Management of flooding of low-production deposits according to geological and field data

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Abstract. The analysis and generalization of the experience of developing high-viscosity oil deposits in carbonate reservoirs, as well as the use of step regression analysis for geological and field modeling, made it possible to propose a number of algorithms and methods. In turn, they make it possible to effectively solve certain problems of analysis, control, regulation and engineering of fields on studied objects and similar objects in terms of geological and field characteristics.

1. Introduction
The slowdown of production costs has always been one of the main tasks aimed at improving the efficiency of oil and gas production enterprises. The solution of this problem becomes particularly urgent in the context of the economic crisis and a significant decrease in oil prices [1-8].

A significant share of the production costs includes the costs of formation pressure maintenance. However, this type of impact on the deposit does not always bring the desired results as an increase in oil production and a decrease in the production cost [9-14]. Thus, for example, in certain Tournaisian oil deposits of the Southeast Slope of the Russian Platform and the Birsk Saddle with the concentration of significant oil reserves at their small degree of production about half of the production wells are not exposed to water injection due to complex geological structure of these objects and the nonconformance of flooding technologies. The reason for this nonconformance is the absence of a methodological base that allows predicting the degree of hydrodynamic interaction of production and injection wells according to indirect data (due to insufficient volumes of hydrodynamic studies).

In this regard, the group of highly viscous oil deposits in carbonate reservoirs of the Volga-Ural oil and gas province was tasked to create a set of methods to forecast well interference to justify the choice of:
- wells for their transfer for injection and organization of focal flooding for deposits under development;
- density of well spacing and flooding systems at the stage of the first design documents;
- process parameters of flooding systems.
2. Materials and methods

Objects of study – reservoir vaults folded with fractured-porous and porous-cavernous reservoir rocks. Production mechanism of a reservoir – elastic water-driven with weak edge and bottom backwaters. The deposits are characterized by the following average values of geological parameters: formation pressure – 13.3 MPa, net oil thickness – 5.0 m, porosity – 12.0%, oil saturation – 79%, permeability coefficient – 50·10⁻³ μm², viscosity of formation oil – 25 mPa·s. At the time of analysis, the deposits were drilled along the grid from 16 to 200 ha/well. The recovery is mainly carried out due to the reservoir drive mechanism and only in some areas due to water injection into the formation. Under these circumstances, the current oil recovery varies from 3 to 20%, and the forecast is 15%.

In solving the set tasks, the first stage implied the analysis of the time series of monthly fluid production for production wells located near injection wells and monthly water injection. The degree of well response was assessed by the maximum values of cross-correlation functions (CCF), which made it possible to identify reacting (CCF ≥ 0.5) and non-reacting (CCF < 0.5) production wells for injection.

3. Results and Discussion

At the second stage, the influence of the following geological and technological parameters on the success of water injection (ratio of the number of production wells reacted to water injection to the total number of the considered production wells in a certain interval of application of geological and technological parameters) was studied: net oil thickness in the production (H₃, m) and injection (H₄, m) wells; total formation thickness in production (H₅, m) and injection (H₆, m) wells; average thickness of oil-saturated sublayers in production (H₇, m) and injection (H₈, m) wells; number of oil-saturated sublayers in production (N₉) and injection (N₁₀) wells; share of reservoir rocks in the total formation thickness in production (K₃) and injection (K₄) wells; complex index of dissimilarity according to M.A. Tokarev (K₅); average values of oil saturation factors (K₆, unit fraction), permeability (K₇, 10⁻³ μm²), productivity (K₈, t/day·MPa), porosity in production (M₉, %) and injection (M₁₀, %) wells; viscosity (μ₉, mPa·s); relative viscosity (μ₁₀); density (ρ₉, kg/m³); gas content (G, m³/t) of reservoir oil; oil saturation pressure with gas (P₉, MPa); formation depth (H₁₁, m), initial formation pressures (P₁₁, MPa) and temperatures (t₁₁, K); monthly production of oil (Q₉⁻¹, t/month), water (Q₁₀⁻¹, t/month), fluid (Q₁₁⁻¹, t/month), watercut (f₁, %), accumulated oil production (Q₁₂⁻¹, t) at the time of water injection into the reservoir; maximum oil production in a well (Q₉ max, t/month) and time from the moment of well commissioning (t) to the moment of water injection into the reservoir; average monthly water injection volume during flooding efficiency analysis (Q₉ max, m³/month); ratio of injection pressure into water formation to overburden pressure (P₉ / P₁₃, unit fraction); distance from injection to production well (F, m).

Using the sequential Wald analysis, it was possible to identify significant parameters according to the Kulbak criterion and establish intervals of their change, in which the probability that the production well will react to injection is more than 50%. The values of these parameters should be as follows: H₃ > 7.2; H₄ > 2.2; M₉ > 13; H₅ > 14.6; K₃ > 0.42; t > 252; H₇ > 7.0; H₈ > 2.1; M₁₀ > 12.3; K₄ > 0.42; Q₉ > 3125; K₇ > 1.5; H₁₁ < 1340; P₉ < 12.8; t₁₁ < 294; Q₊₁ > 53000; F < 600; 0.47 < P₉ / P₁₃ < 0.68.

The obtained results are probabilistic. In order to obtain the possibility of an unambiguous answer to the question about well interaction, the total diagnostic coefficients (TDC) for all pairs of wells are
calculated. It was found that wells that reacted to water injection are in the interval of TDC change calculated using parameters significant according to the Kulbak criterion, from 129 to 180, not reacted – in the interval from minus 212 to minus 139. However, there is also a zone of uncertainty in the range from minus 139 to 129, which includes 28% of wells. By changing the process parameters of flooding the use of TDC distributions allows transferring wells from the zones of uncertainty and zones with a negative effect to the zones with a positive effect.

The practice of developing deposits in carbonate reservoirs shows that in some cases in some areas there are facts of a fundamental water invasion into production wells through crack systems and certain highly porous sublayers, which does not always favorably affect technical and economic indicators. These cases are overwhelmingly associated with high injection pressure. At injection pressures comparable to vertical rock, a system of cracks in the formation is opened and water along certain highly porous cracks breaks into production wells and quickly waters them, which is undesirable.

Since most often, as the analysis showed, water invasions are observed in cases of very good hydrodynamic interaction of production and injection wells, the analyzed wells of the group, where the values of the cross-correlation function are higher or equal to 0.5, were divided into two subgroups: highly responsive to injection (CCF > 0.7) and weakly responsive to injection (0.5 ≤ CCF ≤ 0.7). The group of wells not responding to injection (CCF < 0.5) remained unchanged.

When dividing wells into three groups the calculations were performed on the basis of the canonical discriminant functions (CDF) in six options using different volumes of geological and field data. The representation of wells in the axes of the first two CDF made it possible to establish boundaries separating objects according to CCF values. It should be noted that when using the CDF method, the percentage of wells falling into the uncertainty zone and the uncertainty zone itself is several times less than when using the TDC method.

The resulting distributions can be used to qualitatively estimate the values of cross-correlation functions. To quantify the degree of well interaction, geological and statistical models based on the use of actual field material are typically used.

Simulations were performed using the step regression analysis. The construction of multidimensional models was carried out according to three options:

1 – using all parameters;
2 – using parameters characterizing geological-physical and physicochemical properties of formations and their saturating fluids, mode of occurrence and intensity of the flooding system;
3 – using parameters characterizing technological features of wells and deposits and the intensity of the flooding system.

The following models were obtained:

- according to option 1:

  \[ CCF = \frac{0.095P_{uw}}{P_{opu}} - 0.383F + 0.360H_H^H + 0.540H_B^H + 0.067M^L - 0.308\mu_H + 0.106\kappa_{npd} + 0.223K_{lH}^H + 0.029H_{sdH} + 1.555Q_{H}^H + 0.029Q_{uw} + 1.362Q_{B}^H + 0.191Q_{H}^H_{max} + 0.01f_t - 0.137t; \]

- according to option 2:

  \[ CCF = \frac{0.113P_{uw}}{P_{opu}} - 0.03F + 0.07H_H^H + 0.292H_B^H - 0.035n^H + 0.182H^H_{lH} + 0.523H_B^H + 0.144M^L - 0.473\mu_H - 0.03f_t + 0.141\kappa_{npd} + 0.045K_{lH}; \]

- according to option 3:

  \[ CCF = 0.059f_t + 0.007f_t + 0.161Q_{H}^H_{max} + 0.24Q_{uw} + 1.551Q_{H}^H + 1.166Q_{B}^H + 1.407Q_{H}^H + 0.7P_{uw}/P_{opu} - 0.155F. \]

The relative errors in all options vary in the range from 10.5 (option 1) to 12.2% (option 3), which allows recommending the obtained models to solve the above objectives.
4. Conclusion
The analysis and generalization of the experience of developing high-viscosity oil deposits in carbonate reservoirs, as well as the use of step regression analysis for geological and field modeling, made it possible to propose a number of algorithms and methods. In turn, they make it possible to effectively solve certain problems of analysis, control, regulation and engineering of fields on studied objects and similar objects in terms of geological and field characteristics.

References
[1] Lungwitz B, Fredd C, Brady M, Miller M, Ali S, and Hughes K 2004 Diversion and Cleanup Studies of Viscoelastic Surfactant-Based Self-Diverting Acid SPE International Symposium and Exhibition on Formation Damage Control (Lafayette, 18-20 February 2004) 10 p DOI: 10.2118/86504-MS
[2] Batalov S A, Andreev V E, Lobankov V M and Mukhametshin V Sh 2019 Numerical simulation of oil formation with regulated disturbances. Oil recovery quality simulation Journal of Physics: Conference Series (ITBI 2019 – International Conference "Information Technologies in Business and Industry") 1333(3) 1-6 DOI: 10.1088/1742-6596/1333/3/032006
[3] Kuleshova L S, Mukhametshin V V and Safiullina A R 2019 Applying information technologies in identifying the features of deposit identification under conditions of different oil-and gas provinces Journal of Physics: Conference Series (ITBI 2019 – International Conference "Information Technologies in Business and Industry") 1333(7) 1-5 DOI: 10.1088/1742-6596/1333/7/072012
[4] Nasr-El-Din H A, Van Domeelen M S, Sierra L, and Welton Th D 2007 Optimization of Surfactant-based Fluids for Acid Diversion European Formation Damage Conference (Scheveningen, The Netherlands, 30 May-1 June 2007) 11 p DOI: 10.2118/107687-MS
[5] Batalov S A, Andreev V E, Lobankov V M and Mukhametshin V Sh 2019 Numerical simulation of the oil reservoir with regulated disturbances. Oil recovery stability simulation Journal of Physics: Conference Series (ITBI 2019 – International Conference "Information Technologies in Business and Industry") 1333(3) 1-6 DOI:10.1088/1742-6596/1333/3/032007
[6] Andreev V E, Chizhov A P, Chibisov A V and Mukhametshin V Sh 2019 Forecasting the use of enhanced oil recovery methods in oilfields of Bashkortostan IOP Conference Series: Earth and Environmental Science (International Symposium «Earth sciences: history, contemporary issues and prospects») 350(1) 1–6 DOI: 10.1088/1755-1315/350/1/012025
[7] Akhmetrov R T, Mukhametshin V V and Kuleshova L S 2019 Simulation of the absolute permeability based on the capillary pressure curves using the dumbbell model Journal of Physics: Conference Series (ITBI 2019 – International Conference "Information Technologies in Business and Industry") 1333(3) 1-8 DOI: 10.1088/1742-6596/1333/3/032001
[8] Brian C and Metcalf S 2009 Intensification of oil production at the San Andreas site thanks to the use of weak acid Oil and Gas technologies 12 21–24
[9] Polyakov V N, Chizhov A P, Kotenev Yu A and Mukhametshin V Sh 2019 Results of System Drilling Techniques and Completion of Oil and Gas Wells IOP Conference Series: Earth and Environmental Science (IPDME 2019 – International Workshop on Innovations and Prospects of Development of Mining Machinery and Electrical Engineering) 378(1) 012119 1–7 DOI: 10.1088/1755-1315/378/1/012119
[10] Malyarenko A M, Bogdan V A, Kotenev Yu A, Mukhametshin V Sh, Umethaev V G 2019 Wettability and formation conditions of reservoirs IOP Conference Series: Earth and Environmental Science (IPDME 2019 – International Workshop on Innovations and Prospects of Development of Mining Machinery and Electrical Engineering) 378(1) 012040 1–6 DOI: 10.1088/1755-1315/378/1/012040
[11] Shuchart C E and Buster D C 1995 Determination of the Chemistry of HF Acidizing with the Use of F NMR Spectroscopy SPE International Symposium on Oilfield Chemistry
(San Antonio, Texas, 14-17 February 1995) 12 p DOI: 10.2118/28975-MS

[12] Kuleshova L S, Mukhametshin V V 2019 Elimination of uncertainties in predicting well interaction using indirect geological field information IOP Conference Series: Earth and Environmental Science (IPDME 2019 – International Workshop on Innovations and Prospects of Development of Mining Machinery and Electrical Engineering) 378 (1) (012115) 1-8 DOI: 10.1088/1755-1315/378/1/012115

[13] Khokhlov V I, Galimov Sh S, Devyatkova S G, Kotenev Yu A, Sultanov Sh Kh and Mukhametshin V Sh 2019 Justification of impact and planning of technology efficiency on the basis of limy-emulsion formulation in low-permeability highly-rugged reservoirs of Tyumen deposits IOP Conference Series: Earth and Environmental Science (IPDME 2019 – International Workshop on Innovations and Prospects of Development of Mining Machinery and Electrical Engineering) 378(1) 012114 1–6 DOI: 10.1088/1755-1315/378/1/012114

[14] Valeev A S, Kotenev Yu A, and Mukhametshin V Sh 2018 Evaluation of Water-Alternating-Gas Efficiency when Using Wide Range of Gas Composition IOP Conference Series: Earth and Environmental Science (IPDME 2018 – International Conference on Innovations and Prospects of Development of Mining Machinery and Electrical Engineering) 194(8) 1-8 DOI: 10.1088/1755-1315/194/8/082042