensions of the objects under study and the characteristics of the reservoir system of the productive horizon of the field, presented in geometric form, implemented in the interactive environment of the "Matlab" program.

– In accordance with the proposed method of data processing, the characteristic features of the front presented at different scales are distinguished. The obtained results are interpreted for a diagnostic assessment of the state of the reservoir, which makes it possible to predict the areas of the origin of lateral coning, control the uniformity of the advance of the displacement front, identify reservoir zones that are heterogeneous in terms of permeability, make the necessary adjustments to the processes of influencing the reservoir and regulating the operation mode of wells.

– Justification of the reliability of the obtained results is carried out on the basis of determining the correlation between the calculated time series of the multifractal dimension, the values of the monofractal dimension of the displacement front position at various scales and the actual time series of oil and water flow rates and the volume of the injected agent using real data as an example.

On the basis of the conducted studies, it was shown that by determining the fractal characteristics, it is possible to identify the spatio-temporal position of the oil displacement front in relation to production wells. For this, a new method is proposed for determining the distance between the displacement front and a group of wells between which there is an interference. The method is based on the application of a new distance measure, which is the Hausdorff metric. A joint analysis of the dynamics of the characteristics obtained makes it possible to control the uniformity of the advance of the displacement front, as well as to purposefully correct it when identifying emerging lateral conings. Section 4 presents the results of applying the above methods on the example of Guneshli field data. According to the indicators of the time series of average daily values of the oil and water production rates and the volumetric injection rate, the movement of the front of oil displacement by water was studied.

Based on the analysis of the results of the calculations performed using the methods of applied fractal analysis and wavelet data transformation technology, the following conclusions were drawn:

– Dynamic analysis of the oil production process using fractal analysis methods to data transformed using wavelet transform gives a more detailed picture of the transitions from order to chaos and, vice versa, with the identification of intermediate stages.

– A new approach has been proposed to determine the distance between the oil-water contact front and the zone in which a group of wells is located, between which there is interference.

– A new approach has been proposed for conducting irregular scaling of the study zone of the productive reservoir, based on the use of the quadtree method. The application of the proposed approach makes it possible to reveal in more detail the spatial structure of the oil-water contact front.

– According to the values of the generalized fractal dimension in different parts of the time series, it is possible to identify the nature of the displacement and its spatial localization.

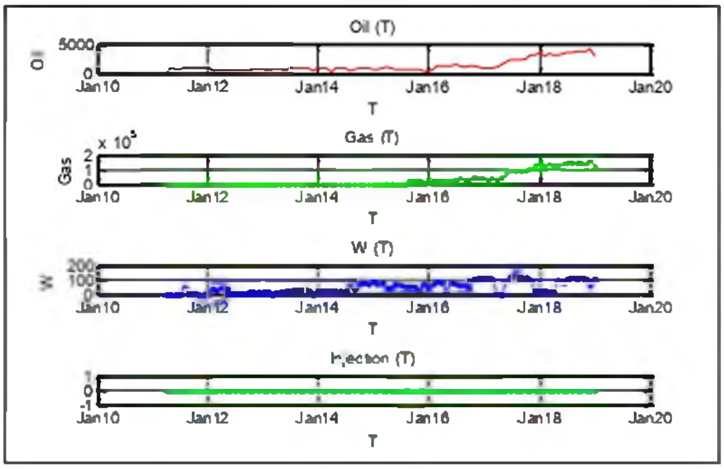
– The impact on the reservoir should be based not only on the principles of reservoir pressure maintenance, but also take into account the process of system self-organization. The most effective method for correcting this impact is the dynamic analysis of the process of oil recovery from the reservoir using applied fractal analysis and the use of meta wavelet data transformation.

The six chapter portrays the results of the practical application of the developed methods and programs for diagnosing the state of the productive horizons QA and QD of the Western Absheron oilfield, in order to make a reasonable choice of EOR. The chapter consists of three paragraphs. The first two paragraphs present the problem statement, as well as a brief description of the "Western Absheron" oilfield.

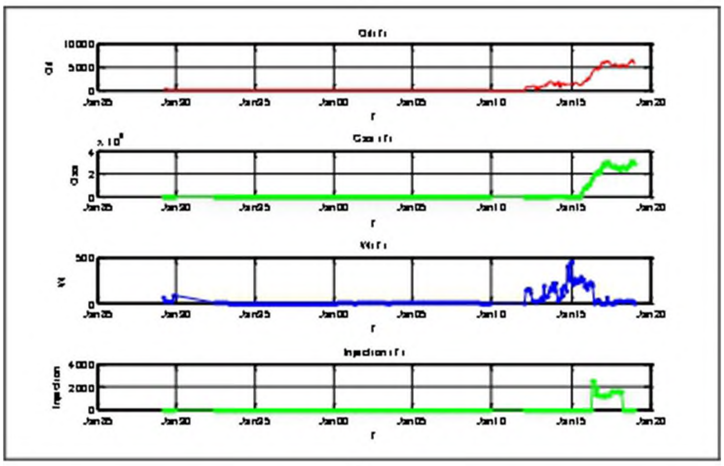
The third section presents the solution to the problem posed on the example of real data. On the figure 2 it is showed the dynamics of production of oil, water, dissolved gas and injected water in different productive horizons of the field. First of all, the determination of the stage of the current development of the "Western Absheron" oilfield was carried out by the Fisher-Shannon method. For each horizon, a Fisher-Shannon joint plot for oil, gas, and water was constructed, and data changing velocity for oil, gas, and water were calculated. On the figure 1 it is showed the current stage of field development by calculating and analyzing the information indicators of the Fisher and Shannon methods for the QA productive horizon. Later, the visualization of the distribution of filtration flows in the QA productive horizon of the "West Absheron" oilfield, and the assessment of the relative permeability for liquid and gas was carried out.

At the next stage of the work, the spectrum of generalized fractal dimensions was obtained and its dynamics was studied using generalized Hurst indicators. The parameters characterizing the dynamics of the water-oil contact line in the formation are calculated, namely: functions of current and potential, fractal dimensions for the time series of oil production, produced and injected water prices, and the minimum distance from the water-oil contact line in the formation to production wells. On the figure 4 and figure 5 there are showed the visualization of the front line of the fluid advance and the fingers formed during the fluid movement, determined on the basis of calculation data in the productive QD horizon of the "West Absheron" oilfield as of 05.2016.

The third paragraph presents the solution of the problem posed on the example of real data. First of all, the selection of the current stage of development of the Western Absheron field was carried out using the Fisher-Shannon method. By calculating and analyzing the information indicators of the Fisher and Shannon methods, the current stage of field development was identified. Further, the visualization of the distribution of filtration flows and the assessment of the relative permeability for liquid and gas in the productive horizon QD of the Western Absheron oilfield were carried out.



a



b

Figure 2. Dynamics of production of oil, water, dissolved gas and injected water in the productive horizons QA (a) and QD (b) of the "Western Absheron" oilfield.

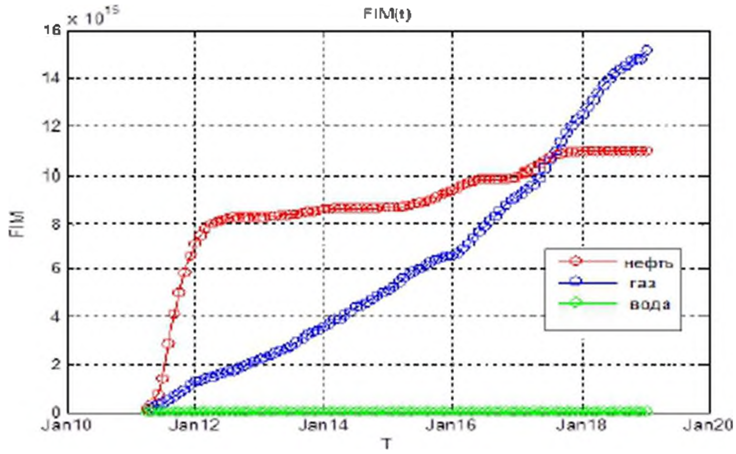


Figure 3. Fisher-Shannon joint plan for oil, gas and water (QA)

At the next stage of the work, the spectrum of generalized fractal dimensions was obtained and, using the generalized Hurst exponents, its dynamics was studied. The parameters characterizing the dynamics of the front are calculated, namely: current and potential functions, fractal dimensions for time series of oil production rates, produced and injected water, and the minimum distance from the displacement front to production wells. For the productive horizon QD, an assessment of the distribution of reservoir pressure and phase permeability was carried out. The obtained diagnostic information made it possible to make a reasonable choice of EOR in accordance with the current state of the reservoir environment. The choice was made on the basis of a modernized secondary screening analysis. When selecting candidate wells for stimulation, it is recommended to use a special procedure for selecting wells that need various types of stimulation treatments in their bottomhole zone in the area under consideration in the first place. This allows to reduce the water cut of well production and increase the volume of oil production.

Thus, on the basis of the conducted studies, it is shown in what sequence it is necessary to apply methods for diagnosing the current state of the reservoir system in order to justify the effectiveness of the chosen methods of influencing the reservoir with a view to increasing oil recovery from the productive reservoirs of the Western

Absheron oilfield. Thus, the following results were obtained during the studies:

– Diagnostics of the state of productive horizons QA and QD was carried out using the methods developed in the previous chapters of the work;

– According to the dynamics of oil production using the Fisher-Shannon method, it was determined that the current state of the productive horizon QA is at the stage of transition to the second stage of development. The QD productive horizon has been in the second stage of development since 2015;

– Based on the well productivity data, an assessment was made of the distribution of hydrodynamic indicators (potential functions, current functions, their gradients, velocity modulus, etc.) taking into account well interference. Based on the content of CO_2 in the composition of the dissolved gas, the distribution of reservoir pressure and relative permeability for oil, gas and water in the studied productive horizon was estimated, taking into account the interference of wells;

– The front line of oil-water contact was determined and its monofractal dimension was calculated. The value of the monofractal dimension shows that the displacement front propagates both along the strike and along the reservoir thickness;

– A new method was used to estimate the critical value of the distance between the displacement front and a group of wells, between which there is interference;

– Using methods for calculating multifractal characteristics, it was revealed to what extent the productive reservoir is covered by the displacement process and how the current field development strategy corresponds to the current state of the reservoir system;

– According to the field and diagnostic data corresponding to the current state of the reservoir in accordance with the criteria for the applicability of methods of influencing the productive formation in order to maintain the pace of field development, methods of stimulating the reservoir were selected, aimed at leveling the water-oil contact front, reducing the rate of water advance, maintaining reservoir pressure and enhanced oil recovery. The choice of methods is based on the results of screening studies, the results of which are reflected in tabular data compiled on the basis of a summary of research in the field of existing secondary and tertiary reservoir stimulation methods.

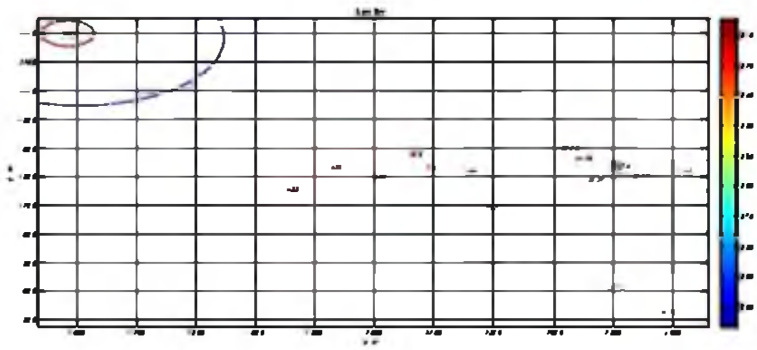


Figure 4. The visualization of the front line of the fluid advance, determined on the basis of calculation data in the productive QD horizon of the "West Absheron" oilfield as of 05.2016.

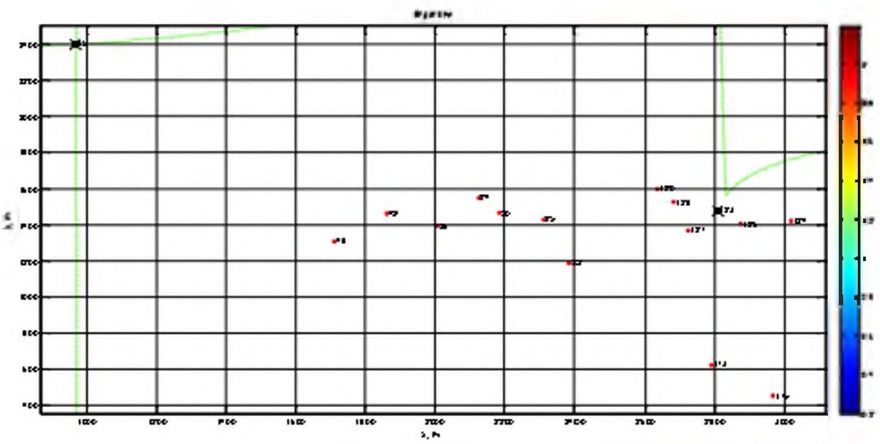


Figure 5. Visualization of fingers formed during the movement of fluid determined on the basis of calculation data in the productive QD horizon of the "West Absheron" oilfield as of 05.2016

CONCLUSION

Provisions are submitted for discussion, the totality of which provides a systemic diagnostic solution for the problem of effective reservoir stimulation in selected areas of the field:

1. It is proposed to use the "limited zone of stimulation on the reservoir" design for the formation of oil production ramp-up zones in an oil and gas field.
2. The prospects of the zonal approach in the formation of oil production growth areas are substantiated.
3. A procedure has been determined to promote the transformation of zones with a low oil recovery factor into zones of growth in oil production in oil and gas fields;
4. Theoretical and practical experience in diagnosing the current state of the reservoir and methods for increasing oil production is summarized with a special emphasis on the mechanisms of zonal impact on the reservoir. A set of problems of the genesis of the zonal approach to increasing oil production in the fields of Azerbaijan and factors contributing to the development of this direction have been identified;
5. The idea of using the method of sources and sinks to visualize the filtration of reservoir fluid in the zones of the reservoir selected for stimulation has been improved, and on its basis a system of methods for diagnosing the current filtration state of these zones has been proposed. A comparative analysis of the obtained results with the results obtained by other methods was carried out. The correctness of using the method of complex potentials for diagnosing the filtration state of the formation in a selected area, before and after the stimulation, is justified;
6. For a rational impact on the reservoirs in the growth zones of oil production, methods for analyzing the dynamics of oil production based on digital visualization of the geometry of streamlines and potentials, the filtration velocity of the reservoir flow and their gradient vectors, pressure reduction and changes in the position of these lines relative to each other on the plane are proposed.

7. When carrying out measures aimed at enhancing oil recovery, along with filtration parameters, it is proposed to assess the impact on the reservoir, taking into account its geomechanical properties that change during the development and operation of the field.
8. Methods have been developed for assessing the distribution of the stress field in the area under study and for determining the pressure gradient of rock fracturing, which is necessary to provide effective impact on the reservoir.
9. The developed system of methods allows for preliminary and subsequent data analysis to improve the efficiency of reservoir stimulation in oil production growth zones. This takes into account the influence of well interference on the timing of the response of the reservoir system to the planned event, which is expressed in a change in the volume and content of the recovered product.
10. To assess the effectiveness of the impact on the formation and early diagnosis of water ingress into the well, it is proposed to use a monofractal and multifractal approach and elements of the wavelet theory;
11. New methods of scaling the stimulation area and determining the distance between the displacement front and wells are proposed.
12. A procedure has been proposed for selecting wells that need various types of stimulation treatments in their bottomhole zone in the area under consideration, which allows to reduce water cut and increase the volume of oil produced;
13. A method is proposed for identifying the staging of oil production and reservoir stimulation processes and the presence of a correspondence between these processes;
14. It is proposed to use the dynamics of data on the percentage of CO_2 in the dissolved gas, which is part of the recovered product, as an indicator signaling the need for zonal stimulation measures;
15. It is proposed to use the calculation of the dynamics of the Fisher, Shannon entropies and other information indicators for time series compiled by the volumes of produced and injected products for early diagnosis of the time boundaries of the stage evolution of the field and its individual zones. Based on the identification of stage

boundaries, an assessment is made of the compliance of the planned impact on the reservoir with the state of the reservoir system.

16. When developing methods and algorithms for analyzing and visualizing the state of the reservoir system, the use of which allows to increase the productivity and reliability of the planned activities, a modular approach is used, implemented in the interactive environment of the "Matlab" program.

17. On the example of the conducted studies using field data on the productive horizons QA and QD of the Western Absheron field, it is shown in what sequence it is necessary to apply the methods for diagnosing the current state of the reservoir system in order to justify the effectiveness of the chosen methods of influencing the reservoir in order to increase oil recovery of productive reservoirs.

List of published works on the subject of the dissertation:

The main provisions of the dissertation are reflected in the following publications issued by the author personally or in co-authorship:

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Doctoral degree-seeker's personal contribution:

[3] - [12], [21] - [23], [30] - performed independently.

[1], [2], [13] - [20], [24] - [29], [31], [32] - [45] - creating a mathematical model, writing a program, performing computer calculations and processing numerical results.

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