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Improving the efficiency of using resource base of liquid hydrocarbons in Jurassic deposits of Western Siberia

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Under conditions of the same type of oil deposits with hard-to-recover reserves in Jurassic terrigenous reservoirs of the West Siberian oil and gas province, a study was made about the influence of the geological structure features of objects and water flooding technologies on the response degree of production wells to water injection. Response degree of the wells was determined by analyzing the time series of production rates and injection volumes of injection wells with the calculation of inter-correlation function (ICF) values. It was believed that with ICF values in a given injection period of more than 0.5, production well responds to the injection. Factors that have a prevailing effect on water flooding success have been identified. Among them: effective oil-saturated thickness of the formation in production wells; relative amplitude of the self polarization of the formation in both production and injection wells; grittiness coefficient of the formation in injection wells; monthly volume of water injection and distance between wells. Methodological approach is proposed based on the application of the proposed empirical parameter of water flooding success, which involves the use of indirect data in conditions of limited information about the processes occurring in the formation at justification and selection of production wells for transferring them to injection during focal flooding; drilling of additional production and injection wells – compaction of the well grid; shutdown of injection and production wells; use of a transit wells stock; use of cyclic, non-stationary flooding in order to change the direction of filtration flows; determining the design of dual-purpose L-shaped wells (determining length of the horizontal part); limitation of flow rate in highly flooded wells with a high degree of interaction; determination of decompression zones (without injection of indicators), stagnant zones for drilling sidetracks, improving the location of production and injection wells, transferring wells from other horizons; choosing the purpose of the wells during implementation of the selective water flooding system in order to increase the efficiency of using the resource base of liquid hydrocarbons.

***Key words*:** resource base of hydrocarbons; oil recovery factor; Jurassic deposits; flooding

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Introduction. Given constant decline in oil production at the fields in favorable climate conditions in areas with developed industrial and domestic infrastructure [2, 6, 9, 11, 18], decrease in the growth rate of oil reserves, increase in the share of oil production in the regions with complex environment conditions and the lack of production base [1, 8, 19], as well as a shift in the structure of residual oil towards hard to recover deposits reserves, highly relevant for maintaining the level of oil production in the country is to increase the resource base of liquid hydrocarbons in the Jurassic deposits of the West Siberian oil and gas province.

Despite the fact that development of reserves in the Jurassic deposits has been carried out since the sixties of the previous century, degree of reserves exploitation using various intra-contour water flooding systems with traditional density of well grids by the end of development will not exceed an average of 20 % in areas with relatively high parameters, characterizing the features of objects' geological structure. At the fields, deposits, areas with adverse environmental conditions of development, injection of water into formation does not always give positive results, and operation of such objects in natural conditions allows producing only 5-10 % of geological reserves by the end of the profitable period with a density of wells from 25 to 40 ha/well [1, 3, 4, 16].

Significant oil reserves concentrated in reservoirs of a given age, low degree of geological reserves extraction, low level of fields' introduction into active development due to high cost of production, especially in areas with spreading of low-productive reservoir rocks, allow considering these objects as significant reserve of oil production, subject to increasing the efficiency of their development using, first of all, traditional intra-contour flooding. However, this requires differentiated approach to the choice of systems, taking into account the peculiarities of the geological structure of various groups of these objects.

Statement of the problem. Experience in the development of Jurassic deposits shows that when maximum possible compliance of the applied development systems with the features of the geological structure of these objects is achieved, oil recovery factor at the end of development can reach 30-35 % in relatively high productivity areas and 15-20 % in low productivity areas with a satisfactory level of profitability.

These facts served as the basis for analysis and generalization of the experience of Jurassic deposits flooding, identified in [7] as an independent group according to a set of parameters characterizing geological and physical, physical and chemical properties of formations and saturating fluids to supplement scientific and methodological justification base of the location choice for production and injection wells to increase the efficiency of oil production in low-productive areas of deposits.

Methodology. To solve the tasks, objects of the distinguished group 6 [7] were used, confined to the Upper and Middle Jurassic formations, located mainly within the North Wart monocline. Same group also includes separate deposits located within the Surgut and Nizhnevartovsk arches and the Yarsomovsky trough.

Characteristic feature of these objects is low degree of their introduction into active development, although some deposits have been drilled with a rather dense grid of wells, with implementation of various systems of intra-contour water flooding, and the current degree of reserves' development in some areas reaches 10-12 % of geological reserves.

At the same time, for many production wells surrounding injection wells, there is no effect of water injection, which is manifested by a decrease in formation pressure, level of fluid production, and the absence of an increase in water cut. These facts are confirmed by field studies, as well as numerous studies at the fields with similar geological parameters abroad [10, 12-15, 17].

Discussion. In the absence of full-scale hydrodynamic studies, interaction of production and injection wells using indirect data was studied. Time series of monthly water injection and fluid production for two hundred pairs of injection and production wells were studied. During the year after start of water injection, values of the inter-correlation function (ICF) were determined monthly. By the maximum value of this function it was determined whether the production well responds to the injection or not. Threshold value, according to [5], was taken equal to 0.5.

Analysis of predicted values for recoverable oil reserves for wells without and with water flooding showed that in 82 % of wells, where ICF is more than 0.5, there is an increase in recoverable reserves, and in 87 % of wells where ICF is less than 0.5, there is no increase, what confirms objectivity of the threshold value choice.

Next, influence of geological and technological parameters on the success of water flooding was studied, which represented the ratio of wells' number that responded to water injection to the total number of wells in the considered interval of values' variation of one or another parameter. Geological and technological parameters of production and injection wells were used, respectively, total H_{t}^{p}, H_{t}^{in}, perforated $H_{\text{perf}}^{\text{p}}$, $H_{\text{perf}}^{\text{in}}$, effective oil-saturated H_{e}^{p}, H_{e}^{in} formation thickness; average value H_{a}^{p}, H_{a}^{in}, root mean square deviation $\sigma_{H_{\text{a}}}^{\text{p}}$, $\sigma_{H_{\text{a}}}^{\text{in}}$, variation $W_{H_{\text{a}}}^{\text{p}}$, $W_{H_{\text{a}}}^{\text{in}}$, entropy $E_{H_{\text{a}}}^{\text{p}}$, $E_{H_{\text{a}}}^{\text{in}}$ thickness of oil-saturated seams and their number n^{p}, n^{in}; coefficients of grittiness K_{g}^{p}, K_{g}^{in}, permeability $K_{\text{per}}^{\text{p}}$, $K_{\text{per}}^{\text{in}}$, porosity m^{p}, m^{in}, oil saturation K_{o}^{p}, K_{o}^{in}, relative amplitude PS $\alpha_{\text{PS}}^{\text{p}}$, $\alpha_{\text{PS}}^{\text{in}}$; formation resistance by IK $\rho_{\text{IK}}^{\text{p}}$, $\rho_{\text{IK}}^{\text{in}}$, by two-meter probe $\rho_{2,25}^{\text{p}}$, $\rho_{2,25}^{\text{in}}$, by BK M_{BK}^{p}, $M_{\text{BK}}^{\text{in}}$; formation depth $H_{\text{dep}}^{\text{p}}$, $H_{\text{dep}}^{\text{in}}$; distance between production and injection wells F; pressure P_{in} and volume Q_{in} of water injection into the well. Other geological parameters and their influence were not considered due to insignificant intervals of change, or the lack of their mass determination for all wells.

Analysis showed that with an increase in the perforated and effective oil-saturated thickness, average thickness of oil-saturated seams, grittiness coefficient, relative amplitude PS, formation resistance by IR, two-meter probe and BK, and decrease in the formation depth, success in production wells naturally increases. With the growth of perforated, effective oil-saturated thickness, number of seams, coefficient of grittiness and a decrease in the formation depth, success in injection wells also naturally increases. An increase in injection pressures, volumes of injected water and a decrease in the distance between production and injection wells can significantly increase the response degree of wells to injection.

Calculations performed using Wald procedure made it possible to establish that following parameters are informative according to the Kullback criterion: effective oil-saturated thickness, average thickness of oil-saturated seams, relative amplitude PS; formation depth in production wells, perforated formation thickness, number of oil-saturated seams, grittiness coefficient, formation resistance by IR, BK in injection wells, as well as volume of injected water and the distance between production and injection wells.

From physical point of view, results do not contradict existing ideas about influence of considered parameters on oil recovery process, however, number of wells that fall into the region of unambiguous characteristics is clearly not enough to use these dependencies for practical purposes. So, for example, the best dependence allows unambiguously answering the question about the success of water flooding in only 13 % of wells, and interval of unambiguous assessment is 46 % of total interval of parameter values' variation. Parameters are largely correlated.

Use of correlation matrix made it possible to exclude mutually correlated informative parameters. Critical values of correlation coefficients were determined in [10] at 5 % significance level.

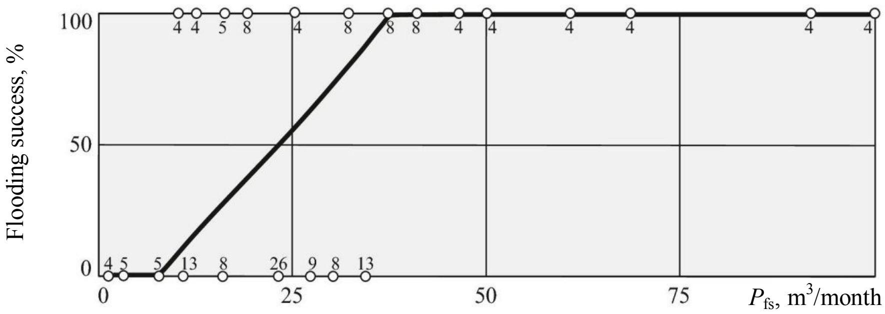
Enumeration of remaining parameters and use of informational criteria allowed obtaining water flooding success parameter

$$P_{\rm fs} = \frac{H_{\rm e}^{\rm p}\, \alpha_{\rm PS}^{\rm p} \alpha_{\rm PS}^{\rm in}\, K_{\rm g}^{\rm in} Q_{\rm in}}{F}. \qquad (1)$$

At application of this parameter, as can be seen in the figure, significant differentiation of the points occurred. Information measures significantly increased: number of wells that entered unambiguous assessment zone was 33 %, and unambiguous assessment interval increased to 70 %. Four areas are identified, in two of which success of flooding is unambiguously determined: at $P_{\rm fs} < P_{\rm fs}^{\rm crit}$ = 7,5 m^3/month success is zero; at $P_{\rm fs}^{\rm crit} \le P_{\rm fs} \le P_{\rm fs}^{50}$ = 25 m^3/month success will be less than 50 %; at $P_{\rm fs}^{50} < P_{\rm fs} \le P_{\rm fs}^{\rm min}$ = 37,5 m^3/month success will be more than 50 %; at $P_{\rm fs} > P_{\rm fs}^{\rm min}$ success is 100 %.

Using parameter $P_{\rm fs}$ allows conducting a diagnostic procedure for assessing the success of water flooding in the deposits where it is planned to transfer production wells to injection.

On deposits that have already been drilled and are exploited, selection of points for water injection can be made based on the formula (1):



Effect of successful water flooding parameter on water flooding success Points' number – amount of wells

$$F \le F_{\max} = \frac{1}{P_{\text{fs}}^{\min}} H_{\text{e}}^{\text{p}} \alpha_{\text{PS}}^{\text{p}} \alpha_{\text{PS}}^{\text{in}} K_{\text{g}}^{\text{p}} Q_{\text{in}} = 2{,}7 \cdot 10^{-2} H_{\text{e}}^{\text{p}} \alpha_{\text{PS}}^{\text{p}} \alpha_{\text{PS}}^{\text{in}} K_{\text{g}}^{\text{in}} Q_{\text{in}}, \quad (2)$$

at this, success is 100 %;

$$F_{\max} < F < F_{50} = \frac{1}{P_{\text{fs}}^{50}} H_{\text{e}}^{\text{p}} \alpha_{\text{PS}}^{\text{p}} \alpha_{\text{PS}}^{\text{in}} K_{\text{g}}^{\text{in}} Q_{\text{in}} = 4 \cdot 10^{-2} H_{\text{e}}^{\text{p}} \alpha_{\text{PS}}^{\text{p}} \alpha_{\text{PS}}^{\text{in}} K_{\text{g}}^{\text{in}} Q_{\text{in}}, \quad (3)$$

at this, success is will change from 50 to 100 %.

If $F > F_{50}$, water flooding success will be less than 50 % and transfer of the selected well to injection will be unjustified.

Obtained results can also be used to improve water flooding systems for deposits that are under development, considering justification and selection of production wells for transferring them to injection during focal flooding; drilling of additional production and injection wells - compaction of the well grid; shutdown of injection and production wells; use of a transit wells stock; use of cyclic, non-stationary flooding in order to change the direction of filtration flows; determining the design of dual-purpose L-shaped wells (determining length of the horizontal part); limitation of flow rate in highly flooded wells with a high degree of interaction; determination of decompression zones (without injection of indicators), stagnant zones for drilling sidetracks, improving the location of production and injection wells, transferring wells from other horizons; choosing the purpose of the wells during implementation of the selective water flooding system.

Conclusion. Conducted analysis of the water flooding success for a group of the same type of deposits in terrigenous reservoirs of the West Siberian oil and gas province confined to Jurassic deposits allowed proposing a methodological approach using indirect data with limited information about the processes occurring in the formation, to justification of water injection into the formation to increase the efficiency of using the resource base of liquid hydrocarbons.

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