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Elimination of uncertainties in predicting well interaction using indirect geological field information

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Abstract. For different groups of wells of the West Siberian oil and gas province, algorithms for reducing the degree of uncertainty in predicting the interaction of production and injection wells using factor analysis methods and indirect geological information were developed. The boundary values of discriminant functions were established. They help divide production wells into interacting and non-interacting ones with a high degree of accuracy (up to 90%).

1. Introduction

It is known that the waterflooding of productive layers of oil fields significantly increases the degree of oil reserves and reduces the cost of production compared with the development under natural modes [1–10]. However, the waterflooding systems and their parameters have to be justified and comply with the peculiarities of the geological structure of the impact objects.

Analysis of the results of studies presented in [11-14] showed that the efficiency of oil displacement by water is largely determined by the degree and nature of interaction of production and injection wells.

In [15], it was proposed to determine the efficiency of waterflooding using waterflood efficiency parameters for various groups of fields in the West Siberian oil and gas province (WSOGP) confined to terrigenous reservoirs of the Cretaceous system.

Despite the fact that the use of the waterflood efficiency parameter can solve the issue concerning the influence of injection on the production well, about half of the wells fall into the zone of uncertainty.

2. Methods and materials

To improve the accuracy of prediction, the principal component method (PCM) and discriminant analysis (DA) were used.

On the reservoirs of the objects of group 7 [16], all the pairs of production and injection wells were grouped according to 23 parameters:
- general \((N_{gen}^P, N_{gen}^I (m))\), perforating \((N_{perf}^P, N_{perf}^I (m))\), efficient oil saturated \((N_E^P, N_E^I (m))\) formation thicknesses;
- average value \((N_P^P, N_P^I (m))\) of the thickness of oil saturated interlayers;
- number of oil saturated interlayers \((n_P, n_I)\);
- coefficients of sandiness \((K_p^s, K_p^t)\), permeability \((K_p^{\text{per}})\), porosity \((m_p, m_l(\%))\), oil saturation \((K_s, K_l(\%))\);
- relative SP amplitude \(SP\) \((\alpha_{SP}^{P}, \alpha_{SP}^{L})\);
- formation resistance by an IL \((\rho_{IL}^{P}, \rho_{IL}^{L}(\Omega \cdot m))\), a two-meter probe \((\rho_{225}^{P}, \rho_{225}^{L}(\Omega \cdot m))\), a LL \((M_{LL}^{P}, M_{LL}^{L}(\Omega \cdot m))\);
- distance between the production and injection wells \((F, m)\), where \(P\) and \(I\) characterize parameters in production and injection wells.

3. Results and discussion

Analysis of the results of the decision by the CIM (see table) showed that of the twenty-three main components, the first five ones account for 63.7% of the total dispersion of parameters, i.e. when dividing groups of wells, it is sufficient to consider them in the space of only these principal components. Each of the five main components is informative.

**Table 1.** Factor loads for CIM by the wells of group 7

| Parameters       | Principal components | \(Z_1\) | \(Z_2\) | \(Z_3\) | \(Z_4\) | \(Z_5\) |
|------------------|----------------------|---------|---------|---------|---------|---------|
| \(N_{gen}^P\)    | 0.001                | 0.272   | 0.181   | 0.555   | -0.030  |
| \(N_{per}^P\)    | 0.084                | 0.163   | 0.166   | 0.862   | -0.049  |
| \(N_{E}^P\)      | 0.137                | 0.286   | 0.090   | 0.883   | -0.088  |
| \(N_{L}^P\)      | 0.149                | 0.069   | -0.017  | 0.721   | 0.067   |
| \(n^P\)          | -0.059               | 0.170   | 0.100   | 0.026   | -0.142  |
| \(m^P\)          | 0.876                | 0.099   | -0.108  | 0.092   | 0.194   |
| \(K_{per}^P\)    | 0.835                | 0.020   | -0.046  | 0.093   | 0.066   |
| \(\alpha_{SP}^P\)| 0.820                | -0.007  | -0.020  | 0.176   | -0.119  |
| \(\rho_{IL}^P\)  | 0.586                | 0.333   | 0.282   | -0.008  | -0.097  |
| \(M_{LL}^P\)     | 0.689                | 0.000   | 0.279   | -0.184  | -0.030  |
| \(K_{L}^P\)      | 0.618                | 0.189   | 0.206   | 0.142   | 0.219   |
| \(N_{gen}^L\)    | 0.058                | 0.908   | -0.086  | 0.187   | -0.034  |
| \(N_{per}^L\)    | 0.027                | 0.904   | 0.092   | 0.241   | -0.018  |
| \(n^L\)          | 0.147                | 0.936   | -0.028  | 0.151   | 0.089   |
| \(m^L\)          | 0.237                | 0.498   | 0.097   | 0.029   | 0.236   |
| \(n^l\)          | -0.071               | 0.323   | -0.216  | 0.078   | -0.139  |
| \(m^l\)          | 0.100                | 0.177   | 0.152   | 0.044   | 0.867   |
| \(K_{per}^l\)    | 0.039                | -0.003  | 0.173   | -0.091  | 0.908   |
| \(\alpha_{SP}^L\)| 0.064                | -0.278  | 0.100   | -0.134  | 0.641   |
| \(\rho_{IL}^L\)  | 0.077                | -0.058  | 0.911   | 0.074   | 0.120   |
| \(M_{LL}^L\)     | 0.065                | 0.172   | 0.808   | 0.125   | 0.018   |
| \(K_L^L\)        | -0.066               | -0.112  | 0.873   | 0.122   | 0.260   |
| \(F\)           | 0.149                | 0.048   | 0.252   | -0.093  | 0.176   |
| Explanatory dispersion | 3.528           | 3.400   | 2.738   | 2.649   | 2.336   |
The first principal component characterizes reservoir properties in the production wells, since the main contribution is made by porosity (21.8 %), permeability (19.9 %), oil saturation (10.8 %), relative SP amplitude (19.1 %) and formation resistance by IL (9.7 %) in the production wells. The total value of this contribution is 81.2 %.

The second principal component characterizes thickness properties of the reservoir in the injection wells, since general (25.8 %), perforating (24.2 %), effective oil saturation (24.0 %) thicknesses and average thickness of the oil-saturated interlayers (7.3 %) in the injection wells make up 81.3 % of the total dispersion of parameters in this component.

The third principal component characterizes reservoir properties in the injection wells. The main contribution is made by the formation resistance according by IL (30.3 %) and LL (23.8 %) and the oil saturation coefficient (27.8 %).

The fourth principal component characterizes thickness properties of the reservoir in the production wells, because general (11.6 %), perforating (28.0 %), effective oil saturation (29.4 %) thicknesses and average thickness of oil-saturated interlayers (19.6 %) make up 88.6 % of general dispersion of the parameters in this component.

The fifth principal component characterizes permeability coefficients (35.3 %), porosity (32.2 %) and the relative SP amplitude (17.6 %) of the reservoir in the injection wells.

The geometric representation of the objects in the coordinate axes of the main components Z1 – Z2, Z1 – Z3, Z1 – Z4, Z1 – Z5 (Figure 1) made it possible to draw a border on which the values of the cross-correlation functions are equal to 0.5. It can be seen that accuracy of the answer to the question about the effect of injection on fluid production increases to 60–89 %, and the resulting separation allows us to predict the efficiency of waterflooding by the values of the principal components which have the following form:

\[
Z_1 = 0.030N_{\text{gen}} - 0.017N_{\text{per}} - 0.0005N_E - 0.073N_P + 0.090n^P + 0.288m^P + \\
+ 0.301K_{\text{per}} + 0.291\alpha_{\text{SP}} + 0.118\rho_{\text{IL}} + 0.203M_{\text{LL}} + 0.125K^D_N - 0.024N_{\text{gen}} - \\
- 0.055N_{\text{per}} - 0.030N_E - 0.020N_P + 0.028m^N - 0.022m^N - 0.017K_{\text{per}}^N + \\
+ 0.031\alpha_{\text{SP}} - 0.006\rho_{\text{IL}} - 0.029M_{\text{LL}} - 0.047K^N_N + 0.023F; \tag{1}
\]

\[
Z_2 = -0.013l_{\text{gel}} + 0.082l_{\text{per}} - 0.046l_E - 0.071l_P + 0.025n^P - 0.045m^D - \\
- 0.074K_{\text{per}} - 0.096K_{\text{sp}} + 0.118\rho_{\text{IL}} + 0.007M_{\text{LL}} + 0.028K^D_N + 0.294l_{\text{gel}} + \\
+ 0.290l_{\text{per}} - 0.315l_E + 0.188l_P + 0.082m^d + 0.038m^l - 0.002K_{\text{per}}^l - \\
- 0.086l_{\text{sp}} + 0.028\rho_{\text{IL}} + 0.055M_{\text{LL}} - 0.050K^l_I + 0.008F; \tag{2}
\]

\[
Z_3 = 0.028l_{\text{gel}} + 0.061l_{\text{per}} - 0.024l_E - 0.074l_P + 0.062n^P - 0.018m^P - \\
- 0.069K_{\text{per}} - 0.058K_{\text{sp}} + 0.142\rho_{\text{IL}} + 0.145M_{\text{LL}} + 0.039K^D_N - 0.028l_{\text{gel}} + \\
+ 0.034l_{\text{per}} - 0.033l_E - 0.020l_P - 0.037m^d - 0.055m^l - 0.034K_{\text{per}}^l - \\
+ 0.034l_{\text{sp}} + 0.357\rho_{\text{IL}} + 0.316M_{\text{LL}} + 0.334K^l_I + 0.060F; \tag{3}
\]

\[
Z_4 = 0.198l_{\text{gel}} + 0.370l_{\text{per}} + 0.360l_E + 0.347l_P - 0.042n^P + 0.012m^P + \tag{4}
\]
The values of the parameters in the equations of the principal components should be standardized based on the expression

\[ Z_5 = -0.042l_{\text{perf}}^I - 0.076l_A^I - 0.064l_R^I - 0.007n^I + 0.033m^I + 0.002K_{\text{per}}^I + \\
+0.017\alpha_{SP}^I - 0.029\rho_{P}^I - 0.040M_{LL}^I + 0.022K_{I}^I - 0.078F; \]

\[ +0.033l_{gel}^P + 0.018l_{\text{perf}}^P + 0.006l_A^P + 0.029l_R^P + 0.011n^P + 0.075m^P + \\
+0.032K_{\text{per}}^P - 0.106\alpha_{SP}^P - 0.102\rho_{P}^P - 0.038M_{LL}^P + 0.053K_{I}^P + 0.025l_{gel}^I \\
-0.014l_{\text{perf}}^I + 0.008l_A^I - 0.047l_R^I + 0.127n^I + 0.422m^I + 0.455K_{\text{per}}^I + \\
+0.302\alpha_{SP}^P - 0.059\rho_{P}^P - 0.138M_{LL}^P + 0.062K_{I}^P + 0.0003F. \] (5)

The discriminant analysis made it possible to divide the wells into interacting and noninteracting ones.

Figure 1 shows the distribution of wells in the axes of the principal components \( Z_1 - Z_3 \) (group 7): ● objects experiencing the injection effect; ○ objects not experiencing the injection effect; – is the curve dividing the wells experiencing and not experiencing the injection effect; ○ is the percentage of correctly divided objects.

The discriminant analysis made it possible to divide the wells into interacting and noninteracting ones.

Figure 2 shows the distribution of grouping centers and zones of the most probable concentration of objects in the axes of two canonical variables \( y_1 \) and \( y_2 \).

This presentation makes it possible to refer production wells to one group or another with a high degree of accuracy than in the axes of the principal components. The percentage of well-divided wells...
varies from 86 to 92%, reducing the degree of uncertainty in forecasting by almost 2 times compared to the dependencies presented in [15].

The equations of canonical variables have the following form:

\[ y_1 = 5.236 + 0.00121H_{gen}^p - 0.094H_E^p - 0.004K_{per}^p - 0.164\rho_l^P - 0.048K_N^p + 0.0022F; \]  
\[ y_2 = -2.453 - 0.208H_{gen}^p + 0.475H_E^p - 0.0015K_{per}^p - 0.091\rho_l^P + 0.041K_N^p + 0.0003F. \]  

The algorithm for determining (predicting) a group of wells that did not participate in the grouping is as follows:
- calculation of the values of the first five principal components \(Z_1 - Z_5\) and canonical variables \(y_1 - y_2\) by the above presented equations;
- grouping of the well in the axes of the principal components;
- grouping of the well in the axes of canonical variables in order to verify the correctness of the assignment of an object to a specific group.

**Figure 2.** The distribution of groups of objects and grouping centers in the axes of canonical variables (group 7): 1, 2 - grouping centers of non-interacting and interacting wells, respectively; \(\bullet\) - wells responding to the injection; \(\bigcirc\) - wells not responding to the injection; \(\sim\) - the curve dividing the wells responding and not responding to the injection; \(\%\) - percentage of correctly divided objects

If the well in the axes of the principal components is not included in any group, it is important to determine the group of wells that has the closest values of the parameters. The search for this group should be as follows:
- calculation of the values of canonical variables of the well and its position in axes \(y_1 - y_2\);
- determination of the grouping center which is the closest to the well in the Euclidean space of canonical variables by formula

\[ d_j = \sqrt{\sum_{i=1}^{m} (y_i - y'_i)^2}, \]  

where \(d_j\) is the Euclidean distance between the well and the j-th grouping center; \(y_i\) is the value of the i-th canonical variable of the well; \(y'_i\) is the value of the i-th canonical variable of the j-th grouping center; \(m\) is the number of canonical variables \(m = 2\).
As can be seen from Figure 2, the main contribution to well division is made by variable $y_1$. Therefore, for practical purposes it is enough to use only this canonical variable. The boundary of well division into interacting and non-interacting ones is 0.8.

For the objects of group 2 [16], the resulting similar equation of the canonical variable has the following form:

$$y_1 = 12.3 + 0.147H^d_{gen} - 0.205H^d_{perf} - 0.852n^D - 0.884m^D + 0.00338 - 0.532\rho_{p}^D + 0.07R_{p}^N - 0.142H^N_{perf} + 0.718H^N_{p} + 0.741n^N + 0.262m^N + 0.004K_{per}^N - 0.279\rho_{ll}^N + 0.09M_{ll}^N - 0.038F.$$ (10)

The boundary value of variable $y_1$, dividing the wells into interacting and non-interacting ones is zero, and the percentage is 92%.

4. Conclusion

Based on the research results,

- an algorithm for reducing the degree of uncertainty in predicting the efficiency of flooding based on the use of the principal component method and discriminant analysis, indirect geological field information and a limited number of geological and technological parameters was developed;
- boundary values of the discriminant functions were established. They help divide production wells into interacting and non-interacting ones with a high degree of accuracy (up to 90%).

References

[1] Alvarado V, Thyne G and Murrell G R 2008 Screening Strategy for Chemical Enhanced Oil Recovery in Wyoming Basin SPE Annual Technical Conf. and Exhibition (Denver, Colorado) p 14

[2] Yakupov R F, Mukhamedshin V Sh and Tyncherov K T Filtration model of oil coning in a bottom water-drive reservoir Periodico tche quimica 15(30) 725–33

[3] Armstrong L, Edmunds J L and Clare J B 2008 Environmental Considerations for Transferring Offshore Facilities to National Oil Company Operators SPE Int. Conf. on Health, Safety, and Environment in Oil and Gas Exploration and Production (Nice, France) p 8

[4] Mukhamedshin V Sh, Zeigman Yu V and Andreev A V 2017 Rapid assessment of deposit production capacity for determination of nanotechnologies application efficiency and necessity to stimulate their development Nanotechnologies in Construction 9(3) 20–34

[5] Khatmullin I F, Khatmullina E I, Khamitov A T, Gimaletdinov R A and Mezikov S E 2015 Identification of zones with poor displacement in fields with hard-to-recover reserves Oil Industry 1 74–9

[6] Akhmetov R T and Mukhamedshin V V 2018 Range of application of the Brooks-Corey model for approximation of capillary curves in reservoirs of Western Siberia Advances in Engineering Research (AER) (Int. conf. “Actual issues of mechanical engineering” (AIME 2018) vol 157) pp 5–8

[7] Leffler W L, Pattarozzi R and Sterling G 2003 Deepwater Petroleum Exploration & Production: A Nontechnical Guide (PennWell) p 166

[8] Tyncherov K T, Mukhamedshin V Sh, Paderin M G, Selivanova M V, Shokurov I V and Almukhametova E M 2018 Thermoacoustic inductor for heavy oil extraction IOP Conf. ser. Mat. Sci. 327(4) 042111

[9] Almukhametova E M, Fattakhov D I, Zakirov A I and Safiullina A R 2018 The analysis of the hydraulic fracturing efficiency at the Potochnoe field facility AV1–2 IOP Conf. ser. Earth Env. 194(8) 082004

[10] Almukhametova E M, Zakirov A I, Fattakhov D I, Faizullin A A and Safiullina A R 2018 Analysis of the technology of intensifying oil production through the bottomhole formation zone treatment in the Potochnoe field IOP Conf. ser. Earth Env. 194(8) 082005

[11] Byrnes A P and Bhattacharya S 2006 Influence of Initial and Residual Oil Saturation and Relative
Permeability on Recovery From Transition Zone Reservoirs in Shallow-Shelf Carbonates
SPE/DOE Symposium on Improved Oil Recovery (Tulsa, Oklahoma, USA) p 11

[12] Kadyrov R.R., Kuleshova L S and Fattakhov I G 2018 Technologies and technical devices for annual regulated flooding of a productive strata Advances in Engineering Research (AER) (Int. conf. “Actual issues of mechanical engineering” (AIME 2018) vol 157) pp 232–35

[13] Muslimov R Kh 2014 Oil recovery: Past, Present, Future (production optimization, maximization of recovery factor) (Kazan: Fen) p 750

[14] Akhmetov R T, Mukhametshin V V, Andreev A V and Sultanov Sh Kh 2017 Some testing results of productive strata wettability index forecasting technique SOCAR Proc. 4 83–7

[15] Mukhametshin V V and Kuleshova L S 2019 Asset management improving with productive bed flooding employing (Ufa: USPTU) p 153

[16] Mukhametshin V V 2018 Rationale for trends in increasing oil reserves depletion in Western Siberia cretaceous deposits based on targets identification Bull. of the Tomsk Polytechnic Univer. Geo Assets Engineering 329(5) 117–24