SOCAR

SOCAR Proceedings

Reservoir Engineering

journal home page: http://proceedings.socar.az

EMERGING SOURCES CITATION INDEX

Scopus

USE OF INDIRECT DATA IN SOLVING PROBLEMS OF INCREASING THE EFFICIENCY OF FLOODING OF CARBONATE DEPOSITS OF HIGH-VISCOSITY OIL

V. V. Mukhametshin

Ufa State Petroleum Technological University, Ufa, Russia

A B S T R A C T

The work is devoted to assessing the possibilities of using indirect geological and field information in solving applied problems of oil field development using flooding. In the conditions of deposits in carbonate reservoirs of high-viscosity oil of the South Tatar arch, the influence of geological and technological factors on the degree of hydrodynamic interaction of producing and injection wells was studied. The optimal set of parameters is proposed, which determines and characterizes the interaction of wells to the greatest extent, allowing, on the basis of the proposed algorithms, to solve the problems of increasing the efficiency of pumping water into the reservoir under conditions of various kinds of uncertainties, including the absence of direct hydrodynamic studies at various stages of development. The research methodology is based on the calculation of the total diagnostic coefficients for each group of objects, qualitatively characterizing the value and relevance of the data. The results of the simulation made it possible to reliably identify criteria for evaluating the hydrodynamic interaction of wells, which, in conditions of low density of geological and field information, is a source for preliminary determination of the profitability of various technological operations that increase the efficiency of oil reserves extraction. The developed scientific and methodological approach is relevant due to the possibility of its application at the initial stages of drilling sites when it is impossible to promptly update information about the real impact of producing wells on water injection into the reservoir.

Keywords: deposits of carbonate reservoirs; identification of well interactions; flooding of oil reservoirs; geological and statistical modeling; intensity of flooding systems; development of oil fields.

Date submitted: 07.10.2024 **Date accepted:** 09.12.2024

Introduction

It is known that oil deposits in carbonate reservoirs are characterized by a wide variety of formation conditions, which necessitated an individual approach to their development [1-5]. At the same time, on the basis of factor analyses, various groups of objects are distinguished, similar in one way or another, characterizing the features of the geological structure of these objects [6-10]. Within each selected group, various tasks are solved differentially, aimed at increasing the efficiency of reserve production and reducing the cost of production [11-15]. Significant reserves are concentrated in the Tournaisian deposits of high-viscosity oil in the Ural-Volga region, a low degree of their production during natural development [16-20], low profitability require the use of technologies aimed at increasing the efficiency of the oil recovery process [21-25]. The process of intra-contour flooding of productive layers demonstrates the greatest efficiency to date [26-30]. However, in conditions of different groups of objects, efficiency is characterized by different values, and in other cases it is absent, which requires studying the influence of various factors on this efficiency and creating algorithms for scientific justification of water injection parameters.

One of the most important factors determining the effectiveness of flooding of oil deposits in carbonate reservoirs is the degree of hydrodynamic interaction between producing and injection wells [31-35]. After the fields are put into development, the degree of well interaction is determined according to hydrodynamic studies and geological field analysis [36-40]. However, it is important to know how wells will interact already at the stage of drafting the first design documents. This will allow you to choose the right grid density and well location system, flooding system, technological parameters of injection, which ultimately largely determines the efficiency of pumping water into the reservoir, the efficiency of the development of the oil facility as a whole. In other words, at the stage of field withdrawal from exploration, there should be a set of methodological techniques that allow diagnosing the degree of hydrodynamic interaction of wells based on indirect data at different values of distances between wells and injection pressures into the reservoir in areas with different values of geological parameters.

In addition, the lack of a wide range of data from hydrodynamic studies of wells and reservoirs in the process of developing oil fields due to financial and organizational reasons does not allow making scientifically sound decisions

E-mail: vv@of.ugntu.ru
http://dx.doi.org/10.5510/OGP20240401018

to improve flooding systems, which also requires the development of a special methodological base that allows solving issues of improving the efficiency of development using current geological and field information available in the fields.

Research and methods of solving the problem

In order to solve this complex of issues in the conditions of high-viscosity oil facilities of the Tournaisian tier of the South Tatar arch, at the first stage, an analysis of the time series of monthly liquid production from producing wells located near injection wells and monthly water injection was carried out. Geological and field data were used for wells in which no impact was carried out on the bottom-hole zone in order to exclude extraneous «noises». The assessment of the degree and response time of wells to water injection was carried out by analyzing changes in cross-correlation functions (CCF) over time [41, 42], which made it possible to identify producing wells that react and do not react to water injection. The response threshold value was taken to be the CCF value equal to 0.5, recommended by Mirzajanzade A. H., Levchenko V. S., Bench A. R.

The calculations of the values of the cross-correlation functions made it possible to allocate the maximum value CCF (R) producing wells with the observed effect (class A) ($R \geq 0.5$) and with no effect (class B) ($R < 0.5$). At the second stage, the influence of geological and technological parameters on the success of water injection into productive formations was studied. The success of water injection was understood as the ratio of the number of producing wells that reacted to water injection (change in technological parameters of operation) to the total number of producing wells under consideration in various intervals of changes in geological and technological parameters [43-46].

The following were considered as independent variables influencing the success of water injection:

- parameters reflecting the geological and physical properties of formations and their geological heterogeneity: general (H_1^1, H_1^2), effective oil-saturated (H_2^1, H_2^2) formation thickness, average thickness of oil-saturated interlayers (H_3^1, H_3^2) and their number (n^1, n^2),average porosity value in geophysics (M_1^1, M_1^2) the share of reservoir rocks in the total thickness of the formation (K_1^1, K_1^2) accordingly, in producing and injection wells, the average value of oil saturation coefficients (K_3), permeability (K_4), productivity (K_5) and the complex indicator of heterogeneity according to M. A. Tokarev (K_6) on the site where flooding is organized;
- parameters characterizing the physico-chemical properties of the fluids saturating the reservoir: viscosity (μ_1), relative viscosity (μ_2), density (ρ_1), gas content (G) formation oil, oil saturation pressure with gas (P_1);
- parameters reflecting the initial conditions of formation occurrence: depth of occurrence (H_1), initial reservoir pressure (P_2) and the temperature (t_1);
- parameters characterizing the technological features of well and reservoir operation: accumulated (Q_1^1), maximum (Q_1^2), monthly (Q_1^3) oil and water production (Q_1^4), liquids (Q_1^5),water content of products (f_1), time from the moment of commissioning (t) wells at the time of the organization of water injection into the reservoir;
- parameters characterizing the intensity of the flooding system: the average monthly volume of water injection during the efficiency analysis (Q_6), the ratio of water injection pressure to mountain pressure (P_3/P_4) and the distance between the wells (F).

The selection of parameters that have a predominant effect on the success of the organization of water injection into the reservoir was carried out using the sequential Wald procedure. Informative signs were considered, the informative value of which, according to the Kulback criterion, reflecting the measure of discrepancy between different objects, was more than 0.5.

Table

The intervals of change in the values of significant geological and technological parameters, in which the success of the organization of water injection into the reservoir is more than 50%

Values of parameter intervals			
$H_2^2 > 7.2$	$H_2^1 > 7.0$	$H_1 < 1340$	$t > 252$
$H_3^2 > 2.2$	$H_3^1 > 2.1$	$P_2 < 12.8$	$Q_6 > 3125$
$M_1^2 > 13.0$	$M_1^1 > 12.3$	$Q_1^1 > 53000$	$0.47 < P_3/P_4 < 0.68$
$H_1^2 > 14.6$	$K_1^1 > 0.42$		$F < 600$
$K_1^2 > 0.42$	$K_5 > 1.50$		

Discussion of the results

The distribution of wells was considered depending on changes in the values of informative geological and technological parameters. The criterion of effectiveness in this case was the maximum value of the cross-correlation function, it was assumed that when $R \geq 0.5$ producing wells respond to water injection and the organization of flooding is considered effective. By $R < 0.5$ producing wells do not respond to injection and the organization of flooding, of course, is not effective.

The analysis of the results showed that the success of the organization of water injection into the reservoir (according to the criterion – the maximum value of the cross-correlation function) increases significantly in deposits with high values of effective oil-saturated thickness and average thickness of oil-saturated layers in both producing and injection wells. So, with the values $H_2^2 > 7.2$ m; $H_2^1 > 7.0$ m; $H_3^1 > 2.1$ m; $H_3^2 > 2.2$ m the success rate is more than 50%.

With an increase in the values of the porosity coefficient, a decrease in geological heterogeneity reflected by the proportion of reservoir rocks in the total thickness of the formation in both producing and injection wells, as well as with an increase in the total thickness of the formation in injection wells and the average value of the productivity coefficient as a whole for the site or deposit, the success of water injection increases significantly $M_1^2 > 13.0\%$; $M_1^1 > 12.8\%$; $K_1^2 > 0.42$; $K_1^1 > 0.42$; $H_1^2 > 14.6$ m; $K_5 > 1.5$ t/day MPa becomes more than 50%.

The results obtained confirm the classical ideas about the influence of the features of the geological structure of deposits on the effectiveness of flooding, however, in conditions of deposits similar to those studied, when choosing flooding systems and improving existing systems, it is necessary to use the proposed intervals of parameter changes presented in the table.

It can be seen from the table that with an increase in the depth of the Tournaisian deposits, and therefore with an increase in reservoir temperature and reservoir pressure, the success of flooding decreases. This fact is explained by the fact that with increasing depth of occurrence, reservoir rocks are compacted and, as a result, permeability decreases and well productivity decreases. Among the technological indicators of wells and deposits, two turned out to be significant. The table shows that with the growth of accumulated oil production, success increases with $Q_1^1 > 53$ thousand tons it becomes more than 50%. This fact is explained by the fact that wells with high values of effective oil-saturated thickness, porosity, and productivity coefficient have high values of accumulated oil production. These parameters, as shown above, have a significant impact on the success of water injection into the reservoir.

Among the parameters characterizing the intensity of intra-circuit flooding, all turned out to be significant according to the Kulback criterion. With an increase in injection volumes, injection pressure relative to vertical mining and a decrease in the distances between producing and injection wells, the success of water injection increases significantly, and at values of Q_6>3125 t/month; 0.47<P_3/P_4<0.68; F<600 m the probability that the producing well will react to the injection of water is more than 50%.

Thus, the results obtained, summarized in the table, make it possible to diagnose the effectiveness of improving development systems by transferring production wells to injection in areas with different geological heterogeneity and under development, to plan injection volumes and pressures. At the same time, there is no possibility of an unambiguous answer to the question of success in specific pairs of wells (production – injection), since the results obtained are probabilistic in nature.

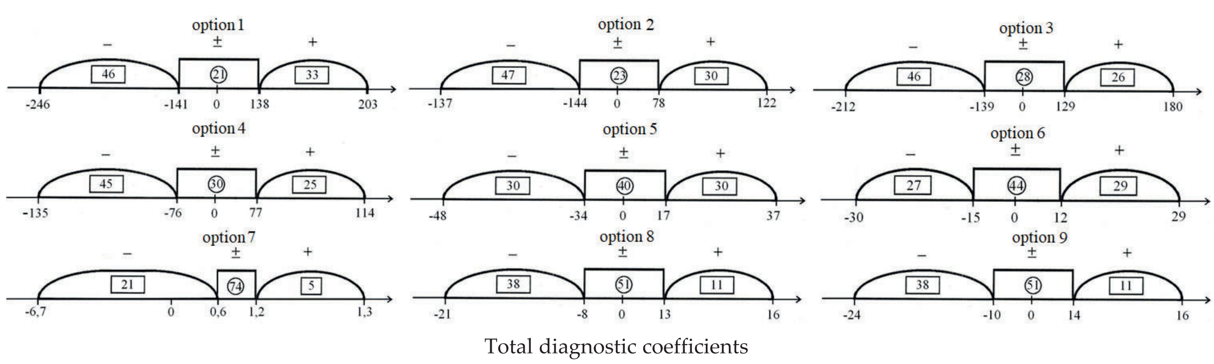
In order to obtain an unambiguous answer to the question of well interaction, the values of the total diagnostic coefficients for all pairs of wells were calculated. Nine calculation options were carried out:

- 1, 2 – using all parameters and parameters that are significant according to the Kulback criterion, respectively;
- 3, 4 – using all parameters and parameters significant according to the Kulback criterion, respectively, reflecting the geological and physical properties of formations in wells, the physico-chemical properties of reservoir fluids, the initial conditions of occurrence and the intensity of the flooding system;
- 5, 6 – using all parameters and parameters that are significant according to the Kulback criterion, respectively, reflecting the technological features of wells and deposits, as well as the intensity of the flooding system;
- 7, 8, 9 – using F, P_3/P_4 and F, P_3/P_4, F and Q_6 accordingly.

The distribution of wells depending on the change in the values of the total diagnostic coefficients and calculation options are shown in the figure.

It can be seen that it was possible to obtain a certain separation of wells according to the success of the organization of water injection into the reservoir. In the first variant, wells that reacted to water injection were in the range of changes in the values of the total diagnostic coefficient (TDC) from 138 to 203; those that did not react were in the range from minus 246 to minus 141. However, there is also an uncertainty zone in the range from minus 141 to 138, which included 21% of wells.

Calculations carried out according to options 3 and 5 also allowed us to identify zones for an unambiguous answer to the question of whether the producing well will react to injection or not. At the same time, it should be noted that when using all parameters reflecting the geological and physical properties of formations in wells, the physico-chemical properties of reservoir fluids, the initial conditions of occurrence and the intensity of the flooding system, 28% of wells fall into the uncertainty zone (option 3), and when using all parameters reflecting the technological features of the work wells and deposits and the intensity of the flooding system, 44% of all wells involved in the analysis were already in this zone. In other words, the technological parameters of wells and deposits are in themselves less informative parameters compared to geological ones. At the same time, the joint use of this group of parameters makes it possible to reduce the



\+ – the interval of change in the values of the TDC for well reacted to the water injection (R≥0.5);

– – the range of changes in the values of the TDC for wells that did not react to the injection of water (R<0.5);

± – the zone of uncertainty;

[29] – percentage of wells that reacted and did not react to water injection;

(44) – percentage of wells in the uncertainty zone

Fig. The distribution of wells depending on the change in the values of the total diagnostic coefficients

percentage of wells in the uncertainty zone from 28 to 21.

The analysis of the distribution of wells depending on the change in the values of the total diagnostic coefficients, where the values of parameters significant according to the Kulback criterion were used in the calculations, showed that there are also zones that allow us to unambiguously answer the question of the response of producing wells to water injection. It was also noted that the technological performance of wells and deposits had a lower impact on the success of water injection compared to a group of parameters characterizing the features of the geological structure of objects, but their combined use makes it possible to reduce the percentage of wells in the uncertainty zone to 23.

A comparison of options 1, 3, 5 and 2, 4, 6 (see fig.) shows that the use of the entire complex of analyzed parameters compared with the use of parameters significant according to the Kulback criterion does not significantly reduce the percentage of wells in the uncertainty zone, i.e. does not give a significant increase in information during the image recognition procedure. For example, option 2 used 18 parameters that were significant according to the Kulback criterion, and option 1 used all the analyzed parameters, i.e. 34 parameters. At the same time, the percentage of wells in the uncertainty zone increased in option 2 compared to option 1 by only 2%, namely from 21 to 23%. A similar pattern occurs in variants 3-4 and 5-6. In variants 4 and 3, an increase in the number of parameters from 13 to 27 reduced the percentage of wells in the uncertainty zone from only 30 to 28%, and in variants 6 and 5, an increase in the number of parameters from 5 to 10 reduced the percentage of wells in the uncertainty zone from 44 to 40%. Thus, it can be seen that in practical use of the obtained distributions, it is sufficient to use parameters that are significant according to the Kulback criterion.

The results shown in the figure for options 7-9 show that among the parameters characterizing the intensity of the flooding system, the most informative are the distance between producing and injection wells and the ratio of water injection pressure to vertical mining pressure. The least informative is the volume of injected water, since this parameter is correlated with the parameter P_3/P_4. As you can see, in a distribution where only the parameter is used F, 74% of wells were in the zone of uncertainty (see fig., op. 7). When used together F and P_3/P_4 51% were already in the zone of uncertainty (see fig., op. 8), and when using F, P_3/P_4, Q_6 (see fig., op. 9) this percentage has not changed, i.e. no increase in information has been received. It should be noted that using only the parameters characterizing the intensity of the flooding system allows for a reliable forecast in only 50% of wells. To increase this percentage to 80, it is necessary to use parameters characterizing the features of the geological structure of deposits, the physico-chemical properties of reservoir fluids, the initial conditions of occurrence of objects, as well as parameters characterizing the technological features of wells and deposits.

Conclusions

Thus, the results of the conducted studies allow:

1. To determine the minimum number of parameters necessary for conducting the image recognition procedure, namely, determining wells that either react or do not react to water injection into a specifically selected injection well;
2. Get an unambiguous answer to the question of success during diagnosis;
3. To carry out the selection of producing wells at a qualitative level to transfer them to injection in deposits under development;
4. Approximately choose the intensity of flooding systems in deposits with different geological characteristics being put into development;
5. By changing the parameters characterizing the intensity of flooding, transfer wells from zones with a negative effect and zones of uncertainty to zones with a positive effect;
6. Diagnose and select producing wells to transfer them to injection at different volumes of field information and at different stages of development (after the well is put into operation, when there is no reliable data on the technological parameters of the well, option 5 can be used; in the absence of reliable data on the geological and physical properties of the formation, option 6).

References

1. Kontorovich, A. E., Livshits, V. R. (2017). New methods of assessment, structure, and development of oil and gas resources of mature petroleum provinces (Volga-Ural province). *Russian Geology and Geophysics*, 58(12), 1453-1467.

2. Kleshchev, K. A., Shein, V. S. (2010). Russian oil and gas fields: handbook in 2 books. Book 2: The Asian part of Russia. *Moscow: VNIGNI.*

3. Muslimov, R. Kh. (2005). Modern methods of oil recovery increasing: design, optimization and performance evaluation. *Kazan: FEN Publ.*

4. Mukhametshin, V. Sh., Khakimzyanov, I. N. (2021). Features of grouping low-producing oil deposits in carbonate reservoirs for the rational use of resources within the Ural-Volga region. *Journal of Mining Institute*, 252, 896-907.

5. Baykov, N. M. (2010). On the energy strategy of Russia for the period up to 2030 (in the order of discussion). *Oil Industry*, 4, 34-37.

6. Kozhin, V. N., Demin, S. V., Bakirov, I. I. (2023). The study of new methods for the development of carbonate deposits with contact water–oil zones. *Oil Industry*, 3, 32-35.

7. Kuleshova, L. S., Mukhametshin, V. V., Gilyazetdinov, R. A. (2024). The role and significance of the tectonic-stratigraphic factor in the formation of the structural features of hydrocarbon deposits of the Volga-Ural oil and gas province. *SOCAR Proceedings*, 1, 10-17.

8. Evseenkov, A. S., Guz, V. S., Shpetny, D. N., Yudin, E. V. (2023). Short–term forecasting of well flow rate based on an ensemble approach. *Oil Industry*, 2, 78-83.

9. Nasybullina, S. V., Sattarov, R. Z., Ibatullin, R. R., et al. (2022). The use of analytical methods to assess the effectiveness of the development of carbonate reservoirs of PJSC Tatneft. *Oil Industry*, 7, 24-27.

10. Mukhametshin, V. Sh., Kuleshova, L. S., Safiullina, A. R. (2021). Grouping and determining oil reservoirs in carbonate reservoirs by their productivity at the stage of geological exploration. *Bulletin of the Tomsk Polytechnic University. Geo Assets Engineering*, 332(12), 43–51.

11. Khatmullin, I. F., Khatmullina, E. I., Khamitov, A. T., et al. (2015). Identification of zones with poor displacement in fields with hard-to-recover reserves. *Oil Industry*, 1, 74-79.

12. Kudryashov, S. I., Khasanov, M. M., Krasnov, V. A., et al. (2007). Technologies application patterns – an effective way of knowledge systematization. *Oil Industry*, 11, 7-9.

13. Mukhametshin, V. V., Gilyazetdinov, R. A., Kuleshova, L. S., et al. (2024). On the depth of identification of objects in the study of the influence of the density of the grid of wells on the degree of production of oil reserves. *SOCAR Proceedings*, SI1, 26-31.

14. Sun, S. Q., Wan, J. C. (2002). Geological analogs usage rates high in global survey. *Oil & Gas Journal*, 100(46), 49-50.

15. Yartiev, A. F., Khakimzyanov, I. N., Petrov, V. N., Idiyatullina, Z. S. (2016). Improving technologies for the development of oil reserves from heterogeneous and complex reservoirs of the Republic of Tatarstan. *Kazan: Ikhlas*.

16. Mukhametshin, V. Sh. (1989). Dependence of crude-oil recovery on the well spacing density during development of low-producing carbonate deposits. *Oil Industry*, 12, 26–29.

17. Minnikhanov, R. N., Maganov, N. U., Khisamov, R. S. (2016). On creation of research and testing facilities to promote study of nonconventional oil reserves in Tatarstan. *Oil Industry*, 8, 60-63.

18. Agishev, E. R., Dubinsky, G. S., Mukhametshin, V. V., et al. (2023). Prediction of hydraulic fracturing fracture parameters based on the study of reservoir rock geomechanics. *Journal of Luminescence*, 257, 107-116.

19. Shmal, G. I. (2017). Oil and gas complex in response to geopolitical and economic challenges: problems and solutions. *Oil Industry*, 5, 8-11.

20. Mikhailov, N. N., Gurbatova, I. P., Motorova, K. A., Sechina, L. S. (2016). New representations of wettability of oil and gas reservoirs. *Oil Industry*, 7, 80-85.

21. Sergeev, V. V., Belenkova, N. G., Zeigman, Yu. V., Mukhametshin, V. Sh. (2017). Physical properties of emulsion systems with SiO_2 nanoparticles. *Nanotechnologies in Construction*, 9(6), 37–64.

22. Iktisanov, V. A., Smotrikov, N. A., Baigushev, A. V. (2022). Filtration features in carbonate deposits, determined according to the data of injection well studies. *Oil industry*, 2, 74-78.

23. Sayakhutdinov, A. I., Ambartsumyan, R. A., Gabdullina, N. R. (2022). Further development of reserves at a late stage of development of a complex carbonate reservoir on the example of a field in the Timan-Pechora oil and gas province. *Oil Industry*, 9, 85-89.

24. Lozin, E. V. (2024). On the conclusions obtained during scientific substantiation and field tests of physico-chemical methods for increasing oil recovery in the fields of Bashkortostan. *Oil Industry*, 2, 48-51.

25. Mannapov, M. I., Nasybullin, A. V., Yemelyanov, V. V., et al. (2023). Development of a methodology for promoting design injection wells in the EPSILON software package. *Oil Industry*, 9, 17-21.

26. Muslimov, R. Kh. (2014). Oil recovery: past, present, future (production optimization, maximization of oil recovery). *Kazan: FEN.*

27. Veliyev, E. F. (2021). Polymer dispersed system for in-situ fluid diversion. *Prospecting and Development of Oil and Gas Fields*, 1(78), 61–72.

28. Khuzin, R. R., Andreev, V. E., Mukhametshin, V. V., et al. (2021). Influence of hydraulic compression on porosity and permeability properties of reservoirs. *Journal of Mining Institute*, 251(3), 688-697.

29. Shipaeva, M. S., Nurgaliev, D. K., Sudakov, V. A., et al. (2022). Determining the relationship of wells based on a set of methods for retrospective analysis of well operation and geochemical studies. *Oil Industry*, 1, 64-69.

30. Grishchenko, V. A., Mukhametshin, V. Sh., Rabaev, R. U. (2022). Geological structure features of carbonate formations and their impact on the efficiency of developing hydrocarbon deposits. *Energies*, 15(23), 9002.

31. Vladimirov, I. V., Bakirov, I. I., Loshcheva, Z. A., Khisamutdinov, N. I. (2017). Placement of production and injection wells in oil deposits with expanded zones of a collector decompactification. *Petroleum Engineering*, 7, 5-9.

32. Kostrigin, I. V., Khatmullin, I. F., Khatmullina, E. I., et al. (2009). Rapid evaluation of the waterflooded reservoir energy and production potential forecasting. *Oil Industry,* 11, 39-41.

33. Mukhametshin, V. V., Kadyrov, R. R. (2017). Influence of nanoadditives on mechanical and isolating properties of cement-based compositions. *Nanotechnologies in Construction*, 9(6), 18–36.

34. Muslimov, R. Kh. (2008). Methods of increasing an oil fields development efficiency at a late stage. *Oil Industry*, 3, 30-35.

35. Stabinskas, A. P., Sultanov, Sh. Kh., Mukhametshin, V. Sh., et al. (2021). Evolution of Hydraulic Fracturing Fluid: from Guar Systems to Synthetic Gelling Polymers. *SOCAR Proceedings*, SI2, 172-181.

36. Iktisanov, V. A., Smotrikov, N. A., Baigushev, A. V., et al. (2022). Maximum permissible pressures in injection wells during the development of carbonate deposits. *Oil Industry*, 1, 70-73.

37. Gilyazetdinov, R. A., Mukhametshin, V. Sh., Gizzatullina, A. A., et al. (2024). Development and adaptation of hybrid algorithms for assessing the degree of well interaction. *SOCAR Proceedings*, 1, 70-75.

38. Salavatov, T. S., Huseynova, D. F., Suleymanov, A. A., Al-Rabbash, D. A. (2016). Application of nonparametric criteria in the analysis of oil field development processes. *Geology, Geophysics and Development of Oil and Gas Fields*, 3, 57-59.

39. Khasanov, M. M., Bakhitov, R. R., Lakman, I. A, Timiryanova, V. M. (2023). Spatial modeling of the interaction of producing wells. *Oil Industry,* 10, 51-55.

40. Iberla, K. (1980). Factor analysis. *Statistics*, 398.

41. Zade, L. A. (1976). The concept of a linguistic variable and its application to making approximate decisions. *Moscow: Mir.*

42. Mirzadzhanzade, A. Kh., Khasanov, M. M., Bakhtizin, R. N. (2004). Modeling of oil and gas production processes. Nonlinearity, nonequilibrium, uncertainty. *Moscow-Izhevsk: Institute of Computer Research.*

43. Suleimanov, B. A., Veliyev, E. F., Aliyev, A. A. (2020). Colloidal dispersion nanogels for in-situ fluid diversion. *Journal of Petroleum Science and Engineering*, 193(10), 107411.

44. Suleimanov, B. A., Rzayeva, S. C., Akberova, A. F., Akhmedova, U. T. (2021). Deep diversion strategy of the displacement front during oil reservoirs watering. *SOCAR Proceedings*, 4, 33-42.

45. Suleimanov, B. A., Abbasov, E. M. (2024). Predicting of water breakthrough time into the well on pressure build-up curves. *Applied and Computational Mathematics*, 23(2), 219-227.

46. Suleimanov, B. A., Rzayeva, S. C., Akhmedova, U. T. (2021). Self-gasified biosystems for enhanced oil recovery. *International Journal of Modern Physics B*, 35(27), 2150274.